An Approach to Optimize the Cargo Distribution in Urban Areas

Emilian Szczepański, Marianna Jacyna
Faculty of Transport, Warsaw University of Technology, Poland

The paper contains considerations concerning the approach to determin acceptable plans for distribution in urban areas. The distribution systems as an area of research in terms of reliability and ecological transport were presented. Multilevel distribution systems were characterized. Formalization of the city transport network model and optimization task were done. An algorithm to solve the problem of route optimization based on the solution of the VRP (Vehicle Routing Problem) was proposed and described.

Keywords: multistage distribution system, vehicle routing problem, city logistic, reliability and ecology in distribution systems.

1. INTRODUCTION

Transportation of cargo in urban areas has a significant impact on the efficiency of the economy, quality of life, accessibility and attractiveness of the local community [7]. Unfortunately in the comparison to passenger transport little attention is paid to these issues.

Cargo freight is the main factor enabling development of most economic and social activities taking place in urban areas, which is related to the supply of shops and places of work and recreation, and to waste management. On the other hand, freight transport is the major factor disturbing social life and urban residents. Improvement of urban logistics is related to decrease of high-volume traffic in cities in order to reduce congestion, pollution, and increase traffic safety. Such an effect can be achieved through effective transport planning and increase in the use of means of transport and minimizing the length of the delivery routes [1].

It should be noted that the design of the distribution system is a complex decision-making process, which requires the designer to make decisions taking into account various interests of the participants in the process [8]. The decision is often made intuitively, but also in the light of experience and knowledge acquired previously by a decision maker. Therefore, a greater interest in specialized programs to assist the decision making process is involved.

To make good decisions is the key to obtain acceptable solutions, i.e. to choose the best variant, in which the maximum benefits are achieved with minimal effort.

2. PROBLEMS OF CARGO DISTRIBUTION

Distribution of cargo covers the planning, organization and delivery to make it to the consumer market in a timely manner and at a reasonable cost [1]. Distribution of goods is a challenging research area include the analysis of many issues. It should be considered from the point of view of research on distribution system reliability, the broader aspects of the ecology of transport, methods and means of distribution as well as optimizing the delivery schedule due to the cost and timeliness of delivery.

Research about reliability of the distribution system is very complex and requires sophisticated mathematical apparatus. It takes into account the theories of stochastic processes. These actions may result from the need to achieve different objectives such as knowledge of the impact of the factors on the reliability of the system and search for optimal solutions in terms of reliability. As indicated by the authors [17], researches and evaluation of the reliability of the distribution system, from the viewpoint of the accuracy analysis of the implementation of specific transport process requires a functional approach. It is expressed in the form of the process of delivery reliability, process safety and reliability of the transport logistics infrastructure [18]. Elements of the distribution system assessment, due to the reliability of the areas mentioned above, are presented in the Figure 1.

As it was noted by the author [14], with the continuous development of technology a growing demand for energy can be seen, which may be the cause of many risks resulting from fuel combustion. The reasons, among others, include: global increase in fuel consumption, increase the number of vehicles and traffic jams. The issue of ecology is reflected in studies among others the relationship between energy sources and vehicles (Figure 2).

cities do not choose to support initiatives related to funding and assisting users of electric vehicles. This may be due to a lack of research on the recycling system of such measures. Nevertheless, there are several examples of initiatives which not only promote the electric vehicle, but also other vehicles of EFV group [20] (Table 1).

Taking into account the above considerations in order to reduce the negative impact of transport in urban areas, the problem should be solved systemically. Such an approach allows the city logistics, which can reduce the size of transport work performed in urban areas by the appropriate organization of the transport processes. It also involves using appropriate methods and means of distribution [12].

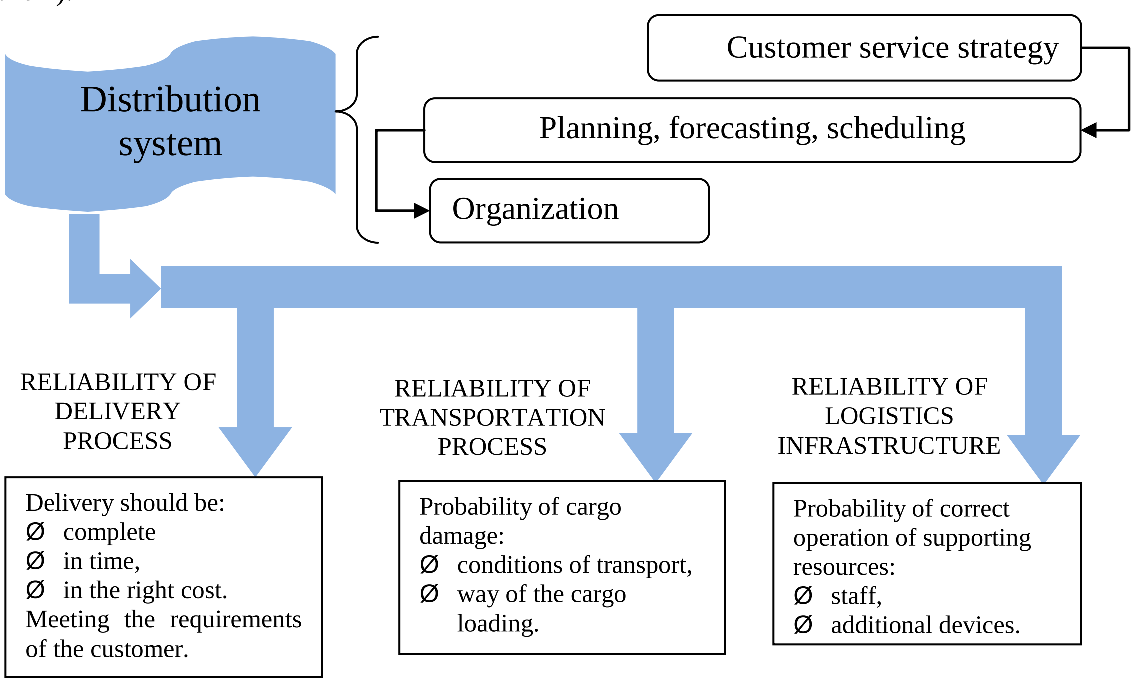

Fig. 1. Elements of the distribution system evaluation
Source: own development based on [18].

Achievement of objectives related to ecology is only possible if there is the will of the authorities to develop and implement new regulations for transport. Some European cities introduce facilities for companies deciding to purchase and use of environmentally friendly vehicles, with reduced emissions. The use of EFV (Environment-Friendly Vehicles) affects considerably the reduction of the level of air pollution and noise. Despite this, most

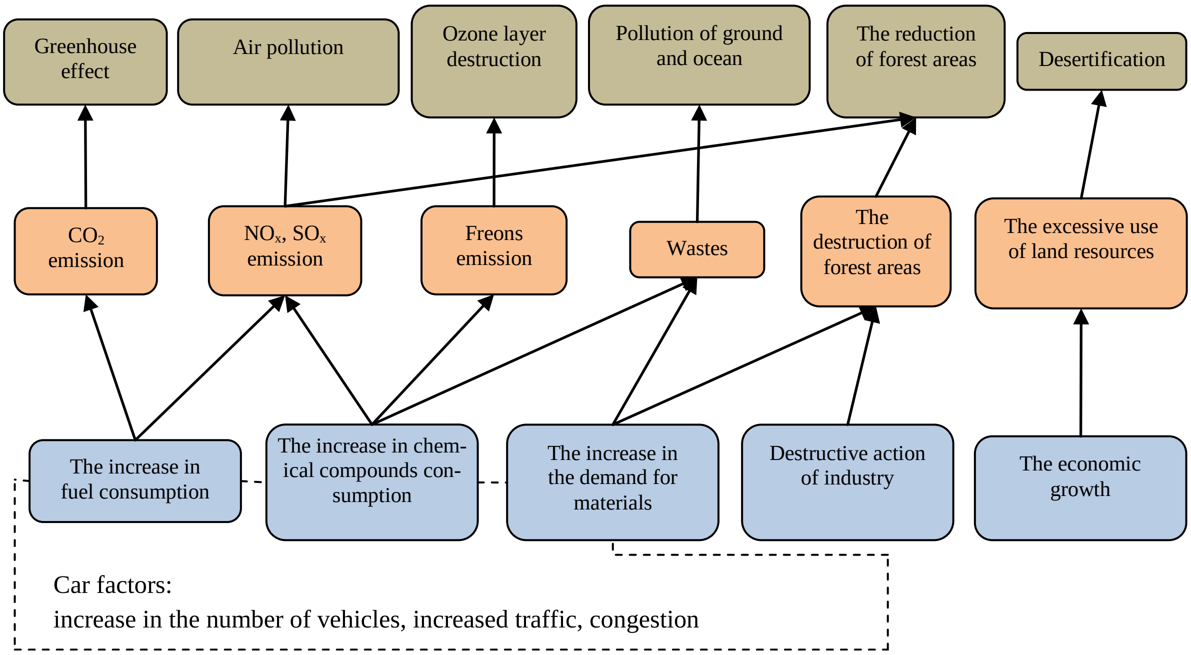

Fig. 1. Elements of the distribution system evaluation
Source: own development based on [18].

Table 1. Examples of initiatives in order to promote EFV vehicles

Initiatives to promote the EFV solutions	Examples
Informal initiative: the city authorities, transport operators and local companies have decided to join forces to work on a more environmentally friendly form of cargo transportation in the city.	PIEK and DEMO programs in the Netherlands and the project of night deliveries by quiet equipment in Barcelona.
Tax relief and facilities for companies using EFV vehicles that use alternative fuels and modern filtration systems for Diesel engines	Lower tax rates for companies that use alternative fuels in the UK, France and Switzerland
Transport operators, using the EFV in urban operations often take part in research projects financed from public funds	Hermes Logistik Gruppe in Germany
	La Petite Reine in France
	Experiment with the use of electric vehicles L'Oreal/Gefco/EDF
Special permits for entry into the business and commercial areas of the city by vehicles meeting certain emissions criteria	Green Zone (Low Emission Zone) in Sweden
	Project ELCIDIS La Rochelle Consolidation Center using electric vehicles
	A trial projects in Copenhagen, Denmark
	CUDE Project in Malaga, Spain
Toll systems including discounts for cars that meet emissions criteria	London toll collection system, United Kingdom
	Heavy Vehicle Fee (LSVA) in Switzerland
Funding innovative research projects and experiments in the field of urban freight transport with EFV	"Green truck experiment" project co-financed by ADEME and promoted by the Paris, France

source: [20].

Requirements for transport services in urban area concerning the timely delivery and quality necessitate to take improvement actions. One of such measure is the use of multistage distribution system based on the Cargo Consolidation Centers (CCC) and transshipment HUBs. CCC provides services such as warehousing, picking and transport of goods. In CCC after separation and picking, cargo is loaded on a vehicle and delivered to HUBs. In HUBs after cargo separation it is loaded on a vehicle with a lower capacity (Fig. 3) [11]. This approach can be used for large cities with high population density and a large number of retail outlets. CCC allows to integrate and coordinate the distribution and collection of cargo between entities located in city area and large manufacturers in its environment. This exchange is most important especially in the central part of the city.

Multistage distribution systems in urban areas consist of Cargo Consolidation Centers (CCC) located on the outskirts of cities and of urban transshipment points (HUBs). In approach of the implementation process of distribution, the following systems can be distinguished: direct, indirect, mixed [4].

Direct systems are known as a "door to door" transport, but they require the use of special loading equipment (e.g. car lifts and hand pallet trucks) at the senders and recipients. Indirect systems use transshipment points such as CCC as a consolidation of cargo, or HUBs as a point of distribution. The mixed delivery systems can use direct distribution and transshipment points [2].

Cargo Consolidation Center is an important part of the National Logistics System. It is related to the cargo distribution for sale to retail customers (Figure 4). The process involves many transportation logistics providers, freight forwarders and carriers. To ensure the efficient cargo flow all the elements of such a system must be coordinated, which involves the integration of high-quality material and information flow. Coordination is based on the rational planning of delivery routes and relates to one or more recipients the same or different kinds of cargo. This is done by small vehicles. Reduction in transport as well as the use of environmentally-friendly means of transport is possible to achieve with the use of Cargo Consolidation Center [19].

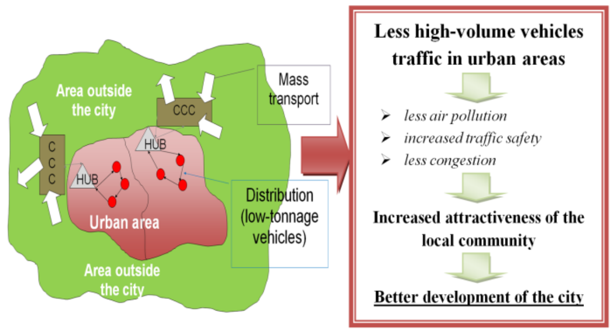

Fig. 3. Graphic illustration of logistics services: indirect two-stage system

Source: own development based on [11].

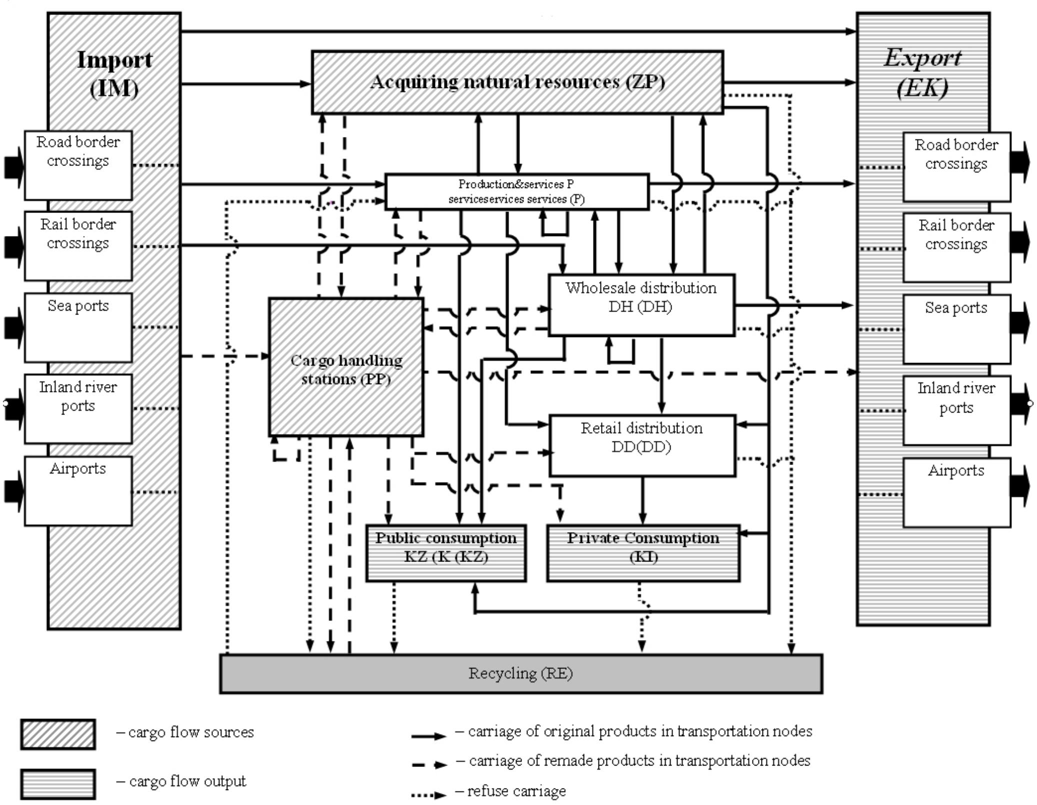

Fig. 4. Diagram of the relation between the functional elements of the National Logistics System

source: [9].

3. SELECTED VARIETIES OF PROBLEMS IN OPTIMIZATION OF CARGO DISTRIBUTION

Improving the cargo distribution in urban areas mainly involves the reduction of high-volume traffic in cities to increase traffic safety and reduce congestion and pollution. Such an effect can be achieved through effective transport planning that is to increase the use of means of transport and to minimize the length of routes of delivery [4],[6].

In addition to the ways to improve the functioning of transportation in cities listed in point 1 and 2, modern computer tools can be used. The proposed decision support approach using modern desktop applications is the least invasive and can be made at any time in the company. In addition, every company should strive to improve their systems to be competitive [3], [21].

The research presented in this article applies to optimize transportation plan for multistage distribution system in an urban area. The concern is the problem of VRP (Vehicle Routing Problem). That is based on the Traveling Salesman Problem (TSP) and more specifically on its modification known as a Multiple Travelling Salesman Problem (MTSP). In contrast to the MTSP problem in the VRP task each transport mode (vehicle) has a defined capacity, and each customer has his demand. Generally the solution is to minimize the number of vehicles, the number of routes and the total length of the routes [16].

The issue of travelling salesman in simple terms involves the determination of the way between all the customers on the route to its total length, to be as short as possible. An important condition is that the salesman should start and finish the journey at some point. Such an approach requires finding a Hamiltonian cycle in the graph. Hamiltonian cycle is a cycle which contains all vertices exactly once [5]. In the case of the MTSP, looking for Hamilton cycle requires decomposition of the task into sections. In this case, there is a number of salesmen pursuing different routes, with the total length of the routes for the entire job should be as short as possible. There are many variations of VRP problem being the most common are shown in Table 2.

Table 2. Some kinds of the VRP problem

SHORTCUT	NAME	DESCRIPTION
CVRP	Capacity Vehicle Routing Problem	Deliveries take place using vehicles with the same capacity
OVRP	Open Vehicle Routing Problem	The problem of delivery where the last customer leaves the vehicle does not return to the starting point
VRPTW	Vehicle Routing Problem with Time Windows	The problem in which the vehicle capacity is the same, and customers have time windows defined
SDVRP	Site-Dependet Vehicle Routing Problem	Deliveries take place by vehicles with different capacity
MDVRP	Multi Depot Vehicle Routing Problem	The problem extended to several storage facilities
MDVRPTW	Multi Depot Vehicle Routing Problem with Time Windows	MDVRP modification with the time window
SVRP	Stochastic Vehicle Routing Problem	The delivery problem taking into account the stochastic data
VRSPD	Vehicle Routing Problem with Stochastic Demands	The problem with random supply needs under certain assumptions
RDPTW	Rich Delivery Problem with Time Windows	The problem taking into account the time windows and different size of loads and vehicles

source: own development based on [16].

4. STRUCTURE OF TRANSPORT NETWORK IN URBAN

In general, the graph is a structure that consists of a set of vertices and edges. Graphs can be used when dealing with objects and relation between them that is occurring such as to render the structure of the transport network and the relation that occur in it. Thus, to map the structure of the problem on the network was used graph $\boldsymbol{G}$ (formula 1) [10]:

$$\boldsymbol{G} = \langle \boldsymbol{W}, \boldsymbol{L} \rangle \tag{1}$$

where:

$\boldsymbol{W}$ – is a set of vertices in $\boldsymbol{G}$ (formula 2):

$$\boldsymbol{W} = \{w: w = 1, \dots, a, \dots, w', \dots, b, \dots, M\} \tag{2}$$

$\boldsymbol{L}$ – edges (arcs) set in graph $\boldsymbol{G}$.

Assuming that $\boldsymbol{L}$ defines arches and is a relation defined on the Cartesian product. Arc (w, w') is understood as a transition from node w to w'node, presented as formula 3:

$$\boldsymbol{L} \subset \boldsymbol{W} \times \boldsymbol{W}; \boldsymbol{L} = \{(w,w'): (w,w') \in \boldsymbol{W} \times \boldsymbol{W};\ w \neq w' \tag{3}$$

Route in the graph $\boldsymbol{G}$ from node a to b will be a sequence (formula 4):

$$p(a,b) = < a, \dots, w, w', \dots, b > \text{if } a, w, w', b \in \boldsymbol{W} \tag{4}$$

When all the nodes are different, it is a **straight way.**

node in structure is an interpretation of recipient number located in the urban area.

This allows to define:

– set $\boldsymbol{N}$ of CCC numbers (formula 7):

$$\boldsymbol{N} = \{w \equiv n: \gamma(w) = 0, w \in \boldsymbol{W}, n = 1,2, \dots, \bar{N}\} \tag{7}$$

where: n– number of n-th CCC; $\bar{N}$ – number of CCC in total.

– set $\boldsymbol{H}$ of HUB's numbers (formula 8):

$$\boldsymbol{H} = \{w \equiv h: \gamma(w) = 1, w \in \boldsymbol{W}, h = \bar{N}+1, \bar{N}+2, \dots, \bar{N}+\bar{H}\} \tag{8}$$

where: h– number h-th transshipment point; $\bar{H}$ – number of transshipments points in total.

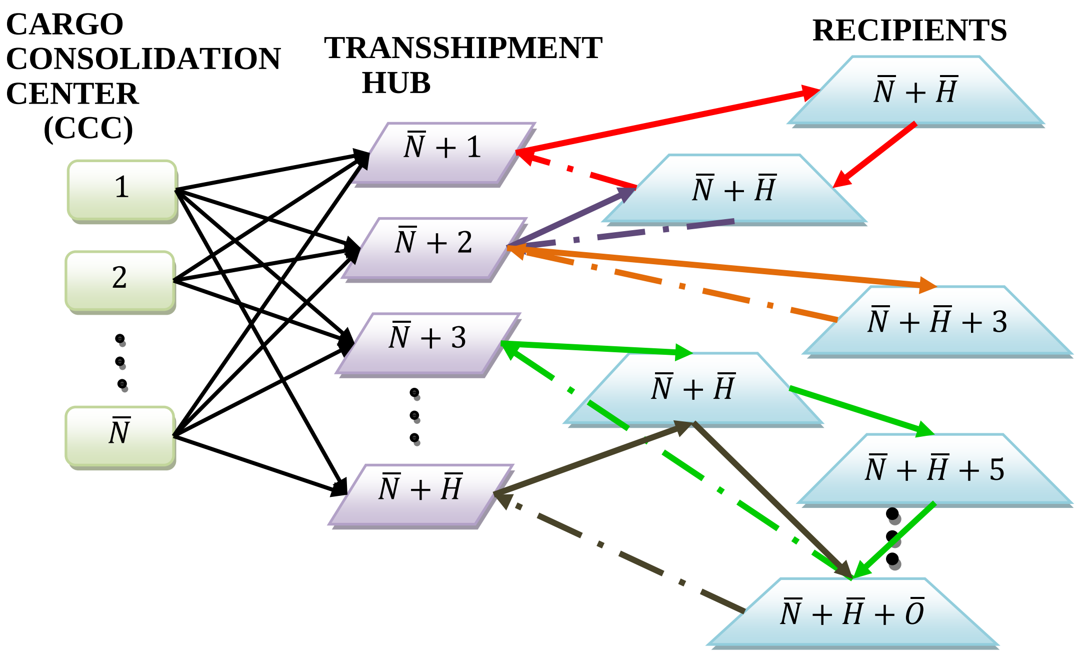

Fig. 5. The structure of the transport network is described by graph
Source: own development.

The set of all paths from node to a node b marked as $\boldsymbol{P^{ab}}$ (formula 5):

$$\boldsymbol{P}^{ab} = \{p(a,b): a, b \in \boldsymbol{W}\} \tag{5}$$

Cyclic route in the graph $\boldsymbol{G} = \langle \boldsymbol{W}, \boldsymbol{L} \rangle$ is called path $p \in \boldsymbol{P^{ab}}$ where $a = b$ for $a, b \in \boldsymbol{W}$. For the study, it was assumed that on the set $\boldsymbol{W}$ made g representation, which elements of this collection transforms the set $\{0,1,2\}$, ie (formula 6):

$$\gamma: \boldsymbol{W} \longrightarrow \{0,1,2\} \tag{6}$$

if $\gamma(w) = 0$then$w$-th node in structure is an interpretation of CCC number, when $\gamma(w) = 1$ then w-th node in structure is an interpretation of HUB's number, in case of $\gamma(w) = 2$ then w-th

– set $\boldsymbol{O}$ of recipients number (formula 9):

$$\boldsymbol{O} = \{w \equiv o: \gamma(w) = 2, w \in \boldsymbol{W}, o = \bar{N}+\bar{H}+1, \bar{N}+\bar{H}+2, \dots, \bar{N}+\bar{H}+\bar{O}\} \tag{9}$$

where: o– number o-th recipient; $\bar{O}$ – number of recipients in total.

At the same time these sets are disjoint in pairs.

In addition, for the research was necessary to define a set of routes numbers (formula 10):

$$\boldsymbol{T} = \{t: t = 1, 2, \dots \bar{T}\} \tag{10}$$

where: t– number t-th route; $\bar{T}$– number of routes in total.

Relation between elements in network describes a set of connection between:

– CCC and HUBs (formula 11):

$$\boldsymbol{L^{nh}} = \{(n,h): n \in \boldsymbol{N}, h \in \boldsymbol{H}\} \quad (11)$$

– HUBs and recipient (formula 12):

$$\boldsymbol{L^{ho}} = \{(h,o): h \in \boldsymbol{H}, o \in \boldsymbol{O}\} \quad (12)$$

– recipients (formula 13):

$$\boldsymbol{L^{oo'}} = \{(o,o'): o \in \boldsymbol{O}, o' \in \boldsymbol{O}; o \neq o'\} \quad (13)$$

Graph of structure of distribution system in the analyzed issues was presented in Figure 5.

5. MATHEMATICAL MODEL OF OPTIMIZATION TASK IN MULTISTAGE DISTRIBUTION SYSTEM

In order to provide a mathematical model of multi-level distribution system to serve customers located in urban areas, specify the input data, decision variables, constraints, and function criteria. The formal record of the optimization task is as follows:

For data:

$\boldsymbol{G} = \langle \boldsymbol{W}, \boldsymbol{L} \rangle$- graph of transportation network;

$\boldsymbol{Z} = [z_o: z_o \in \boldsymbol{Z}^+ \cup \{0\};\ o \in \boldsymbol{O}]$ - matrix of recipients demand;

$\boldsymbol{D1} = [d_{nh}]$- distance matrix between *n*-th CCC and *h*-th HUB;

$\boldsymbol{D2} = [d_{ho}]$- distance matrix between h-th HUB and *o*-th recipient;

$\boldsymbol{D3} = [d_{oo'}]$- distance matrix between *o*-th and *o'*-th recipient;

$\boldsymbol{D4} = [d_{o'h}] = [d_{ho}]^T$- transposed matrix - distance between *o'*-th recipient and *h*-th HUB ;

ks- cost of realization each route from HUB (fixed cost);

$c_1(n,h)$- cost of transport each cargo on 1 km distance between CCC, and HUB;

c_2- cost of 1 km travel during distribution process (between HUB and recipients);

q- vehicle capacity.

determinate decision variables values with interpretation:

- $\boldsymbol{X1} = [x_{nh}: x_{nh} \in \boldsymbol{Z}^+ \cup \{0\}]_{\bar{N}\times\bar{H}}$ – volume of transport between n-th CCC and h-th HUB;
- $\boldsymbol{X2} = [x^t_{ho}: x^t_{ho} \in \boldsymbol{Z}^+ \cup \{0\}]_{\bar{H}\times\bar{O}\times\bar{T}}$ – volume of transport between h-th HUB and o-th recipient, during t-th route realization;
- $\boldsymbol{X3} = [x^t_{oo'}: x^t_{oo'} \in \boldsymbol{Z}^+ \cup \{0\};\ o \neq o']_{\bar{O}\times\bar{O}\times\bar{T}}$ – volume of transport between o-th recipient and o'-th recipient, during t-th route realization;
- $\boldsymbol{Y} = [y^t_{o'h}]_{\bar{O}\times\bar{H}\times\bar{T}}$ - binary variables determining the existence of a connection between o'-th recipient and h-th HUB, during t-th route realization;

$$\forall_{o'\in\boldsymbol{O}}\forall_{h\in\boldsymbol{H}}\forall_{t\in\boldsymbol{T}} y^t_{o'h} = \begin{cases} 1 - when t - th route\ include\ connection\ (o',h) \\ 0 - in\ otherwise\ case \end{cases}$$

having regard to the constraints:

demand p_o, of o-th recipient must be satisfied (formula 11):

$$\forall_{o\in\boldsymbol{O}};\ o \neq o' \sum_{t\in\boldsymbol{T}}\sum_{h\in\boldsymbol{H}}\sum_{o'\in\boldsymbol{O}} [\![(x]\!]^t_{ho} + x^t_{o'o}) = po \quad (11)$$

volume of cargo incoming from CCC to HUB must be equal to volume of cargo outgoing from HUB (formula 12):

$$\forall_{h\in\boldsymbol{H}} \sum_{n\in\boldsymbol{N}} x_{nh} = \sum_{t\in\boldsymbol{T}}\sum_{o\in\boldsymbol{O}} x^t_{ho} \quad (12)$$

volume of cargo outgoing from CCC must be equal to recipient demand (formula 13):

$$\sum_{n\in\boldsymbol{N}}\sum_{h\in\boldsymbol{H}} x_{nh} = \sum_{o\in\boldsymbol{O}} p_o \quad (13)$$

capacity of vehicle on *t*-th route cannot be exceeded (formula 14):

$$\forall_{t\in\boldsymbol{T}}\forall_{h\in\boldsymbol{H}}\forall_{o\in\boldsymbol{O}} x^t_{ho} \leq q \quad (14)$$

vehicle travelling from *h*-th HUB must come back to it (formula 15):

$$\forall_{t\in\boldsymbol{T}}\forall_{h\in\boldsymbol{H}} \sum_{o'\in\boldsymbol{O}} y^t_{o'h} = \sum_{o\in\boldsymbol{O}} x^t_{ho} = 1 \quad (15)$$

vehicle during *t*-th route visits *o*-th recipient just ones (formula 16):

$$\forall_{t\in\boldsymbol{T}}\forall_{h\in\boldsymbol{H}}\forall_{o\in\boldsymbol{O}} sgn(x^t_{ho}) \leq 1$$
$$\forall_{t\in\boldsymbol{T}}\forall_{o\in\boldsymbol{O}}\forall_{o'\in\boldsymbol{O}}, o \neq o' sgn(x^t_{oo'}) \leq 1 \quad (16)$$
$$\forall_{t\in\boldsymbol{T}}\forall_{o'\in\boldsymbol{O}}\forall_{h\in\boldsymbol{H}} sgn(y^t_{o'h}) = 1$$

so that the objective function tends to a minimum (formula 17):

$$\mathrm{F}(\boldsymbol{X1},\boldsymbol{X2},\boldsymbol{X3},\boldsymbol{Y}) = \sum_{n\in\boldsymbol{N}}\sum_{h\in\boldsymbol{H}} x_{nh} d_{nh} c_1(nh) + \\ + \sum_{t\in\boldsymbol{T}}\left[\left(\sum_{h\in\boldsymbol{H}}\sum_{o\in\boldsymbol{O}} sgn(x^t_{ho}) d_{ho} + \sum_{o\in\boldsymbol{O}}\sum_{o'\in\boldsymbol{O}} sgn(x^t_{oo'}) d_{oo'} + \sum_{o\in\boldsymbol{O}}\sum_{h\in\boldsymbol{H}} y^t_{o'h} d_{o'h}\right) c_2\right] + \\ + \bar{T}\cdot ks \rightarrow \min \quad (17)$$

6. GENETIC ALGORITHM AS A SOLUTION OF ROUTE PLANNING PROBLEM IN MULTISTAGE DISTRIBUTION SYSTEMS

A genetic algorithm was proposed to solve the problem of route planning. Genetic algorithms are based on the principles of natural selection and inheritance. These algorithms are based on observations of natural biological mechanisms and are subject to evolution. Simplified diagram of algorithm is shown in Figure 6.

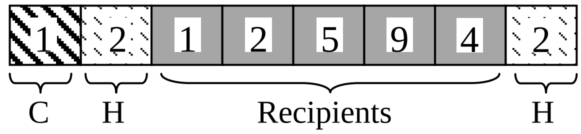

Fig. 7. Example of an individual chromosome

source: own development.

Another element of the genetic algorithm is a crossover. It is one of the most important elements. It is responsible for improving the next designated solutions, but cannot be done completely randomly. To create a child population the best

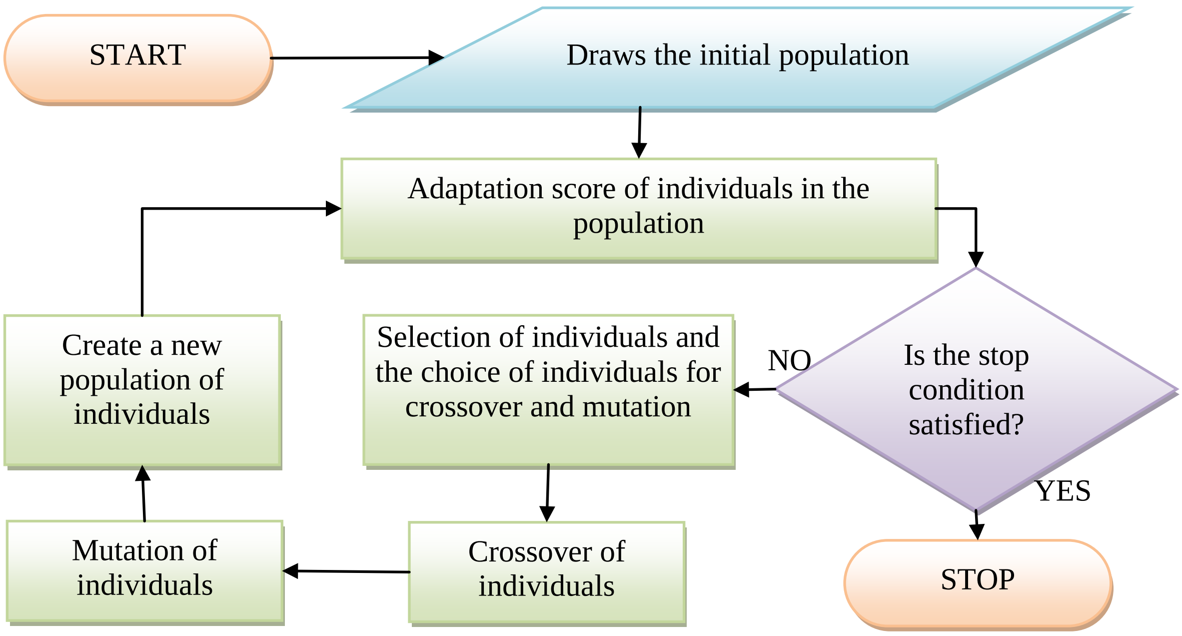

Fig. 6. Functional diagram of genetic algorithm

source: own development based on[15]

To solve the problem a genetic algorithm was used. Finding a solution for it consists of three main procedures:

- draws the initial population,
- crossover,
- mutation.

Draw procedure in genetic algorithms is used only to determine the initial population which represents a feasible solution. An important issue is to design individual chromosome. First gene of individual is responsible for CCC number, the second and the last number represents the HUB, the genes located between the HUB genes are identified as route genes and represent number of recipients visited in the course. An example of an individual chromosome is shown in Figure 7.

individuals are crossed. At the same time, an approach used in the implementation is a Pittsburg, and therefore the rules for each of the individual work together in order to achieve the best evaluation value for the whole population [15]. The method consists in replacing the crossing paths of genes for which the number of recipients is greater than 1. Other individuals representing the so-called direct delivery and subject only to the operation of mutation. An example of crossover is shown in Figure 8.

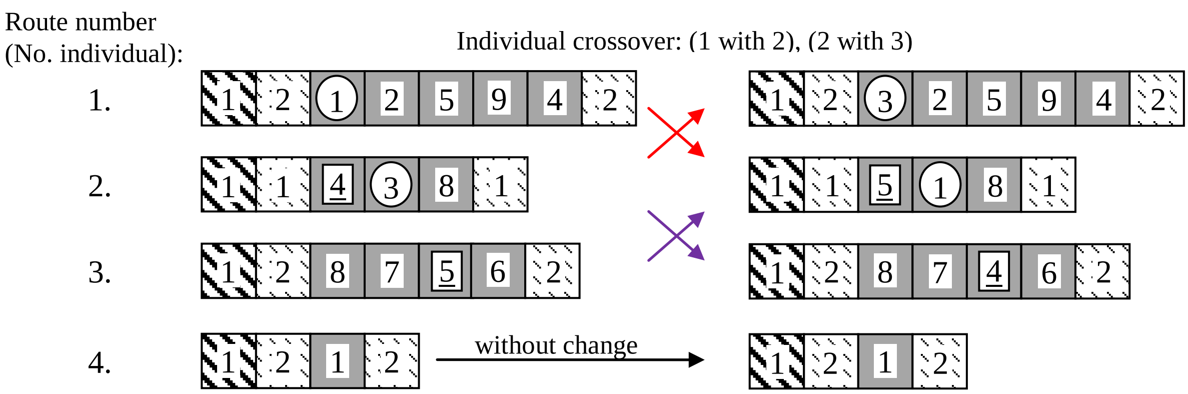

Fig. 8. An example of crossover operation

source: own development.

Mutation is an important mechanism in terms of the accuracy of the search space of solutions. In this way the operator can change the genes of one individual only. The algorithm uses two types of mutation operators. The operator for relation CCC-HUB is encoded in a gene conversion of individual CCC number and HUB number. However, the relation recipient-recipient acts as a replacement for displacement sites or random gene in a random place. Further genes as a result of this operation, move up one place.

25% better results with compared to the random search for a solution. In any case, the use of the genetic algorithm the results obtained were better from 10% to 70%, depending on the size of the task, total number of recipients and transshipment points.

The preliminary work and research on the implementation lead to the conclusion that it is possible to use genetic algorithms to solve such problems.

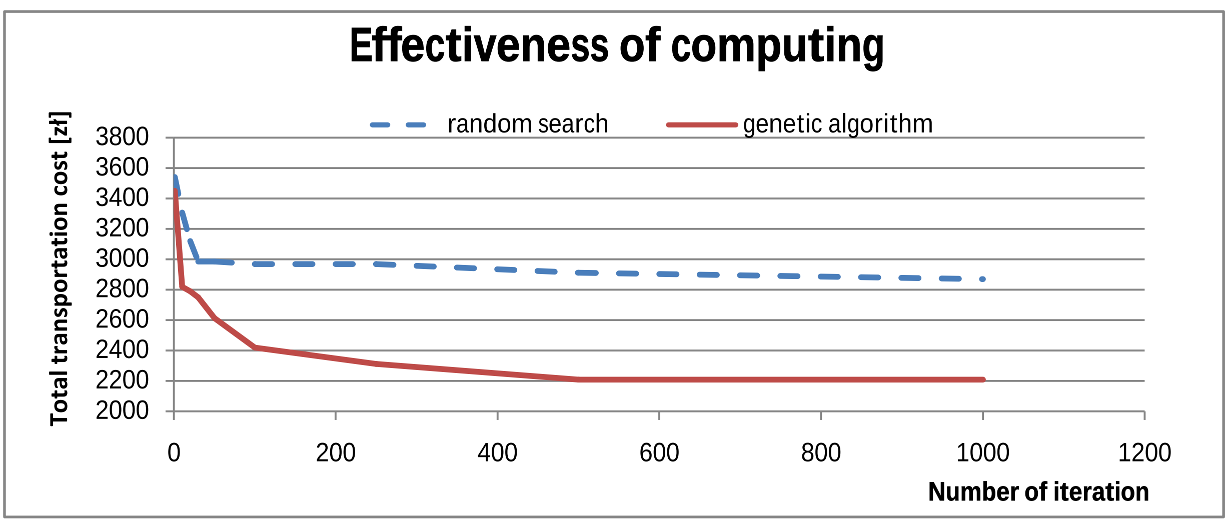

Fig. 9. Chart with effectiveness of computing

source: own development based on UATO program.

In research an attempt was made to implement the above algorithm in the form of the program (UATO), which is a PC application's supporting decision-making in determining rational transportation plan. Chart with effectiveness of the algorithm for 1000 iterations is shown in Figure 9. It should be noted that the same number of iterations using a genetic algorithm gives about

7. CONCLUSION

The The modelling problem of multistage distribution systems in urban areas is very extensive. The article shows an example of route optimization problem solution in that system, taking into account Cargo Consolidation Centres and the transshipment points (HUB).

The paper presents a genetic algorithm as a method of distribution route optimization in urban areas. The presented problem is based on the Multiple Travelling Salesman Problem, known as VRP (Vehicle Routing Problem). Computational complexity takes the form of a polynomial, so the problem belongs to the class of NP problems.

The presented genetic algorithm implementation works properly and helps to improve solutions in subsequent iterations. Thus, it is reasonable to continue to work on modifying and improving implementation. The up-coming articles will present the authoring application and verification of computational algorithm operation.

LITERATURE

[1] Ambroziak T., Jachimowski R.: Problematyka obsługi transportowej w jednoszczeblowym systemie dystrybucji. Logistyka 4/2011.

[2] Ambroziak T., Jacyna M., Wasiak M.: The Logistic Services in a hierarchical distribution System. Transport Science and Technology. ELSEVIER. Chapter 30. ISBN-13: 978-0-08-044707-0 (ISBN-10: 0-08-044707-4) DEC-2006.

[3] Ambroziak T., Pyza D.: Wybrane aspekty modelowania systemów przewozowych. Prace naukowe Politechniki Warszawskiej, Warszawa 2009.

[4] Bluszcz M., Jacyna M.,: Koncepcja modelu obsługi logistycznej miasta. Logistyka 4/2010

[5] Cormen T. H., Leiserson C. E., Rivest R. L., Stein C.: Wprowadzenie do algorytmów. WNT, Warszawa 2004.

[6] Dietrich W.: Freight Transport Strategy for the City of Zurich. Materiały konferencyjne 4-tych warsztatów BESTUFS, Zurich 2006.

[7] Gołembska E., Czajka P., Tomaszewska D.: Logistyka miejska XXI wieku. Eurologistics 3/2001.

[8] Jacyna M., Murawski J., Szczepański E.: Optymalizacja dostaw drewna w relacji nadleśnictwo - zakład produkcyjny z wykorzystaniem pakietu OOT_1. Logistyka 4/2011.

[9] Jacyna M., Pyza D., Nowakowski T.: Selected Aspects of Model Approach to Logistics System of Poland, Logistics and Transport Vol 10, No 1,/2010.

[10] Jacyna M.: Modelowanie i ocena systemów transportowych. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2009.

[11] Jacyna M.: The role of Cargo Consolidation Center in urban logistic system. Urban Transport XII, WIT Press 2011.

[12] McCollom N., Blank L.: Simulation Model For Multi Level Distribution Planning. ANSS '79 Proceedings of the 12th annual symposium on Simulation, New Jersey 1979r., USA.

[13] Merkisz J., Radzimirski S.: Nowe przepisy Unii europejskiej o emisji zanieczyszczeń z pojazdów samochodowych, „Transport Samochodowy" wydawnictwo ITS 2/2011.

[14] Merkisz J.: Zanieczyszczenie środowiska przez transport samochodowy Zeszyty Naukowe Politechniki Poznańskiej, Poznań 2000.

[15] Michalkiewicz Z.: Algorytmy genetyczne + struktury danych = programy ewolucyjne. WNT, Warszawa 2003.

[16] Michlowicz E.: Rozwiązywanie problemów dostaw w systemach dystrybucji. Logistyka 4/2012

[17] Nowakowski T., Werbińska S.: Zagadnienie oceny gotowości systemu logistycznego. Logistyka, nr 5/2007.

[18] Nowakowski T.: Niezawodność systemów logistycznych. Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2011.

[19] Šimák L.:Integration of transport in logistics systems Logistics and Transport Vol 8, No 1, 2009

[20] Thorne G., Browne M., „Przewodnik po dobrych praktykach w towarowym transporcie miejskim", BESTUFS 2007r., str. 30.

[21] Zomer G.R.: Optimisitaion of Urban Freight Systems by strategic co-operations. materiały konferencyjne LIFE-CEDM, Lucca 2008.

Emilian Szczepański
Faculty of Transport, Warsaw University of Technology, Poland
eszczepanski@wt.pw.edu.pl

Marianna Jacyna
Faculty of Transport, Warsaw University of Technology, Poland
maja@wt.pw.edu.pl