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MODELS OF ZONING OF URBAN TERRITORY FOR RATIONAL DELIVERY IN THE MICROCONSOLIDATION SYSTEM

Lidia Savchenko, Volodimir Davydenko. "Models of zoning of urban territory for rational delivery in the microconsolidation system". *Urban logistics (or city logistics) is developing rapidly due to the strong growth of e-commerce. Accordingly, the last-mile urban logistics faces a significant number of orders that need to be fulfilled in a dense urban development, environmental constraints and permanent congestion. One of the possible systems of rational city delivery is the use of a network of consolidation centers at the micro level. Such a network provides for a two-tier system of urban delivery - 1) from the central warehouse or warehouses to the network of microconsolidation centers; 2) from microconsolidation centers to end consumers. This scheme is especially relevant in the presence of restrictions on the movement of trucks or heavy vehicles in certain areas of the city, as well as in significant congestion and the problem of parking trucks when unloading at the location of the client.*

Methods (research methodology). To create a rational delivery network through a microconsolidation system, the primary task is to determine the delivery zones (or geographical clusters) - their number, size, location. To solve this problem, optimization models are proposed based on several minimization criteria - delivery distance, time, cost and integrated distance-time criterion.

Results. The result is the optimization models creation, based on those it is possible to divide urban consumers into several delivery zones. Delivery routes are planned within each zone of the respective centroid and minimize the cost of last-mile logistics. Delivery of goods to the centroids can be carried out by light or medium trucks, and within the zones should be dominated by delivery of environmentally friendly modes of transport (motorcycle or moped, bicycle, car, on foot delivery with the possibility of public transport usage).

Conclusion. Thus, the article provides a mathematical apparatus for obtaining territorial zoning of existing customers of the city in order to minimize the cost (distance, time or their combination) for delivery within each zone.

Perspectives. A perspective study may be an analysis of the costs of operating a network of urban consolidation centers and the delivery of goods from the central warehouse or warehouses to this network.

Accordingly, the task of minimizing the total costs of the city freight delivery system should be solved, taking into account economic, environmental and social aspects.

***Keywords**:* city logistics, zoning of territory, zoning (territorial clustering) of clients, models of optimal territorial zoning, city consolidation, two-level (two-tier) system of urban delivery.

Лідія Савченко, Володимир Давиденко. "Моделі зонування міської території для раціональної доставки у системі мікроконсолідації". *Міська логістика стрімко розвивається завдяки потужному зростанню електронної торгівлі. Відповідно, міська логістика останньої милі стикається зі значною кількістю замовлень, яку потрібно виконувати в умовах щільної міської забудови, екологічних обмежень та перманентних заторів. Однією з можливих систем раціональної міської доставки є застосування мережі консолідаційних центрів на мікрорівні. Така мережа передбачає дворівневу систему міської доставки - 1) від центрального складу чи складів до мережі мікроконсолідаціних центрів; 2) з мікроконсолідаційних центрів до кінцевих споживачів. Особливо така схема є актуальною при існуванні обмежень щодо руху вантажного транспорту або взагалі транспортних засобів у певних районах міста, а також при значних заторах та проблемою у паркуванні вантажних автомобілів при вивантаженні біля місця розташування клієнта.*

Для створення раціональної мережі доставки через систему мікроконсолідації первинною задачею є визначення зон доставки (або географічних кластерів) - їх кількості, розмірів, розташування. Для вирішення цієї задачі пропонуються оптимізаційні моделі, засновані на декількох критеріях мінімізації - відстані доставки, часу, вартості та інтегрованого критерію відстань-час.

Результатом роботи є створення оптимізаційних моделей, на основі яких можливо розбити міських споживачів на декілька зон доставки. Маршрути доставки плануються усередині кожної зони від відповідного центроїду та дозволяють мінімізувати витрати на логістику останньої милі. Доведення товарів до центроїдів може здійснюватися легкими або середніми вантажними автомобілями, а всередині зон має превалювати доставка екологічно дружніми видами транспорту (мотоцикл чи мопед, велосипед, легковий автомобіль, піша доставка з можливістю залучення громадського транспорту).

Таким чином, стаття надає математичний апарат для отримання територіального зонування наявних клієнтів міста з метою мінімізації витрат (відстані, часу або їх комбінації) на доставку усередині кожної зони. Перспективним дослідження може бути аналіз витрат на функціонування мережі консолідаційних центрів та на довезення товарів з центрального складу чи складів до цієї мережі. Відповідно, має бути вирішена задача мінімізації загальних витрат на систему міської доставки з урахуванням економічних та екологічно-соціальних аспектів.

Ключові слова: міська логістика, зонування території, зонування (територіальна кластеризація) клієнтів, моделі оптимального територіального зонування, міська консолідація, дворівнева система міської доставки.

Лидия Савченко, Владимир Давиденко. "Модели зонирования городской территории для рациональной доставки в системе микроконсолидации". *Городская логистика стремительно развивается благодаря мощному росту электронной торговли. Соответственно, городская логистика последней мили сталкивается с большим количеством заказов, которую нужно выполнять в условиях плотной городской застройки, экологических ограничений и перманентных пробок. Одной из возможных систем рациональной городской доставки будет применение сети консолидационных центров на микроуровне. Такая сеть предполагает двухуровневую систему городской доставки - 1) от центрального склада или складов в сети микроконсолидациних центров; 2) с микроконсолидаційних центров до конечных потребителей. Особенно такая схема актуальна при существовании ограничений движения грузового транспорта или вообще транспортных средств в определенных районах города, а также при значительных пробках и проблемой в парковке грузовых автомобилей при выгрузке у места расположения клиента.*

Для создания рациональной сети доставки через систему микроконсолидации первичной задачей является определение зон доставки (или географических кластеров) - их количества, размеров, расположения. Для решения этой задачи предлагаются оптимизационные модели, *основанные на нескольких критериях минимизации - расстояния доставки, времени, стоимости и интегрированного критерия расстояние-время.*

Результатом работы является создание оптимизационных моделей, на основе которых возможно разбить городских потребителей на несколько зон доставки. Маршруты доставки планируются внутри каждой зоны соответствующего центроиду и позволяют минимизировать затраты на логистику последней мили. Доведения товаров до центроидов может осуществляться легкими или средними грузовыми автомобилями, а внутри зон должно превалировать доставка экологически дружественными видами транспорта (мотоцикл или мопед, велосипед, легковой автомобиль, пешая доставка с возможностью привлечения общественного транспорта).

Таким образом, статья предоставляет математический аппарат для получения территориального зонирования существующих клиентов города с целью минимизации затрат (расстояния, времени или их комбинации) на доставку внутри каждой зоны. Перспективным исследования может быть анализ расходов на функционирование сети консолидационных центров и на подвоз товаров с центрального склада или складов в сети. Соответственно, должна быть решена задача минимизации общих затрат на систему городской доставки с учетом экономических и экологически социальных аспектов.

Ключевые слова: городская логистика, зонирование территории, зонирования (территориальная кластеризация) клиентов, модели оптимального территориального зонирования, городская консолидация, двухуровневая система городской доставки.

Introduction. The urgency of clustering (or zoning) of the urban area is relevant to the need to model and build rational routes of vehicles, monitoring of freight and passenger flows between different districts or neighborhoods of the city. During clustering, a certain area of the city is considered as a whole with a certain demand for goods, supply for other areas, with a known number of consumers, shops, vehicles, and so on.

At clustering (zoning) of the territory of the city the following purposes can be set:

– modeling of logistics flows for the rational organization of traffic, construction of routes, assessment of bottlenecks in transport infrastructure, etc.;

– systematization of urban planning (obtaining zones with approximately the same indicators for the application of certain rules, technologies, restrictions, etc.);

– organization of cargo delivery, customer service of the city (division of the city into zones for customer service within each zone).

Urban logistics (or city logistics) is developing rapidly due to the strong growth of e-commerce. Accordingly, the last-mile urban logistics faces a significant number of orders that need to be fulfilled in a dense urban development, environmental constraints and permanent congestion. One of the possible systems of rational city delivery is the use of a network of consolidation centers at the micro level. Such a network provides for a two-tier system of urban delivery - 1) from the central warehouse or warehouses to the network of microconsolidation centers; 2) from microconsolidation centers to end consumers. This scheme is especially relevant in the presence of restrictions on the movement of trucks or heavy vehicles in certain areas of the city, as well as in significant congestion and the problem of parking trucks when unloading at the location of the client.

Analysis of the latest research. The issue of clustering or cluster analysis is reflected in a significant number of mathematical methods and models for dividing a certain set into several groups [1, 2, 3, 4]. Widespread use of clustering (or grouping, separation) methods proves to some extent the universality of this approach and existing methods.

In modern city logistics, grouping of customers by geographical zones is widely used, with the possible assignment of drivers of a certain car or group of cars, couriers to each zone. This method of planning allows drivers and couriers to thoroughly study the service area and establish contacts with receivers, which generally speeds up the delivery process and increases customer satisfaction [6]. However, mathematical methods and models of geographical clustering for the needs of creating a rational distribution system are missing. Against this background, it should be noted a significant number of software products for urban delivery [7-11], which optimize the process of building rational routes, but do not allow to divide them into territorial zones to minimize delivery costs within each zone.

When dividing the territory into transport areas (zones or clusters), the number and size of such areas depend on the size of the city and population. When setting the boundaries of transport areas, it is recommended to adhere to the following principles:

– use of lines of natural and artificial obstacles (rivers, railway lines, etc.);

– observance of administrative zoning of the territory;

– accounting for functional zoning of the city;

– preservation of existing building blocks;

– prevention of formation of transport areas of elongated configuration [5].

The problem of an urban area clustering and possible tasks that can be set for zoning of city customers are considered in [16]. The authors [18] consider possible ways of interaction of participants of the process of city delivery, in particular, with the use of city consolidation centers of different levels.

Accordingly, with a significant number of studies on clustering, in particular territorial, there is a shortage of theoretical and practical information on the rational division of customers into groups for further planning of optimal routes within each group of relevant centroids (for urban logistics - from microconsolidation centers).

Formulation of the purpose of the study. Given the lack of research on territorial clustering to divide city customers into zones and further delivery through a network of microconsolidation centers, the aim of the article is to obtain basic mathematical models for grouping city customers into delivery zones by minimizing delivery costs within the respective zones.

Presentation of the main research. *1. General approaches to clustering that can be used in the city customers zoning for delivery through a network of microconsolidation centers.* Clustering (or cluster analysis) is the task of breaking a set of objects into groups called clusters. From a mathematical point of view, clustering helps to identify a set of closely related (by a certain criterion) objects in a certain set of such objects. Within each group should be "similar" elements, and the elements of different groups (clusters) should be as different as possible. The main difference between clustering and classification is that the list of groups is not clearly defined and is determined during cluster analysis.

The application of cluster analysis in general is based on the following stages:

1. Selection of objects for clustering.

2. Defining the criteria by which objects will be evaluated.

3. Calculation the degree of similarity between objects.

4. Application of a certain method of cluster analysis to create groups of similar objects (clusters).

5. Obtaining and analyzing the results of the analysis. If necessary - adjusting the model.

The first task that is recommended to be performed before starting the cluster analysis is to assess the overall clustering tendency of the available data.

Hopkins statistics are one indicator of a trend toward grouping. To calculate it, several pseudo-data sets are created, randomly generated based on a distribution with the same standard deviation as the original data set. For each observation i with n calculate the average distance to k nearest neighbors: w_i between real objects and q_i between artificial objects and their nearest real neighbors. Then Hopkins statistics

$$H_{ind} = \frac{\sum_{i=1}^{n} w_i}{\sum_{i=1}^{n} q_i + \sum_{i=1}^{n} w_i}$$

greater than 0.5 would correspond to the null hypothesis that q_i and w_i are similar, and the grouped objects are randomly distributed and homogeneous. A value of H_{ind} <0.25 with 90% confidence indicates an existing tendency to group the data.

Clustering with a known number of clusters.

Partitioning algorithms [4] decompose a set of data consisting of *n* observations into *k* groups (clusters) with previously unknown parameters. The search for centroids - the most distant from each other the centers of condensation of points C_k with minimal scatter within each cluster. The separation algorithms include:

- method of *k*-means McKueen (*k*-means clustering; MacQueen, 1967), in which each of the *k* clusters is represented by a centroid;
- division around *k* medoids or PAM (Partitioning Around Medoids; Kaufman, Rousseeuw, 1990), where the medoid is the center of gravity, the coordinates of which are shifted to the nearest of the original data objects;
- CLARA algorithm (Clustering Large Applications) - a method very similar to PAM and used to analyze large data sets.

The most common clustering algorithm is the method of *k* means. It performs clustering as follows:

1. Assign the number of groups (*k*) into which the data should be divided. Randomly, *k* objects of the source set are selected as the initial centers of the clusters.

2. Each element is assigned a group number on the nearest centroid, ie on the basis of the smallest Euclidean distance between the object and the point C_k.

3. List the coordinates of the centroids *μk* of all *k* clusters and calculate the intra-cluster variation $W(C_k) = \sum_{x_i \in C_k} (x_i - \mu_k)^2$. If the data set includes *p* variables, then *μk* is a vector of averages with *p* elements.

4. The general intragroup scatter is minimized $Wtotal = \sum_k W(C_k) \to \min$, for which steps 2 and 3 are repeated many times until the group assignments stop changing or the specified number of *iter.max* iterations is reached.

It is convenient to perform clustering using the programming language *R*. The maximum number of iterations for minimizing W_{total}, set by the function *kmeans* () by default, is *iter.max* = 10 [5].

Clustering by the method of *k* means is a very simple and efficient algorithm. However, the results of clustering are sensitive to the initial choice of group centers. A possible solution to this problem is to repeatedly execute the algorithm with the choice of different primary centroids.

Partition into (approximately) identical clusters.

For urban zoning, obtaining the same clusters makes sense if the clustering objects are customers with certain geographical coordinates. Then the cluster can be a set of such clients, the number of which allows one delivery route, while fully loading the vehicle or courier. Thus, it is possible to get areas of the city with approximately the same number of customers in each of them.

An example of clustering with the same cluster size is proposed in *R* [3].

Evaluation of clustering quality.

After receiving a cluster solution, the question usually arises as to how stable and statistically significant it is. There is an empirical rule here - a stable group must be preserved when changing clustering methods: for example, if the results of hierarchical cluster analysis have a coincidence of more than 70% with clustering by the method of *k* means, then the assumption of stability is accepted. Other methods and criteria for assessing the quality of clustering validation results can be studied in [4].

2. Models of urban area zoning for rational delivery in the microconsolidation system.

In conditions of city delivery freight companies have to deal with an array of customers located in different parts of the city. When planning delivery routes often appeal to clustering of territory, which for the city is called zoning. In this case, we mean the division of the city into zones (clusters) in order to reduce transport costs (Fig. 1).

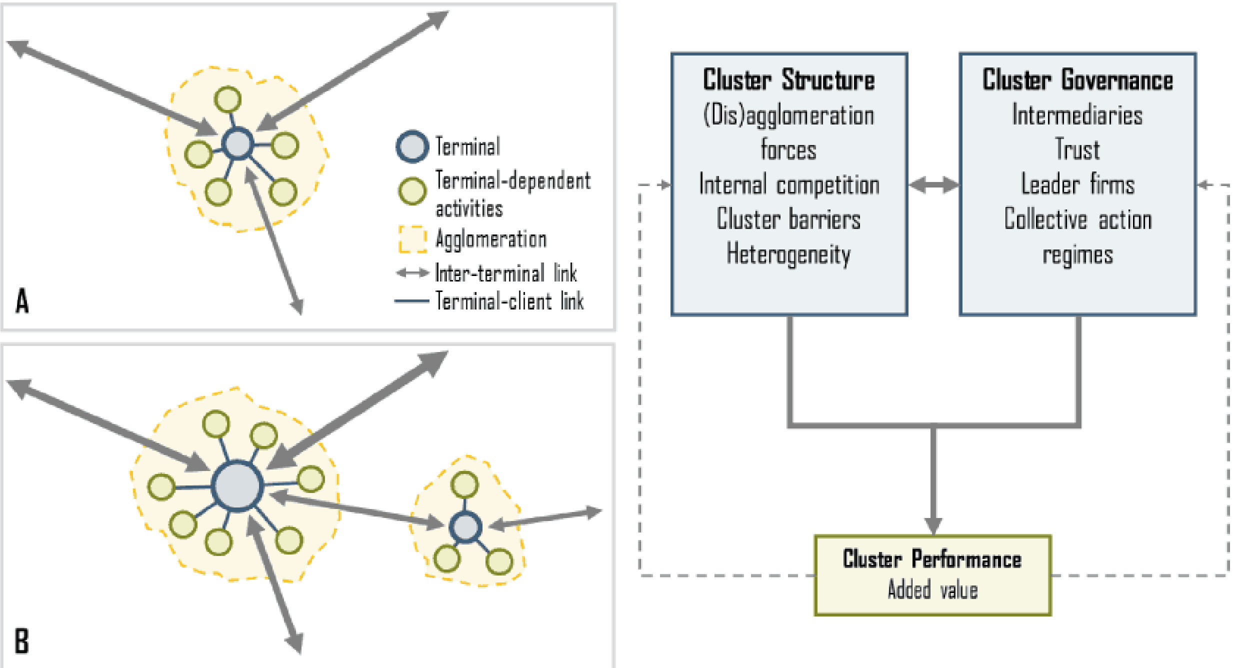

Figure 1 – Terminals (consolidation centers) as centroids [12]

Accordingly, the main criteria used for urban zoning are the distance of the route and the time of transportation. The time criterion is necessary in urban conditions, especially when delivered during morning and evening traffic jams. At this time, the minimum distance does not mean the minimum transport costs. Sometimes increasing the distance even twice allows, on the one hand, to speed up delivery, on the other hand, to reduce transport costs.

Consider the general mathematical formulation of the problem of zoning the urban area.

It is necessary to divide the urban area into zones to minimize delivery costs (Fig. 2).

For zoning of the territory, information is required on:

– the needs of the points of the territory (demand);

– location of points.

The location of the points can be seen on the map, and then set their Cartesian coordinates.

The problem of optimal zoning of the urban territory can be solved with the following criteria:

– minimum delivery distance;
– minimum delivery time;
– minimum shipping cost;
– integrated criterion.

Sometimes the optimal solution is getting a minimum of distance, time, and cost simultaneously. However, in conditions of congestion, toll roads and other limiting undesirable phenomena, one criterion should be selected and based on it, the search for an optimal solution should be made. If necessary, it can be used an additional solving of the problem to determine alternative solutions with different criteria for the problem.

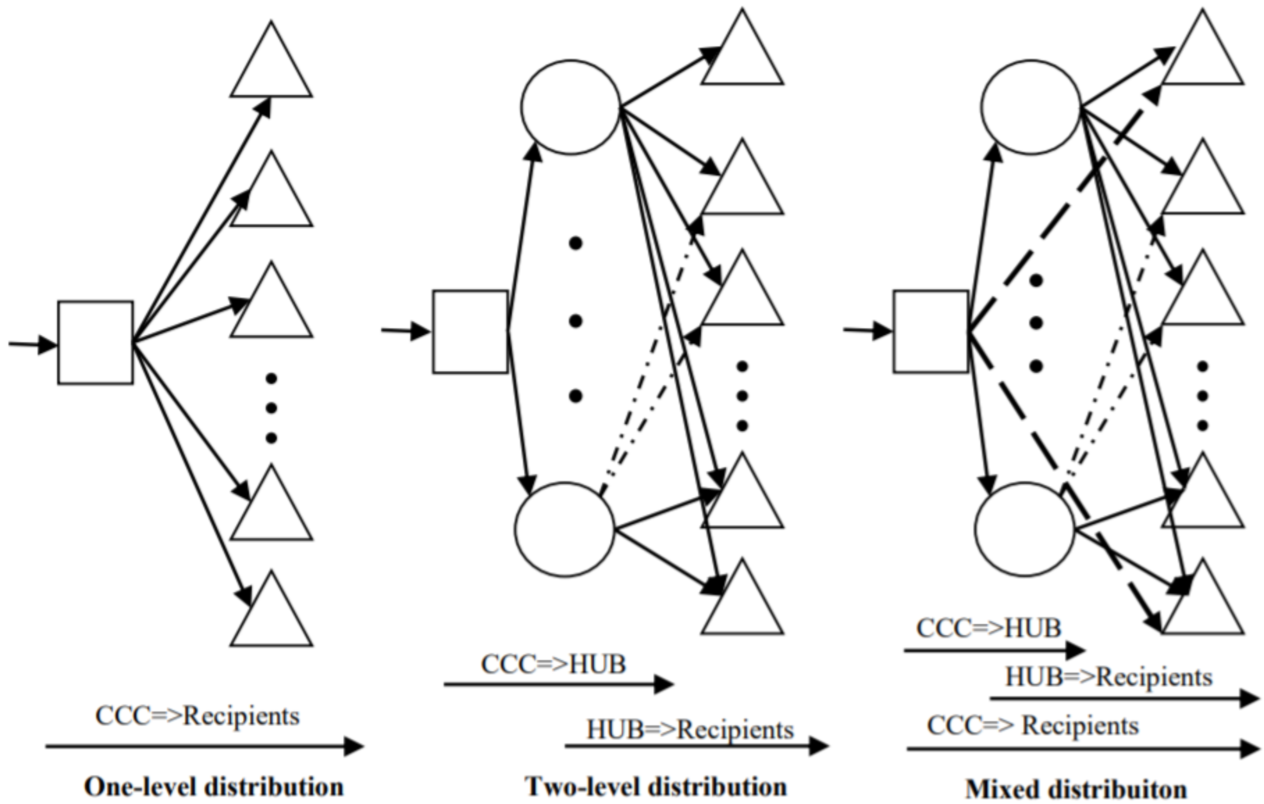

Figure 2 – Solutions based on the concept of multi-tier distribution systems Source: based on [14, 15].

1. Criterion of minimum distance.

The simplest way to determine the distance is the formula

$$R(i,j)=\sqrt{(x_i-x_j)^2+(y_i-y_j)^2} \quad (1)$$

where x_i, x_j, y_i, y_j - Cartesian coordinates of the points in the zone.

That is, the so-called Cartesian distance. Concequently, the objective function (minimization of the sum of all distances between all point of all zones) is

$$OF_d=\sum_{i=1}^{n}\sum_{j=1}^{n}R(i,j)\rightarrow \min \quad (2)$$

or

$$OF_d=\sum_{i=1}^{n}\sum_{j=1}^{n}\sqrt{(x_i-x_j)^2+(y_i-y_j)^2}\rightarrow \min \quad (3)$$

However, the transport network does not always have a direct path between points.

For obtaining more accurate data on the distance, it can be used any tools for laying routes in real time, in particular, Google Map.

If distribution routes are supposed to be used for the delivery to the customers of the zone, the length of the tour/route (L) can be calculated with:

$$L=2l_0+l_{cc}\left(n-1\right), \quad (4)$$

where l_0 – average length of the first and last trip of the delivery tour (route), km;

l_{cc} – average distance between customers on a typical delivery tour (route), km;

n - number of clients/customers included in a zone.

Value l_{cc} could be obtained as an atithmetic average of the distances between the points of the zone:

$$l_{cc} = \sum_{i=1}^{n} \sum_{j=1}^{n} R(i, j) \Big/ n \quad (5)$$

The objective function becomes

$$OF_d = 2ml_0 + l_{cc}(n-1) \rightarrow \min \quad (6)$$

where m - number of routs during the shift (or working day).

One of the constraints to take into consideration is the number of parcels that one delivery vehicle/means can transport in a route from the point of view of vehicle capacity both in terms of weight and volume capacity:

$$n_1 = \min \{ INT \{Q / q\}, INT \{V / v\}\}, \quad (7)$$

where the INT function gives the number to the nearest smaller integer;

Q – weight capacity of a means of delivery, kg;

q – average weight of a parcel, kg;

V – volume capacity of a means of the delivery, m^3;

v – average volume of a parcel, m^3.

The maximum number of routes per shift is calculated as the ratio of the duration of the shift and the time of a route on this shift:

$$m_{\max} = rounddown\{t/T\} = rounddown\left\{ t \Big/ t_{prep} + \frac{l_{cc}(2+n-1)}{V(t)} + nt_{1c} \right\}, \quad (8)$$

where the *rounddown* function rounds numbers down;

t – duration of a shift (working day), h.

The minimal number of routes per one working shift is a ratio of the number of delivery points and capacity of delivery means:

$$m_{\min} = roundup\{n/n_1\}, \quad (9)$$

where *roundup* function rounds numbers up.

While solving the optimal solution equations (8) and (9) are the limitations of the model. Real number of the routes must be not less than m_{min} and not grater than m_{max}.

If we assume that each zone will be served from the so-called centroid, then the distance of zero run can be taken as the distance between route points ($l_0 = l_{cc}$). Then the objective function will look like:

$$OF_d = 2ml_{cc} + l_{cc}(n-1) = l_{cc}(2m+n-1) = \frac{(2m+n-1)\sum_{i=1}^{n} \sum_{j=1}^{n} R(i, j)}{n} \rightarrow \min \quad (10)$$

For the resulting objective function, the variable will be the distance between the route points *R(i, j)*, which can be calculated using Cartesian coordinates.

2. Criterion of minimum time.

Minimizing delivery times is usually more important than minimizing distance. This is due to the ever increasing "cost" of time in business. For delivery services, delivery times have a direct impact on significant cost items such as wages and depreciation. The side of customers waiting for an order should also be taken into account. In case of failures in delivery time, there is a risk of the need for re-delivery if the client did not wait for the courier. In this case, losses are incurred twice, supplemented by reputational losses for the delivery service company.

The delivery time should be calculated taking into account the time of day (availability and intensity of congestion), as well as the number of customers on the route and the time for servicing these customers.

In distribution route, the travel time could be calculated as:

$$T(t)=t_{prep}+2t_0+T_{cc}(t)+T_c=t_{prep}+\left[2l_0+(n-1)l_{cc}\right]/V(t)+nt_{1c}, \quad (11)$$

where t_{prep} – preparatory-final time for delivery tour/route, h;

t_0 – time to travel from the sender's base to the first customer and to return from the last customer to the sender's base by mode l during the working shift j, h;

$T_{cc}(t)$ – travel time between successive customers, h;

T_c – time spent at customers' delivery points, h;

$V(t)$ – average speed, km/h;

t_{1c} – average time spent at customer's delivery point, h.

The speed depends on the time of day, due to the different level of traffic/congestion, as well as on the type of delivery vehicle/means used [17].

$$OF_t=\sum_{i=1}^{n}\sum_{j=1}^{n}T(i,j)\rightarrow \min \quad (12)$$

And finally, if consider $l_0=l_{cc}$:

$$OF_t=mt_{prep}+\frac{(2m+n-1)\sum_{i=1}^{n}\sum_{j=1}^{n}R(i,j)}{nV(t)}+nt_{1c}\rightarrow \min \quad (13)$$

3. Criterion for minimum delivery cost.

With the possibility of calculating direct financial costs on the route, automation and simplicity of this process, it is possible to solve the zoning problem according to the criterion of total costs in monetary terms. Naturally, this criterion is the most acceptable and allows to immediately see the delivery costs. However, the calculation of transportation costs is a rather difficult task, given the constantly changing conditions on the route (different speeds, number of stops, time spent at customers' delivery points, etc.). Therefore, in practice, this criterion is rarely used.

In any case, the objective function for the shipping cost criterion looks like

$$OF_s=\sum_{i=1}^{n}\sum_{j=1}^{n}S(i,j)\rightarrow \min \quad (14)$$

where $S(i,j)$ - transport costs for movement between points i and j.

4. Integrated criterion.

It is often convenient to use an integrated criterion. For this, it is usually taking several local criteria and assign them weights (significance coefficients), showing their mutual significance in the integrated criterion. It is most convenient to use the values of the weights from 0 to 1 with the condition that the sum of the weights of the local criteria is 1. For example, for the distance criterion, the significance coefficient can be taken as 0.3, and for the time criterion - 0.7.

The most rational approach to determining the significance factors is based on the calculation of the cost of a typical transportation. Further, the components of this cost are divided into two groups: 1) depent on the distance of the route; 2) depent on delivery time. If some component of the cost price depends on both distance and time (for example, often the driver's salary consists of two parts - depent on the distance traveled and hours of work), it should be divided into the groups depending on the actual proportion.

After receiving the abovementionned groups of cost components, the total cost of each group is calculated and the share of each group in the total cost is determined. This specific weight should be used as the coefficients of significance in the integrated criterion:

$$OF_I = \sum_{i=1}^{n} \sum_{j=1}^{n} \left(w_d \cdot D(i,j) + w_t \cdot T(i,j) \right) \rightarrow \min \qquad (15)$$

with condition $w_d + w_t = 1$.

It should be noted that modern alternatives to a warehouse can be used as a consolidation center, with a small size and weight of packages requiring delivery (Fig. 3), namely:

1. Unattended delivery systems at the customer's home include the use of:

- Reception boxes;
- Delivery boxes;
- Controlled access systems.

2. Unattended delivery systems away from the customer's home include:

- Pick-up points;
- Collection points;
- Locker banks.

Figure 3 – Principle of working of Automated parcel machine [13]

Conclusions. Assessing the current state of scientific and practical developments in the field of urban zoning to build an effective system of goods delivery to residents, construction sites, business environment, food facilities, etc. it is necessary to state some detachment of theoretical materials from practice. It is obvious that the need of business for high-quality, fast and inexpensive software solutions for planning a rational city delivery is growing. This is confirmed by a wide range of companies offering such solutions on the market of both Ukraine and other countries. Also noticeable is the dynamic development of existing programs in parallel with the development of cloud technologies, blockchain, and other solutions that simplify and clarify the process of transactions of participants in logistics processes, transmission and analysis of information, data processing in real time.

Thus, clustering (or zoning) of the urban territory on a territorial basis helps in the implementation of rational logistics solutions in customer service of the city. Considering the city as a set of neighborhoods with a certain number of delivery customers in each allows to make rational delivery routes and provide a reliable level of logistics service by minimizing delays and errors in the implementation of last-mile logistics. Such a delivery scheme is possible in the presence of a network of microconsolidation centers located in each defined area of the city. The environmental and social aspects of the solution are reinforced by the use of environmentally friendly vehicles or on foot delivery within each zone. Thus, the rational division of the city into delivery zones in combination with the principle of microconsolidation will reduce 1) the load on the city road network, 2) harmful emissions into the city atmosphere and 3) accidents and noise pollution in densely populated areas.

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