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Directions in logistics coordination in cities and metropolitan areas: economic-mathematical vision

Kierunki koordynacji logistyki w miastach i obszarach metropolitalnych

Abstract: *The article is devoted to the formation of an economic-mathematical model of logistic coordination flows in cities and metropolitan areas. The author reveals the essence, objectives and priorities of the transport, financial and information logistics coordination. The model of logistic coordination of transport flows is proposed. The model of logistics coordination of financial flows in cities and metropolitan areas, based on the Black-Scholes model, is proposed. The model of logistics coordination of information flows is proposed.*
Keywords: economic-mathematical modelling, model, transport logistics coordination, financial logistics coordination, information logistics coordination

Streszczenie: *Artykuł jest poświęcony utworzeniu ekonomiczno-matematycznego modelu koordynacji logistyki w miastach i obszarach metropolitalnych. Autorka ukazuje istotę, cele i priorytety koordynacji logistyki transportu, finansowania i informacji oraz proponuje model działalności transportowej. Oprócz tego zaproponowano model koordynacji logistyki przepływów finansowych w miastach i obszarach metropolitalnych, bazujący na wzorcu the Black-Scholes, jak również model koordynacji logistyki informacji.*
Słowa kluczowe: modelowanie ekonomiczno-matematyczne, model, koordynacja logistyki transportu, koordynacja logistyki finansowania, koordynacja logistyki informacji

Introduction

Given the fact that output in the unfolding economic, social and ecological processes that determine the formation of the socio-economic situation in the territorial system of higher hierarchical order, problem management sustainable development of cities and metropolitan areas are issues undoubtedly relevant. Maintenance of the sustainable development of cities and metropolitan areas requires developing ways of logistics coordination. Logistics coordination is basic for providing cities' and agglomerations' subsystems, their population with material, financial and information recourses, which use the same infrastructure, that requires coordination of their direction and intensity at the time.

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Key research findings

The city as a logistics system is characterized by a system of input and output flows that occur through the consumption of the socio-ecological and economic resources, the availability of an internal and external environment in which there are basic stages of the logistics process: procurement - production-distribution-consumption that actually confirms the position to review the city as a logistics facility (Gerasymchuk Z.V.& Averkyna M.F., 2014)[2].

The city and metropolitan area as any logistics system is adaptive, open to interaction with the environment is an organized, structured economic system consisting of interconnected and interacting participants, united unity of purpose and economic interests, and which is established to optimize the resources used in economic flows (fig.1).

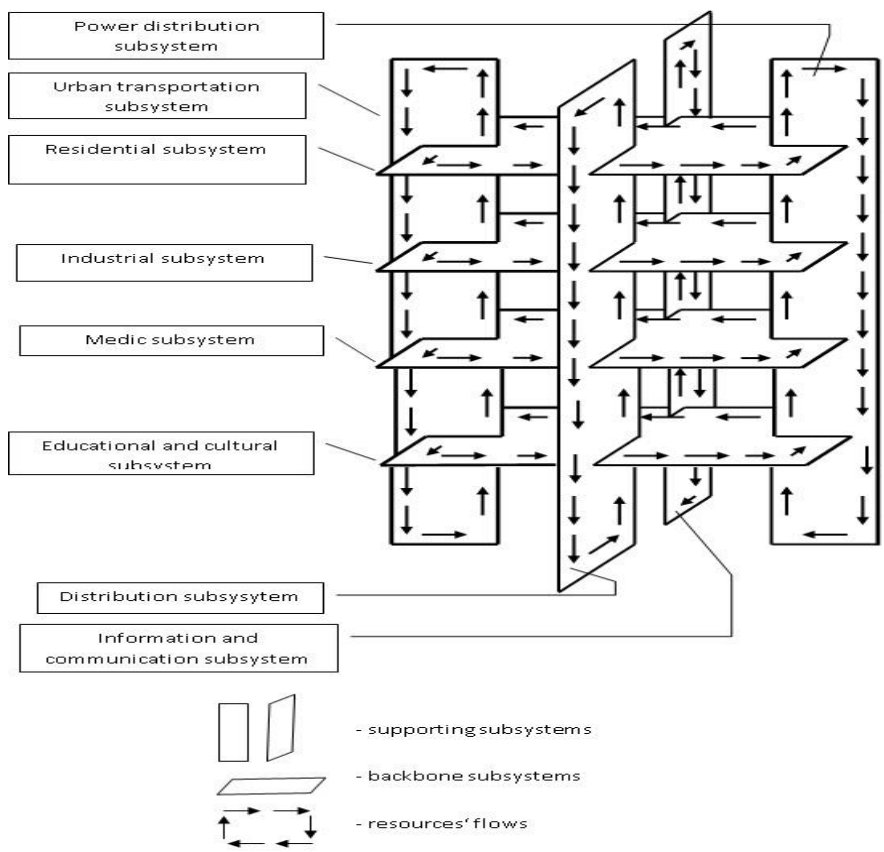

Fig. 1. Backbone and supporting subsystems
Source: own work

[2] Z.V. Gerasymchuk, M.F. Averkyna, Theoretical and methodological foundations for maintaining of sustainable development of the cities and metropolitan agglomeration. Scientific Bulletin of National Mining University, Scientific and Technical Journal No 5 (143)2014, p.134-141.

For logistics coordination of flow in cities and metropolitan areas different scenarios are incidental. Thus, it is critical for the city to coordinate at the time several material flows using the same common infrastructure, and for the metropolitan area it is critical to concentrate the flow of resources, coming through several different streams in several infrastructures into one (eg. commuting workers from satellite towns to the metropolitan centre).

Consider the above, we propose to separate logistical coordination of the "second order", which is caused by the need to concentrate several streams that move certain infrastructures in a particular point in space and at a particular time. Unlike the previous type of coordination, coordination of the "second order" can combine tangible and intangible flows.

This kind of coordination is required when the city is involved in the metropolitan area with the status of "satellite": intercity (suburban) transport in a satellite town should transfer labour forces to the centre of the metropolitan area before the start of the day, and return workers to the satellite town after the end of the working day.

Involvement of several satellite cities and accordingly several infrastructure users in the process of the transport infrastructure causes additional complications in the coordination of logistics flows.

In the context of the above, we consider as effective the decision on development and approval of local government plans for the requirements in material flows at the time; coordination of those plans with the requirements of businesses in cities and agglomerations; coordination of schedules of primary and secondary streams flow through infrastructures (industrial enterprises, institutions, organizations, educational institutions, medicine) and metropolitan areas at the time.

In addition, defined directions of coordination between cities and agglomerations must meet the conditions of the optimization model such as:

$$Ez = \sum_{a} \int_{t(0)}^{t(u_a)} \sqrt{E_{econ.}^2 + E_{soc.}^2 + E_{ecol.}^2}\, dt \to \max \tag{1}$$

Where:

E_z – is general effect, which can be obtained by coordinating flows (labour, material) in the city and metropolitan area;

u_a – traffic (material, labour) flows between places that are u_{kpg} amounts of flow paths for all k, using this item;

a – item number;

$E_{econ.}$ – economic impact after the implementation of the logistics coordination;

$E_{soc.}$ – social impact after the implementation of the logistics coordination

$E_{ecol.}$ – environmental impact from the implementation of the logistics coordination

t – time

It is known[3], that of the patient (extreme) values of integral (1) is reduced to a variational problem, which has the general appearance:

$$\delta E_{заг} = 0. \tag{2}$$

[3] М. П. Моклячук, Варіаційне числення. Екстремальні задачі. / М. П. Моклячук. – К.: ВПЦ «Київський університет», 2010, p. 399.

Depending on the type of restrictions and functional in (1) variational problems (2) should be reduced in each case or to linear programming problems, or the problems of dynamic programming.

As for the linear problem, solutions of which fully meet the practical needs of optimizing the network traffic of cities and agglomerations, its limitations are that the flow paths u_{kpq} should add up to f_{pq} flow between all pairs of cities agglomeration *p* and *q*:

$$u_a = \sum_{p,q} \sum_{k \in K_{pq}, a \in k} u_{kpq}, \tag{3}$$

$$f_{pq} = \sum_{k \in K_{pq}} u_{kpq}, \tag{4}$$

$$u_{kpq} \geq 0. \tag{5}$$

This model can be shown in action on a linear line, i.e. if there is only one line route between the cities. Then only one integral for one-way route for a given part of the route is to be maximized in the model (1):

$$Ez = \int_{t(0)}^{t(u)} \sqrt{E_{econ.}^2 + E_{soc.}^2 + E_{ecol.}^2}\, dt \to \max \tag{6}$$

According to the theorem of the average value of the integral, previous equality is equivalent to maximization the average value integrand, ie, for a network that consists of only one branch, the optimization problem takes the form:

$$Ez = \sqrt{E_{econ.}^2 + E_{soc.}^2 + E_{ecol.}^2}\, dt \to \max \tag{7}$$

Consider that the common effect is calculated as the root of the sum of even squares of certain effects, providing the maximum of each of these functions gives the maximum total selected function.

Overall for the network of the multi directional routes it is necessary to decide the appropriate optimization problem for directional graph modelling the entire network, and to optimize each area in particular and the entire graph.

Besides the transport logistics coordination, the financial logistics coordination plays an important role in the sustainable development of cities and agglomerations. The financial logistics coordination provides with financial resources those cities and metropolitan subsystems that are most favourable for the rational use of environmental and socio-economic resources, their reproduction, the attainment of socio-ecological-economic security and improvement of logistization. Also, the purpose of financial coordination is to reduce consumption of external resources by the subsystems of the city and the metropolitan area and to maximize the functioning with their internal resources.

The next tasks of financial logistic coordination are treated as basic:

1. Providing the city (metropolitan area) with the necessary financial resources. It includes: estimating the requirements in financial resources,

selection of the supplier of the financial resources, preparation of the plan for strategical activities' funding aimed for sustainable development of the city (metropolitan area).

2. Distribution of the financial resources in the city (metropolitan area) that provides establishing a system for finance resources distribution, determination of basic directions for the financial resources forming and usage, estimation of the financial possibilities to prospective investments into strategical activities, reaching financial transparency for investors in the city (metropolitan area).
3. Establishing sound financial cooperation between the municipal budget, banks, suppliers, customers and other business of the city and metropolitan area that allows Department of Finance to optimize payments between them.

In order to achieve efficient logistic coordination of financial flows in the city (metropolitan area) will be reasonable:

1) to organize local tenders bidding procedures for choosing actors who will be capable to fund certain events necessary for the city (metropolitan area) e.g. building and reconstruction of the municipal property objects;
2) to create local financial organizations e.g. banks, insurance companies, that allows the involvement of financial resources to cities and metropolitan areas;
3) to establish investment trusts with depreciation charges of municipal entities. It allows the concentration of resources for investments intended for large-scale rotation of the worn equipment in the basic and supporting urban subsystems.
4) to establish local mutual-aid funds in order to fulfill the needs of citizens, city and metropolitan areas. These funds should be created within self-government authorities which have to control the financial flows.
5) to provide efficient control for the financial flows in the city (metropolitan area). The activity of financial control authorities should be aimed at preventing and early disclosure of illegal and ineffective activities with local funds, in due time the elimination of disclosed problems, damage mitigation and punishment of the offenders.
6) to create a real-time accounting system, especially weekly designing of municipal (metropolitan area) budget. It enables more transparent consumption of the financial resources by all participants.
7) to stop funding the insignificant programmes in order to support more important programmes aimed at the sustainable development of the city (metropolitan area).

Whereas, the financial flows are defined by volume, cost and direction, pricing is basic for the financial logistic coordination. The financial resources are formed with significant impact of the financial relations between municipal subsystems or homogenous subsystems in the cities joined by the metropolitan area. In order to achieve efficient logistic coordination of the financial flows in the city (agglomeration) it will be reasonable to support more important programmes aimed at sustainable development of the city (agglomeration). The estimation of the programme's priority should be performed on the basis of the

Black-Shoels optimization model, because it defines current cost of the bid for certain goods or services (*e.g. transportation service*) and is defined as

$$C(S,t) = SN(d_1) - Ke^{-r(T-t)}N(d_2), \quad (8)$$

where

$$d_1 = \frac{\ln(S/K) + (r + \sigma^2/2)(T-t)}{\sigma\sqrt{T-t}}; \quad (9)$$

$$d_2 = d_1 - \sigma\sqrt{T-t}; \quad (10)$$

C(S,t) – cost of the applicant bid at the moment «t» till the end of the option term (e.g. competitive tender for public transportation) ;

S – cost proposed by the project contractor (e.g. transfer cost: 1) within city – UAH 3; 2) between cities – UAH 40)

$N(x) = \frac{1}{2\pi}\int_{-\infty}^{x} \exp(-z^2/2)dz = \frac{1}{2}(1 + erf(x/\sqrt{2}))$ – standard cumulative function of normal distribution (probability of deviation to be lesser under standard normal distribution);

K – cost, consumers are ready to pay (e.g. transfer cost: 1) within city — UAH 2,5.; 2) between cities — UAH20);

r – risk-free interest rate (30%);

T-t – time to termination of competitive tender;

σ – income volatility.

«Greeks» of this model allow to estimate sensibility of pricing to factors put in model. In particular, a new interpretation of the Greeks on the proposed model is offered by the author.

«Delta» $\Delta = \frac{\partial C}{\partial S}$ – price sensitivity to the transfer cost proposed by transport operators of the city (metropolitan area). If this parameter is closer to zero than the transfer cost is less influenced by transportation operators position and pricing is efficient and reasonable;

«Vega» $Vega = \frac{\partial C}{\partial \sigma}$ – price sensibility to volatility. With an increase in this parameter the bigger amount of non-transparent components are included in the price.

In ideal circumstances «Delta» and «Vega» should be equal to zero.

In the Black-Shoels optimization model analytic formulas for every «Greek» are provided. They enable analytic analysis of the pricing efficiency for given indicators and further pricing optimization.

Let's substitute values for the Central-Volynian metropolitan area to the mentioned formula:

- option period (T) – 1 year;
- cost of the bid (cost of the ticket in a one-way calculation Rivne-Lutsk) from certain transport operators and their ratio UAH 20−10%, UAH 30−40%, UAH 40−20%, UAH 35−30%)
- cost of the bid – UAH 25.

Based on the proposed data, all the necessary parameters of the model, and the optimal value proposition, to be established by the local government, are set (Table 1).

Table 1. Calculated parameters for the Black-Shoels model for Central Volyn metropolitan area

Model parameter	**Unit**	**Value**
Risk-free interest rate	%	30
Average cost of the bid	UAH.	32,5
Dispersion	Non-dimensional value	0,029586
Income volatility (σ)	%	17, 2
C (S,t)	UAH	31,16

Source: author's calculations.

As information-communication is among the most important urban subsystems, the process of the logistics flows of cities and agglomerations must cover information logistics coordination that allows on the one hand, to improve transport logistics coordination by providing residents with some services without unnecessary movements to the service centre using special technology; on the other hand - timely and unimpeded access to natural and legal persons to information.

The functioning of the metropolitan area is impossible without information support. Therefore, the setting up logistics coordination of the information flow in the city and metropolitan area e-government activities should be launched:

Information management will contribute to:

1) intensification of the pace in providing the requested information to the public, the business community, investors
2) establishing the practice of feedback and public consultation
3) eliminating problems that have arisen in the city and metropolitan area, highlighted by the public in a tight schedule;
4) providing the services by local authorities to individuals and legal entities through electronic means in simple and convenient manner without time and space constraints
5) development of an e-market for the organization of bidding procedures for goods and services purchasing;
6) creation of virtual accreditation, that enable online access for journalists to activities which are provided by local authorities;

7) increasing life quality by improving social services, health services subsystem, providing guaranties for legal and socio-ecological-economic security, spreading the possibilities of urban educational and cultural subsystems;
8) establishing a modern system of public relations for local authorities.

As the up to date information acquisition to the subsystem serves as a determinant of qualitative functioning of the latter and rapid adaptation to changing environmental conditions, it appears appropriate to determine the optimization model information flows coordination in the city and metropolitan area. We use the information entropy principles for evaluation of information flows.

Bandwidth communications network affects the coordination of information flow. In particular, for comparison, the rate of speech or reading is about 120-200 words per minute, i.e. 2-3 words per second. Considering that the average word is composed of 5 sounds (letters) that can be coded with an 8 bits code, information bandwidth for audio communications (such as voice telephony in the sense of transferring useful information) is 3*5*8 = 120 bits/s. Thus, telephone communication is extremely inefficient to transfer large amounts of management information. Paper mail correspondence is even less effective, because the capacity of the channel drops correspondingly to the delivery time.

Thus, the optimal information bandwidth management network of the city and the metropolitan area will be achieved when:

1) communication between all participants is at the maximum bandwidth;
2) communication is a network with a minimum number of intermediaries that can cause loss of information (for example - reprinting messages with the possibility of making additional copies to bugs);
3) entropy is proportional to the width of the channel.

According to such criteria the optimization model will be as:

$$Vk\ (k\ bit\ /t) \rightarrow max \tag{11}$$

$$Vk = \frac{8 \times k}{t}, \tag{12}$$

where
Vk – bandwidth
k – characters quantity in a message
t – the transmission time of messages (s.)

In order to increase the speed of management decision making, installation of fast communication channels in the city should be combined with «administrative cloud» (specialized centres with qualified staff), that provide consultations on legal, economic and management issues. By doing that «administrative cloud» lessen the load on local government because each person on the elective post cannot use fluently the whole scope of urgent issues. «Administrative cloud» shall perform as a specialized centre for providing services by local government.

«Administrative cloud» is a model providing widespread and easy access on demand through the network to a shared pool of the operational skilled

resources, management solutions and expert assessments, that are to be set (eg, communication networks, servers, mass storage, applications, and services) and can be promptly provided and released with minimal management costs and requests to the provider[4].

«Administrative cloud» in the city and agglomeration is a cloud infrastructure designed for free use information and expert resources management programmes that are stored on servers in the Internet, by local authorities and residents of cities and agglomerations.

With the use of «administrative clouds» consumers of information technology can significantly reduce capital costs for building data processing centres, purchase server and network equipment, hardware and software solutions to ensure the continuity and efficiency (a provider of cloud services absorbs these costs). In addition, long-term construction and commissioning of large infrastructure of information technology and their high initial cost of restricting the response flexibility to market needs, while the cloud provides an opportunity to instantly respond to the increasing demand for computing power. Using cloud computing shifts consumer spending towards the operational, providing compensation costs for cloud services providers.

Conclusions

The results of the study permit to assert the feasibility of developed directions of logistics coordination of transport (labour, material), financial and information flows to provide the sustainable development of cities and agglomerations areas. However, the implementation of the transport logistics coordination must be consistent with the methods of planning that will reduce the loss of resources during their displacement, and a reduction of an ecol-destructive impact on city. The introduction of the second kind of logistics coordination in agglomerations is effective in terms of getting the economic, environmental and social effects of the coordination of local authorities identified needs in transport streams over time.

The use of the proposed measures implementing financial coordination of logistics software subsystems enable cities and agglomerations with financial resources as well as the distribution of financial resources to enhance the economic component of sustainable development.

Implementation of measures for information logistics coordination will open for residents of cities and agglomerations, as well as for the legal entities timely access to needed services and information without unnecessary movements to centers of their provision that will have a positive effect on the level of the social component of sustainable development.

[4] The NIST Definition of Cloud Computing [Електронний ресурс]. – Режим доступу: http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf

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