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CONGESTION IN HISTORICAL CITY CENTRES – DISCUSSION ON PHENOMENA AND ANALYSIS WITH NETWORK THINKING METHODOLOGY AND GREY SETS

KONGESTIA W HISTORYCZNYCH DZIELNICACH POZNANIA – CHARAKTERYSTYKA ZJAWISKA Z WYKORZYSTANIEM METODYKI MYŚLENIA SIECIOWEGO I ZBIORÓW SZARYCH

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Summary: Congestion is the result of the accumulation of flows of different nature (i.e. people, goods, waste) in cities, which on the one hand results from their development, the consequence of which is the intensification of flows, on the other is also an example of the main barrier to the functioning and development of cities. This problem defined the purpose of the study and the article which is to characterize the phenomenon of congestion and to identify the structure of this issue, so as to deliberately define actions to alleviate congestion and its negative effects. The aim of the study was achieved using network thinking methodology, based on the knowledge of the appointed expert group. The test results were processed using grey collections and arithmetic. Research methodology was justified by the complexity and multi-faceted nature of the research problem. The research results indicated the potential of shared transport, and thus the importance of ICT, and above all mobile apps in reducing congestion in historical city districts.

Keywords: city logistics, congestion, Grey System Theory, Systemic Thinking.

Streszczenie: Kongestia jest skutkiem nagromadzenia w mieście przepływów o różnym charakterze (ludzie, towary, odpady). Z jednej strony wynika z jego rozwoju, którego konsekwencją jest intensyfikacja przepływów, z drugiej – jest jednocześnie przykładem głównej bariery funkcjonowania i rozwoju miast. Problem ten zdefiniował cel badania i artykułu, którym jest scharakteryzowanie zjawiska kongestii oraz zidentyfikowanie struktury tego zagadnienia, tak aby w sposób celowy zdefiniować działania umożliwiające złagodzenie kongestii i jej negatywnych skutków. Cel badania zrealizowano z wykorzystaniem metodyki myślenia sieciowego, opierając się na wiedzy powołanej grupy eksperckiej. Wyniki badań poddano obróbce za pomocą zbiorów i arytmetyki szarej. Metodyka badawcza uzasadniona była złożonością i wieloaspektowością problemu badawczego. Wyniki badań wskazały na potencjał transportu dzielonego, a co za tym idzie – znaczenie ICT, a przede wszystkim aplikacji mobilnych w ograniczeniu kongestii w historycznych dzielnicach miast.

Słowa kluczowe: logistyka miejska, kongestia, teoria zbiorów szarych, metodyka myślenia systemowego.

1. Introduction

1.1. Problem definition

Modern cities are systems of high complexity in which flows of people, materials and information are implemented with an intensity that allows meeting the requirements of city users.

The discipline that seeks to organize and rationalize these flows is city logistics. It covers all processes of managing flows of people, freight and information within the city's logistics system, in accordance with the needs and development objectives of the city. Moreover, city logistics is linked with respecting the protection of the natural environment, taking into account that the city is a social organization whose primary goal is to meet the needs of its users [Szołtysek 2008].

The concept of city users is broad, as it embraces individual users fulfilling mandatory and optional needs, but also enterprises operating in the city, ensuring the availability of goods at points of sale, realizing production and providing services, offices and institutions. Each of these groups represents different, sometimes contradictory expectations and requirements. Conflicts of interest cause users to compete for the availability of urban infrastructure, which is naturally limited. The more the restrictions, the more competition is intensified and the more severe the effects of using the city are – including congestion, pollution (including noise), and extended transport times.

Nowadays, in solving problems related to city traffic, the support of state-of-the-art information systems is used to manage traffic, energy consumption and emissions [Tundys 2008], providing up-to-date information on the availability of public transport and traffic, yet the problem of congestion remains one of the more serious for modern cities.

1.2. Research object identification

Traffic congestion is undoubtedly the result of the accumulation of flows of a different nature (i.e. people, goods, waste) in a city, which on the one hand results from its development, the consequence of which is the intensification of flows, on the other is also an example of the main barrier to the functioning and development of cities. Virtually all city users experience it in their daily lives [Szołtysek 2009]. The traffic congestion is most intensive in areas where most of the needs of city users are fulfilled. These are central districts in which facilities such as offices, institutions, including universities, restaurants, stores, broadly understood public facilities are located, as well as areas with high population density. The intensity of traffic congestion is also affected by infrastructure, including building density, throughput of communication routes, availability of parking and parking spaces.

Districts susceptible to congestion are considered historical districts, most often located in city centres (in areas delimited by the former city walls), characterized by compact buildings and relatively narrow communication routes. The area analysed in the research and perceived as historical districts of Poznan is marked in Figure 1.

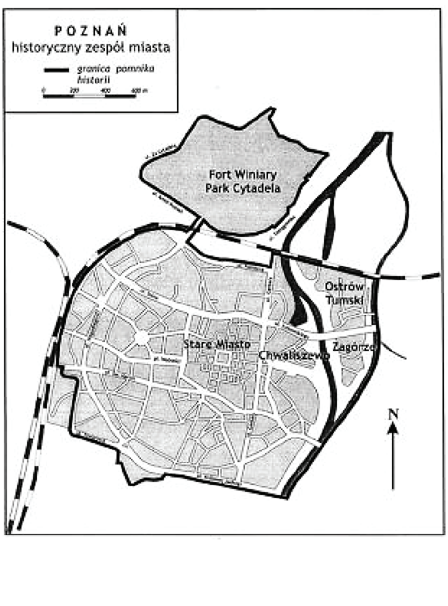

Fig. 1. Historical districts of Poznan

Source: [Rozporządzenie z dnia 28 listopada 2008 r.].

Due to the significance and intensity of the phenomenon of traffic congestion in this area, this article attempts to answer the question of what are the ways of decreasing the traffic in the historical districts of the city. The methodological approach and conclusions drawn from the results obtained are presented in the following sections of the article.

1.3. Traffic congestion characteristics

Traffic congestion is a phenomenon often occurring in cities, most notably in city centres. The definitions of congestion focus on its observable and perceptible manifestations, indicating that [Wilk, Pawlak 2014]:

- traffic congestion is a situation when the demand for the use of an infrastructure object prevents free flow at the maximum allowable traffic speed,
- traffic congestion is the inability to immediately service a means of transport by transport infrastructure due to the need to simultaneously service other means of transport,
- traffic congestion refers to a crowded state of transport infrastructure and vehicles.

Traffic congestion may concern the transport network and means of transport [Ciesielski 1986]. The first option mentioned includes congestion on routes and congestion at transport points, the second concerns means of public transport.

The problem of congestion is complex, which results from the characteristics of the reasons for the congestion phenomenon. These reasons are a derivative of the gap between the potential of urban infrastructure (the key parameters are the size, availability and condition of infrastructure that have a quantitative and qualitative dimension) to the demand for infrastructure (the important parameters in this respect are the population, population density, number of vehicles). The measurable effect of congestion are costs, directly covering the costs of vehicle operation, costs of infrastructure maintenance, costs related to the loss of time of transport users, arduousness of travel, loss of time for freight transport and conditions of performing such transport, costs of road accidents, as well as those related to environmental pollution. This scope of impact proves the great importance of the problem of congestion for individual users of the city, enterprises operating in the city system, the city authorities, region and country.

2. Research process definition

2.1. Research methodology implemented

The methodology of network thinking was selected as the methodical basis for solving the research problem, which is justified by the city's definition as a complex system (consisting in various elements, related by relationships, established to achieve a defined goal – satisfying the needs of users).

One of the processes implemented in the city system is transport, while a phenomenon characteristic for transport realization is the temporary limitation of its effectiveness, namely traffic congestion. Due to the complexity and multifaceted problem of congestion in historical city districts, this problem will be characterized using **network thinking methodology**, then analysed in order to define possible solutions. The large-scale aspect of the congestion problem implies the use of expert knowledge in its solution, hence the appointment of **a group of experts** representing knowledge in the field of urban logistics, transport as well as urban planning and architecture to discuss the problem. Expert opinions were presented using the **grey sets approach**, reflecting the ambiguity and interrelationships between the formulated conclusions.

2.2. Network thinking methodology

Probst, Ulrich, and Gomez [Probst, Gomez 1989] developed the methodology of network thinking in the 1980s. It is based on the assumptions of General System Theory [Bertalanffy 1984] and it allows a holistic view of the problem with an extensive structure. The process of solving the problem is presented in Figure 2.

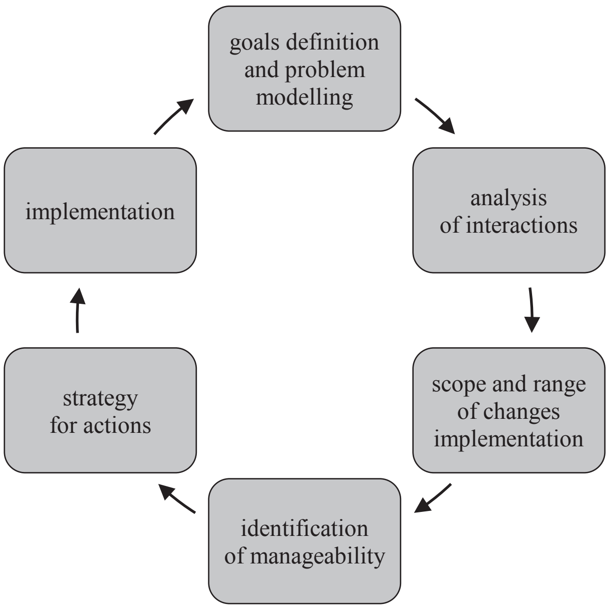

Fig. 2. The scheme of problem solving with network thinking methodology

Source: [Zimniewicz 2000].

The methodology presented above includes a sequence of actions that are performed in a specific order, but due to their connections and interdependencies it is possible to return to the previous steps at any time during the procedure to make additions or corrections resulting from the concepts of implementing the team scheme. The starting point is the identification of the problem and modelling of the problem situation, and then the factors affecting the problem are identified and tested for strength, scope and long-term impact. The results help to identify manageable factors, i.e. those that can be manipulated and non-manageable in a certain way outside the influence of an organization seeking to eliminate the problem or reduce its scale. The key to solving the problem is the awareness that the identified factors are interrelated in different ways, strengthening or weakening their actions - therefore when affecting one of them, the consequences of the impact on the scale of the whole system should be taken into account [Piekarczyk, Zimniewicz 2010].

Given that the city system is a system with multiple and extensive internal connections, the use of network methodology to solve the problem appears to be the most justified, the more so that it allows the use of synergies (identified in the feedback loops) for the efficient and effective elimination of factors influencing the emergence of a problem.

2.3. Experts' definition

The competences of the group of experts solving the problem determines the quality of the solution obtained through the use of network thinking methodology, in addition to the correct implementation of subsequent steps of the procedure (i.e. the aspect of formal correctness). The more complex and varied the structure of the problem, the broader the competencies the solution team must have.

The authors defined a set of competences that they considered important for the problem being solved and included in the group of experts: professionals and dormitories dealing with issues of architecture, urban planning, transport, and traffic engineering. In this way, interpenetrating perspectives were obtained: theoretical (due to taking into account the opinions of academics) and practical (due to taking into account the opinions of professionals), and static (related to elements of the city structure, represented by architects and urban planners) and dynamic (related to the implementation of the process transport, represented by specialists in this field).

In total, the expert group consisted of ten people representing the competence in urban logistics, transport, urban planning and architecture. The experts, using their knowledge and experience in a moderated session conducted in accordance with the principles of network thinking methodology, modelled the structure of the decision-making problem: how to calm the traffic in the historical districts of Poznan. The session's results are presented in the following sections.

2.4. Grey Systems Theory

The Grey Systems Theory (GST) was created in 1982 in China by Huazhong University professor, Juo-Long Deng [1982]. It gained many supporters and began to complement gradually the three approaches previously used to analyse uncertain systems - statistical, fuzzy and coarse.

To analyse systems and solve the problems occurring in them, the characteristics of these systems are necessary, describing their complexity, connectivity, relations with the environment and the dynamics of functioning. In the case of complex systems analysis, such data is difficult to access, and may be, due to its scope, incomplete and uncertain [Liu, Lin 2006]. The system about which knowledge is limited, is called the grey box, whereas incomplete knowledge may be manifested in incompleteness of information about the structure or dynamics of the system and/or uncertainty of the internal and external interactions of the system [Cempel 2014].

The essence of grey modelling is a description of the behaviour of the system observed in reality given as a forecast/endogenous variable: X (0) (k), where: k = 1, 2, n through a set of explanatory variables constituting factors determining the state of the forecast variable. Thus, the endogenous process observable in reality given as X (0) (k) is explained in time N by independent (explanatory) variables. Therefore, in a general sense, the grey model can be written as GM (I, N), which means that the system is described by a first order differential equation with N independent/explanatory variables [Barczak 2014]. Such a description is useful from the point of view of the description of the phenomenon of congestion occurring in the urban system, as the complexity and multi-faceted nature of this phenomenon excludes its full and fully deterministic characteristics.

3. Research results

3.1. Research methodology implementation

The research results were developed based on data collected during the workshop entitled "How to calm the traffic in the historical districts of Poznan?" organized as part of the Urban Development Forum 2018 in Poznan. The authors of the article led the workshops. From the theoretical point of view, the authors of the workshop found the identification of factors determining congestion in the historical districts of the city to be recognized from different perspectives. The utilitarian goal was to try to find solutions to the identified causes of the problems. Both goals were achieved thanks to the workshop session using the network thinking methodology. The session was preceded by a short theoretical introduction regarding both the methodology and the topics discussed. The next stage during the workshop was an open joint discussion of all participants about the possibility of calming the movement in the historic districts of Poznan. The study was moderated by the workshop leaders, members of the expert group appointed as part of the workshop who used research sheets developed by the moderators.

The research sheet consisted of three parts. In the first one, the respondents were asked to write a list of factors requiring change. The result was a list of factors (Table 1) and the relationships between them. The experts' indications are presented in the form of a diagram in which factors of a similar nature are grouped to increase legibility (Figure 3).

Table 1. Factors identified by experts

No	Factor	No	Factor	No	Factor
1	Disobeying law	11	Safety increase	21	Traffic organization
2	Speed	12	Cycling/walking	22	Continuity of traffic
3	Infrastructure accessibility	13	Reverse logistics	23	Urban approach
4	Number of sending/ receiving points	14	Prices of products and services	24	Primary functions of streets
5	Time spending profile	15	Traffic limitation	25	Vehicles condition
6	Delivery point	16	Comfort	26	Attitude of society
7	Emergency situations procedures	17	Environment condition improvement (noise reduction)	27	Resources and budget
8	Overall cleanliness	18	Accessibility of goods/services	28	Discrepancy in city vision
9	Infrastructure condition	19	Health		
10	Traffic intensity	20	Area attractiveness		

Source: own work.

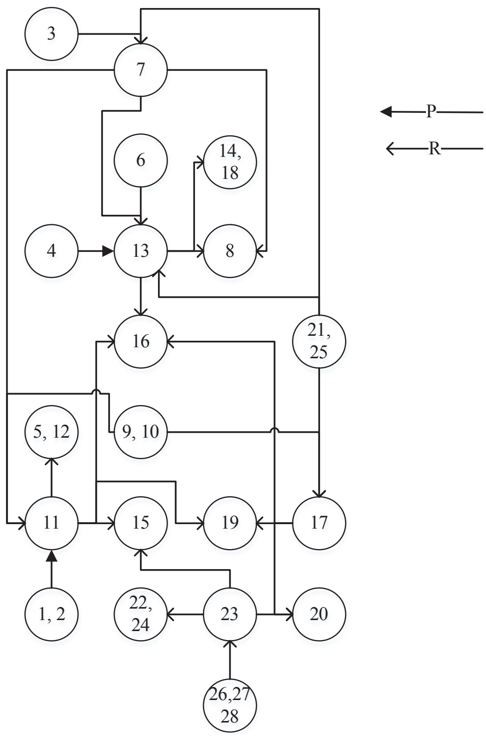

Fig. 3. Diagram presenting factors and relation between them. Impact direction: P – o**P**posite directions, R – pa**R**allel directions. Numbers as in Table 1

Source: own work.

Experts contributing to the research were asked not only to indicate the relationship between the factors, but also to characterize them by determining the strength of exposure and the time of exposure of a given factor under two aspects:

what a given factor affects and what affects a given factor. The direction of influence could be defined as (P) opposite or (R) unidirectional, the strength of impact and the time of exposure were determined on a 5-point scale, according to the following:

- 0 – no effect or no exposure time. In this case, the dependencies were not included on the map.
- 1 – low impact strength or occasional exposure.
- 2 – average impact strength or frequent exposure.
- 3 – intense impact or repeatable exposure.
- 4 – very intense impact or continuous exposure.

The relations between the factors were presented using grey numbers because the definition of the strength and time of exposure was not carried out by accurate measurement only with descriptive values. The adopted grey scale is presented in Table 2.

Table 2. Greyness scale implemented for research purposes

Greyness scale	Lower limit	Upper limit
0	0	0.2
1	0.2	0.4
2	0.4	0.6
3	0.6	0.8
4	0.8	1

Source: own work.

Table 3. Impact analysis in interrelations network

Factor impact	Medium impact	Median	Max. value	Min. value
Safety improvement	0.54 ; 0.66	0.5 ; 0.63	0.69 ; 0.81	0.5 ; 0.63
Environment condition improvement (noise reduction)	0.63 ; 0.75	0.69 ; 0.81	0.69 ; 0.81	0.5 ; 0.63
Reverse logistics	0.5 ; 0.63	0.5 ; 0.63	0.5 ; 0.63	0.5 ; 0.63
Urban approach	0.53 ; 0.66	0.5 ; 0.63	0.69 ; 0.81	0.44 ; 0.56
Emergency situations procedures	0.38 ; 0.5	0.31 ; 0.44	0.5 ; 0.63	0.31 ; 0.44
Using network for transit	0.5 ; 0.63	0.5 ; 0.63	0.5 ; 0.63	0.5 ; 0.63
Comfort requirements	0.18 ; 0.3	0.13 ; 0.25	0.31 ; 0.44	0.06 ; 0.19
Lack of public transport solutions	0.38 ; 0.5	0.5 ; 0.63	0.5 ; 0.63	0.13 ; 0.25
Lack of integration of public transport	0.38 ; 0.5	0.31 ; 0.44	0.69 ; 0.81	0.13 ; 0.25
Lack of infrastructure for cycling/ walking	0.59 ; 0.72	0.59 ; 0.72	0.69 ; 0.81	0.5 ; 0.63

Source: own work.

For each factor, its effect on other factors in the network of connections and susceptibility to influence was determined using grey number arithmetic by calculating (Table 3):

- median impact,
- maximum impact,
- minimal impact,

where impact = impact strength × exposure time.

The most important aspect related to the problem of congestion is environmental pollution and noise emissions, which confirms the importance of ecological issues for modern society. Experts also attached great importance to the proper use of space and adapting the infrastructure to walking and cycling. Technical and organizational impacts focused on these aspects will contribute to reducing congestion to the greatest extent.

3.2. Discussion on research results

The characteristics of the connections indicate that the factors identified by the expert group are of an active nature, so affecting them will contribute to limiting the problem to the greatest extent. At the same time, active factors are slightly affected by external influences, which in turn means that from the management point of view, manipulation of these factors is subject to the least risk.

The identified factors and relationships are an original interpretation of the problem situation implemented in a specific place and time by a group of experts selected deliberately to represent knowledge in the area in which the research problem is embedded. The presented opinions relate to the area of the city of Poznan. It can be presumed that the analysis made by another group and for another city would be different from the one presented. However, the authors' understanding of the literature regarding the problem situation indicates that the presented results are consistent with the views presented in the literature.

4. Conclusion

The purpose of the study presented in this article was to characterize congestion and identify the structure of this phenomenon in order to define deliberate measures to alleviate congestion and its negative effects. The goal was achieved using network-thinking methodology, based on the knowledge of the appointed expert group. The results of the research were processed by means of grey sets and arithmetic. The research methodology was justified by the complexity and multi-faceted nature of the research problem.

The conclusion of the research indicates the scope of the most effective actions, which should include the modification and reorganization of infrastructure and the development of ecologically oriented solutions. According to the authors, the concept of shared transport fits perfectly into this scope, implemented not only in Poznan, but also in other cities in Poland and around the world.

Shared transport is a set of solutions covering not only public transport, but also bicycles, scooters and city scooters, and cars for short periods of time (usually electric). These solutions reduce congestion, contribute to the improvement of the natural environment and the general condition of users, and therefore meet the demands of experts. It is important, however, that they should not be implemented without the use of modern information technologies. Mobile apps are the basis for the operation of individual means of shared transport, provide access to them, and enable billing for them. They are globally available, enabling the use of shared transport for not only city dwellers, as well as tourists who also contribute to congestion. Universal access to mobile telephones, the Internet and basic skills in the use of mobile apps create the great potential of individual means of shared transport, lending hope for the reduction of congestion in city centres.

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