

EXAMPLE OF RATIONAL MODAL SPLIT IN THE TRANSPORT NETWORK – TECHNICAL AND ECONOMIC ISSUES

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Abstract

In recent decades, almost all over the world, the issue of sustainable development has been strongly promoted in the transport policy. Initially, it applied chiefly to creating specific documents defining basic terms, for instance Brundtland Report (UN Documents 1987). In further years, documents containing more specific guidelines started to be developed focusing on directions for developing transport systems and activities to be implemented to achieve the goal of sustainable transport. At the moment, there are a number of official guiding or mandatory documents in the field, for example White Papers (COM(2001)370; COM(2006)314; COM(2011)144) and communications (including COM(2013); SEC(2009)). The idea of sustainable development of transport expressed in those documents is gradually realized in the form of EU supported projects. The article focuses on modal split in the transport network while using basic decision-making process facilitation methods; an activity which aims at making transport development sustainable. The proposed method provides a holistic approach to the transport network, as a structure comprising specific coherent space regimes undergoing continuous interaction. Modal split is optimized in all those space regimes, whereas the splitting procedure itself is presented using an example.

Key words: transport network, modal split, basic decision-making process facilitation methods

Introduction

The definitions of sustainable development of transport can be found in a number of publicized documents (including those mentioned above). Simply, we may assume that for the purpose of the article sustainability is present (achievable) when the share of particular modes of transport aims at a pre-defined proportion. Those proportions can be referred to as the status of 'green' balance (e.g. present EU supported project of Green Travelling) (Celiński, 2013). The balance between modes of transport, in line with sustainable development, can be expressed:

$$MT_1 : MT_2 : MT_3 : \dots : MT_l : \dots : MT_k : \dots : MT_n = const = \{const_{lk}\} \quad (1)$$

where:

MT_k -k-th means of transportation [-], passenger car, bus, tramway [vehicle], etc.

In the context of the equation (1) it is important to explain certain basic issues. The number of means of transport having various operational features has been growing in transport systems ($n \gg 0$). They include means of public transport on request, without a fixed route, and without a fixed timetable (e.g. mini-bus lines in Ankara, Istanbul, Bilbao and other, or Telebus in Cracow). The diversity in functionalities of means of public transport is expected to grow in the years to come. It means that the development of modal split ceases to be a simple bipolar issue of differentiating between individual vs. public transport. It necessitates simple and at the same time effective methods for analyzing the issue. Another question is to adjust modal split to technical parameters of the transport network. The split cannot be imposed in an arbitrary manner, and it should take into consideration a number of issues pertaining to the operation of transport networks, both technical and economic ones. Of course, it should also (or perhaps first of all) consider needs of people travelling. Shaping their transportation behavior extends beyond the scope of this article (literature list includes several items referring to those issues more extensively, e.g. Nosal, 2011; Okraszewska, 2013; Sierpiński, 2011).

The transport network is an organism which should be approached holistically. Its immanent properties result from various, frequently distant sub-areas. Nevertheless, for calculation and organizational purposes it is easier to manage sections of the network (space regimes and subareas) rather than its entire area. Such an approach is justified while managing all sub-areas simultaneously in a larger part of the transport network. Space regimes can be described in the form of a matrix $[r_i]$ or $[r_{ij}]$, depending on

delimitation. In the first case the division into regimes is random and in the second, it is based on symmetrical shapes (squares, rectangles, triangles, hexagons, etc.). This enables describing the network through convenient square matrixes, taking into consideration mutual incidences of space regimes. For simplicity reason, it was assumed that the network will be divided into i , non-homogenous space regimes (in terms of their area). Each of the space regimes can be quantified as regards its technical parameters, such as transport volume and capacity, while using methods for estimating those parameters (e.g. Goras, Waltz, 2000; CTRE 2014; Cambridge Systematic 1996; TRB 2014; Ned Levine & Associates 2010; Mathew, Krishna Rao, 2014). The regime may include an area of a single transport node. Therefore, it is possible to assign capacity value C_i to each regime, if it covers a larger number of nodes, as an aggregated value of infrastructure elements within an i -th regime area. Consequently, it is possible to determine capacity CAP_i for each i -th space regime. The value can be estimated using contemporary traffic detection systems within interval for capacity i in time Δt in the case of capacity itself.

Technical parameters of the transport network (capacity, volume and others) can usually be determined. Theoretically, using a relevant detection system, we can determine real proportions of particular means of transport in all m space regimes:

$$\{cMT_{1..n}^1 : cMT_{1..n}^2 : \dots : cMT_{1..n}^i : \dots : cMT_{1..n}^m\} = \{const^i\} \quad (2)$$

where:

i – number of space regime [-].

n – number of means [-]

Calculating those values is usually a question of using relevant calculation methods for determining particulars of the transport network and using an appropriate detection system as regards the number and type of means of transport. A separate issue is matching an economic dimension which depends on e.g. $\{const^i\}$ with the value of modal split in its i -th space regime. Each way of shaping modal split involves certain cost related to operation of vehicles, environmental cost, other social cost, etc. There are LCA methods for calculating cost related to a specific development of the transport network (Góralczyk, Konieczny, 2001). Several companies on the transport service market provide such calculations, e.g. Factor CO₂, 39. Therefore, we may allocate the cost related to the existing modal split V_i to each space regime. General cost in regime V_i is the aggregate of indirect cost which results from spreading the cost on particular modes of transport:

$$V_i = \sum v_k \quad (3)$$

where:

$$v_k = v_E + v_C + v_{ENV} + \dots + v_o$$

v_E - operating cost [PLN],

v_C - community cost [PLN],

v_{ENV} - environmental cost [PLN].

Attention should be drawn to the fact that modal split influences the distribution of general cost in the transport network. We may expect that a relevant modal split enables reducing total operation cost of a transport network. The question which remains is to find a relevant optimization method.

1. Sustainable development

The transport system is an integral part of the city structure. A natural consequence of this is a strict relationship between city development and its public transport system. Changing social and economic conditions determine directions for the development of a city. A frequent trend, related to dense urban development, is creating new housing estates, companies and other public utility facilities beyond boundaries of a core city center, and investing in green areas or developing neighboring rural areas situated within one hour drive from the city. Urban sprawl (also known as suburbanization (Pawlak, Pawlak, 2014)) has been particularly vivid since the second half of the 20th c. Growing distance between sources and destinations results in longer travelling routes and significant changes in distributing traffic flows in the existing transport network. This contributes to increased number of travels, especially using individual means of transport (passenger cars) which leads to congestions on roads, increased noise levels and emission of noxious substances from transport, etc.

While defining sustainable development, the UN report (commonly known as Brundtland report) is quoted most often. It reads (UN Documents 1987): ‘sustainable development is a development which meets current generation needs while preserving opportunities for future generations, in terms of meeting current and future needs. It is based on two fundamental assumptions: Firstly, we need to focus on the concept of needs, in particular basic needs of the poor. Secondly, while meeting current and future needs, we should take into consideration limited possibilities, and do not ignore boundaries set by the natural environment for technological advancement and social order’.

According to the definition, every action should be taken in response to a need. Such an approach to investing should be reflected in every field of life, including planning the development of transport systems. At the same time, we should remember not to limit business activity of companies and individuals while trying to reduce transport intensity in the economy. This should result in rationalizing mobility among citizens, improving spatial structure in cities and reducing the impact of transport on the environment (Tundys, 2008). As regards the concept of needs, it is necessary to provide thorough analysis of traffic and defining sources and destinations, motivations, as well as frequency. Only full knowledge about the subject, including not only a situation in the current transport system, but also real expectations of people travelling, enables arranging appropriate solutions and properly used new technologies (Celiński et al. 2012; Kowalska, Markusik, 2011; Celiński, Sierpiński, 2012). The issue of optimization of transport development towards more environmentally friendly ways of travelling can be analyzed from different angles. Some of the main approaches include technical, organizational and economic perspectives. The latter refer to the cost incurred by the transport system (holistic approach) and the environment (Pawłowska, 2000; Bąk, 2009; Pawłowska, 2013).

2. Calculation method

The solution to the problem has two aspects. The first one is purely technical and applies to ‘packing’ of vehicles in a given space regime, at a specific modal split supported by technical parameters of the transport network. While solving the problem, a knapsack algorithm (Kleinberg, Tardo, 2006; Martello, Toth, 1990) might be useful. The algorithm is known in the field of decision-making facilitation systems. The second issue refers to optimization of modal split at known costs, correlated with different types of means of transport (Kleinberg, Tardo, 2006; Martello, Toth, 1990).

Once we determine a permissible modal split for a single i -th space regime, the issue of modal split can be expressed in the form of the following equation:

$$b_1 MT_1^i + b_2 MT_2^i + \dots + b_k MT_k^i + \dots + b_n MT_n^i \leq C^i \quad (4)$$

where:

b_i – decision variable [-], discrete value [vehicle], $b_i \in N$

C^i – capacity or volume (CAP) of space regime,

MT_i^i – number of specific means of transport in given space regime.

We should remember that values of C' heavily depend on intensity, directional structure and kinds, as well as other parameters of road traffic. On the other hand, they are time related parameters. Once we know the cost related to a specific modal split in i -th space regime V_i and cost of particular means of transport v_i , the issue of optimization of cost related to a specific modal split can be expressed as follows:

$$V_i = \min \sum_{k=1}^n v_k b_k \quad (5)$$

with limitation:

$$B_i = \sum_{k=1}^n b_k MT_k \leq (C' \text{ lub } CAP) \quad (6)$$

Therefore, from the point of view of sustainable development, the optimization of modal split in the transport network boils down to determining of time t' , or interval Δt , set of values: $\{V_i\}$ and $\{B_i\}$ in particular i -th space regimes. The first set of values defines minimum cost related to a specific modal split, the second one technical parameters of a space regime (packing and cost reduction).

It should be noted that there are several technical solutions that enable supporting the development of modal split in selected areas of transport networks. In relation to the city public transport, it is possible to apply the following:

- separate lanes for buses,
- specific arrangement of platforms and bays,
- priority at cross roads,
- other transport telematics solutions,
- optimizing of routes,
- clear tariff policy and common tickets (e.g. $\acute{S}$ KUP in Silesia).

Yet another environmentally friendly means of transport is bicycle (in cities). In this particular case we may distinguish as follows:

- coherent and safe bike routes,
- safe parking for bicycles,
- city bike concept (public),
- bike rental.

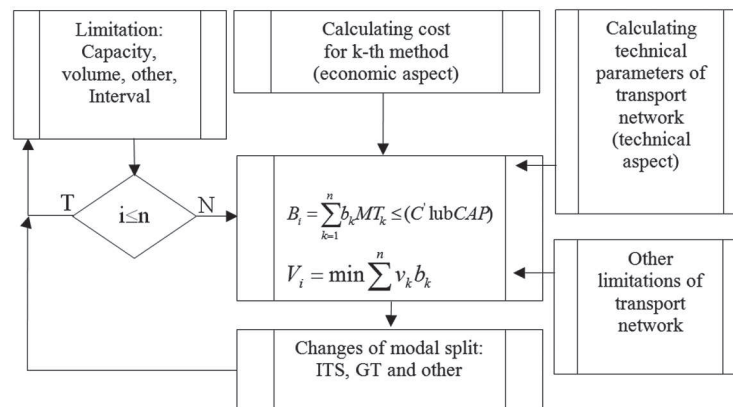
The last solution worth mentioning is a system of co-using a car by several people, including joint commuting to work, school, etc. In Poland, the system is still little popular (so called carpooling) and may also include certain incentives:

- separate lanes,

- reduced parking fees, separate car parks,
- reduced fees for entry into paid zones.
- discounts at petrol stations.

Figure 1 shows a flow chart of the method of selecting an optimized modal split in a transport network as regards reduction of the transport network operating cost (sustainable transport).

Figure 1. Modal split selection method



Source: Own study.

It is obvious that certain reserves of 'green' modal split could be observed between space regimes in the transport network. And in specific regime sit will not be possible to set/develop modal split which reduces cost. The method of distributing reserves within the transport network should be added to the above mentioned modal split selection method.

3. Example of calculation

Below presented are example calculations as regards selecting modal split in an individual space regime (example data). Discrete decision variables were assumed (this may also apply to calculating parameters of network in relation to people and not vehicles) (Celiński, Sierpiński, 2014). The volume of the transport network in a space regime was selected as a limitation expressed in the maximum length of the network [in meters]. The parameter is fairly easy to calculate for every transport network (Mathew, Krishna Rao, 2014). The volume was then used to calculate the maximum number of vehicles of a given means of transport that can fit into the space regime concerned. While calculating lengths of vehicles, a buffer of 1 m was adopted on each side of a vehicle. Data and calculation are included in figure 2.

Figure 2. Calculation example, modal split selection to the volume of space regime of a transport network (SO – passenger cars, SD – delivery vans, Mb – mini-buses, SC – trucks, SCP – trucks with trailers and semi-trailers, A – buses, AP – articulated buses, other – e.g. horse drawn carts, special vehicles, tractors, harvester (agricultural vehicles), etc., M/R – motorcycles/bicycles)

		limit		25650	[m]		
	$l [m] + 2 \cdot D$	bi	xi	$b \cdot x$		%	R %
1	2	3	4	5	6	7	8
SO		6	1282	7692	7695	30	29,99
SD		7	366	2562	2565	10	9,99
Mb		9	285	2565	2565	10	10,00
SC		12	106	1272	1282,5	5	4,96
SCP		20	25	500	513	2	1,95
A		13	493	6409	6412,5	25	24,99
AP		18	114	2052	2052	8	8,00
Inne		14	91	1274	1282,5	5	4,97
M/R		3,5	366	1281	1282,5	5	4,99
	suma	102,5	3128	25607	25650	100	99,83
	średnio	11,39					

Source: Own study.

Figure 2 presents a table based on calculations performed in an Excel sheet. The calculation used application Solver. The top of the table presents the limitation of the regime, which is the total available volume expressed in meters: 25650 [m]. Column 1 shows types of vehicles (any reasonable division of vehicles into groups can be used). Column 3 includes lengths of the selected types of vehicles including buffer in the front and rear (1 m each side). Column 4 presents decision variables x (in equation 5 and 6 it is b , number of vehicles of specific type 'let into' regime). Column 5 is the product of the decision variable b_k multiplied by the length of a given vehicle. Column 6 and 7 show limitations for a regime as regards servicing vehicles of specific type. Column 6 expresses a limitation in space (meters) whereas column 7 defines percentage of the total available volume 26,650 [m] to be used for traffic of a specific type of vehicles in the space regime concerned (desired percentage figure defined for each type). In the example, according to the principle of sustainable development, about 30% of transport volume was assigned for passenger cars in the regime, 43% for public transport, and about 5% for motorcycles and bicycles. The method enables shaping (any) modal split. The Solver application based on PCL determines

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numbers of vehicles in specific groups that can be serviced in a given space regime in line with the sustainable development principle. The operation of the system should be based on ITS functionalities. Inbound traffic to a given space regime should be directed in such a way to have the same number of vehicles of a given type in each interval as set according to the proposed methodology. Consequently, such analyses can be linked to predetermined economic measures for servicing vehicles of a given type.

We may assume that the cost of servicing in a space regime in interval 5' is as provided in table 1 (example data).

Table 1. Cost of servicing vehicles of given type in regime in interval 5'

	Type of vehicle	Cost[PLN]	Cost per person [PLN]	Comments
1	SO	0,05	0,038	Mean value of number of person in vehicle 1,3
2	SD	0,07	0,053	1,3
3	Mb	0,06	0,012	5
4	SC	0,09	0,09	1
5	SCP	0,1	0,1	1
6	A	0,08	0,0026	30
7	AP	0,1	0,002	50
8	Inne	0,09	0,09	1
9	M/R	0,001	0,001	1

Source: Own study.

Similarly to the previous example, we can optimized modal split in the regime concerned in line with the principle of sustainable development of transport. Further calculations are presented in figure 3.

Figure 3. Calculation example, selecting optimized modal split reducing cost in transport network regime

		limit	25650	[m]								Personal cost		Conditions
	l [m]+2*D	bi	xi	b*x		%	R %	x'i	c	c*x	b*x	0,05	0,038462	
1	2	3	4	5	6	7	8	9	10	11	12	0,07	0,053846	
SO		6	1282	7692	7695	30	29,99	428	0,038462	16,46154	2568	0,06	0,012	>=10%
SD		7	366	2562	2565	10	9,99	0	0,053846	0	0	0,09	0,09	
Mb		9	285	2565	2565	10	10	0	0,012	0	0	0,1	0,1	
SC		12	106	1272	1282,5	5	4,96	0	0,09	0	0	0,08	0,002667	
SCP		20	25	500	513	2	1,95	0	0,1	0	0	0,1	0,002	
A		13	493	6409	6412,5	25	24,99	198	0,002667	0,528	2574	0,09	0,09	>=10%
AP		18	114	2052	2052	8	8	1104	0,002	2,208	19872	0,001	0,001	
Inne		14	91	1274	1282,5	5	4,97	0	0,09	0	0			

M/R		3,5	366	1281	1282,5	5	4,99	0	0,001	0	0
	sum	102,5	3128	25607	25650	100	99,83	0		19,19754	25014
	mean	11,39									

Source: Own study.

Figure 3 presents an example of optimized modal split in the space regime. A criterion for the PLC algorithm is the average cost generated per one person travelling in a regime in interval 5'. Additionally, it was assumed that individual traffic can be less than 10% of the total transport volume in the space regime. Moreover, it was assumed that buses (articulated bus) cannot account for less than 10% of the transport volume in a given space regime. Percentages in other groups of vehicles were not limited in any way. Results of the cost efficient modal split are presented in figure 3. Other criteria can be used alike. Therefore, one can focus on various means of transport. In principle, to realize modal split in a transport network, the following should be determined:

- network volume (or capacity) in relations to particular delimitation units,
- physical parameters of vehicles (mean values),
- average cost of vehicle maintenance in a given space regime (optional),
- desired split criteria (percentage shares for particular vehicles or priorities in traffic management).

Thus, it is possible to estimate quantitative and qualitative measures for the traffic management system, it is capable of controlling isolated areas in the city transport network. Control here is understood as at least capability of the system to perform two operations: segregation of vehicles into separate lanes and if possible controlling each vehicles separately. The proposed method combines technical and economic dimensioning of traffic in the transport network.

Is it possible to determine arbitrarily proportions of particular means of transport in the modal split? In recent years, a number of papers were developed on traffic modelling in transport networks (e.g. Celiński et al. 2012). For example, in the Upper Silesia-Zagłębie Agglomeration, modal split determined in 2009-2011 between individual cars and public transport was roughly balanced (50/50) (Karoń et al. 2009). However, small differences in those proportions matter. On the one hand, it seems that a good criterion can be examining occupancy rates in means of public transport. This enables determining possible changes in modal split in particular space regimes of the transport network (occupancy between stops). On the other hand, occupancy in individual cars should be controlled by using such techniques as: car-sharing, carpooling and HOV (Sierpiński, 2011).

Conclusions

Due to steady increase in mobility of societies, the development of transport systems is undoubtedly a challenge for coming years. Establishing proper directions for the development, and then implementing measures that enable achieving goals are not easy. May be in the nearest future it will be possible to apply the method presented in the article.

The procedure enables shaping modal split in line with the sustainable development policy and available volume or capacity of the transport network. The precision of the method should be adjusted to traffic management equipment available in a given transport network. The method is based on a possibility of road traffic management ensuring saturation with vehicles of various types in space regimes. However, proportions between various vehicles are strictly defined (certain vehicles enjoy priority in access to space regime). The method necessitates segregating of vehicles between various lanes assuming that several different lanes are available. It also requires changes of traffic management algorithms (changes of effective green signals in line with predefined 'green' proportions of traffic involving different types of vehicles). In order to implement the method, it is necessary to promote further development of services available in domestic ITS architectures.

Further research by the authors will add a number of procedures to make it possible to use the method in traffic management algorithms.

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