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SELECTION OF THE MOST ADEQUATE TRIP-MODELLING TOOL FOR INTEGRATED TRANSPORT PLANNING SYSTEM

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Abstract: *This paper deals with the problem of selection the most suitable trip-modelling tool (TMT), which is a part of the more complex integrated transport planning system (ITPS) at the regional scale. Since an application of TMT is not autonomous and several different users exist the selection problem is not a trivial. In this paper, an original five-phase selection procedure is presented. The first phase consists in specification of both, detailed expectations of all identified users and technical requirements of ITPS. Second phase deals with research on available TMT while a third one is concentrated on defining a comprehensive set of criteria. In this phase critical criteria as well as selection criteria are defined. First one is utilised to eliminate unacceptable TMTs in phase four and second one to evaluate and select most adequate TMT in phase five. In the paper an exemplary application of this procedure is presented. The authors have defined 2 critical criteria and a set of 19 selection criteria. The last one is divided into 3 main subsets, i.e. functional, technical and financial contexts of selection process. All the selection criteria are characterised by 43 sub-criteria and some of them are more detailed extended. Using this procedure 3 out of 6 alternative TMTs including Emme, Aimsun and Visum have been initially accepted and next evaluated. Finally, Visum has been selected and recommended for application into ITPS.*

Key words: *trip-modelling tool, selection procedure, integrated transport planning.*

1. Introduction

The Public Transport Act in Poland states the local authority at the regional level is responsible for organisation of public transport (Sejm RP, 2011). Their responsibility covers several activities, including planning, organizing and managing of the public transport in the region (at the voivodeship territory in this case). Meeting this obligation, the most of authorities rely on very simplified assumptions and very often it is inadequate to the complexity of defined duties. In fact, according to many expert's opinions regional administration should use more sophisticated solutions. In fact, different tools and methods can support in design of the most rational configuration of public transport system. Lee (2004) has presented a comprehensive review on different techniques applied in this matter. The authors of this paper in their previous works have also proposed and applied different techniques, e.g. a combination of expert knowledge and simulation (e.g. Bieńczak et al., 2015a) or optimisation of transport network (e.g. Bieńczak et al., 2015b).

In this paper a complex *integrated transport planning system* (ITPS), which is a decision support system based on two mutually communicated components i.e. the *knowledge base* (KB) and *trip-modelling tool* (TMT) is considered (see Fig. 1). First component is used to store structured information, which is both, input for current calculations and a set of output of such results. While KB is strictly customised to users' demand, TMT is typical software, which have to meet target user's requirements. Trip model assists transport engineers, specialists and decision makers in forecasting traffic flows and utilisation of transport infrastructure in a certain transport system. It helps to generate a set of evaluation measures useful for assessment transport system behaviour and its operation. These parameters can also be applied to construct alternative transport solutions.

Typically, any TMT consists of two key interrelated components, including demand (i.e. passengers' travel needs and their motivations) and supply (i.e. transport capabilities, network structure, fleet, etc.).

The problem considered in this paper is referred to construct a universal procedure for TMT selection to meet a several target users' needs on the one hand, and to involve TMT as a part of global system - ITPS, on the other hand.
The paper is composed of five sections and references. The first section is an introduction to the paper. In the section two a brief research on software selection techniques has been proposed. The concept of TMT selection procedure as a part of ITPS is presented in section three. An exemplary application of the procedure is demonstrated in section four, and the final conclusions and remarks are drawn in section five.

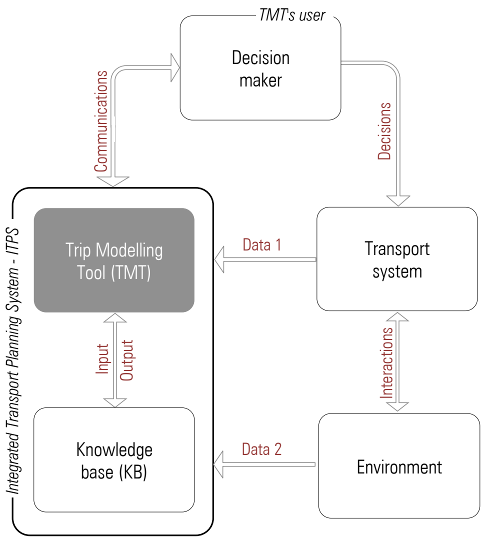

Fig. 1. General idea of ITPS and the role of TMT as a key component of the system
Source: based on Fierek et al., 2015

2. State of the art software selection

Software selection has been widely discussed issue in the literature. Many authors, define the guidelines and risk analysis of selecting enterprise resource planning systems - ERP (Spencer and Johnston, 2014; Panorama Consulting Solutions, 2016; Ayağ and Özdemir, 2007). They claim that many entities, before purchasing specialized software, make a comparison of tools available on the market. The methods used to identify a set of possible candidate solutions are, for the most part, subjective. The individual, or group of them, performing the assessment have various experiences that determine the decision process, either consciously or subconsciously.
Other authors emphasize that a successful evaluation of computer tools should be made on the basis of a formalized procedure (Sai, 2004). This means that a whole process of the selection and evaluation should be established and documented in a manner, which allow repeatability. Bandor (2006) claims that beside the typical criteria, which are determined by the functional requirements, it is very important to take into account intangible factors and risk as well. Intangible factors are not the traditional "quality" factors, but rather characteristics that can affect on the overall utilizing of software by the individuals, e.g., competence interface language, ease of adaptation to changing requirements, fitness of features (avoidance of paying for many features that cannot be used), or open source code (possibility to modify software).
Typically, after selection of evaluation criteria, a formal assessment mechanism has to be defined to compare all alternative software. Some authors (e.g. Lai, Wong and Cheung, 2002; Lai et al., 1999) use AHP method or balanced scorecard technique (Marr and Neely, 2003). Several works exists on using artificial neural network based on analytic network process approach (Yazgan et al. 2009). All of these methods allow comparing various products by using the selection criteria and assigning a value to the considered criteria. The software with the best result is the preferred one. Each criterion might have its own weight in the computation procedure, and the final result is a weighed score in such a case.
Although the software selection is well known problem in the literature, the problem of trip-modelling tool selection has not been discussed yet. There are a few papers describing the selection of trip-modelling software, but they are mostly concentrated on micro-simulation traffic tools (e.g. Dowling et al., 2002, 2004; Maciejewski, 2010). In these circumstances, the authors of this paper have decided to propose a formal procedure and describe its application in a real world case.

3. A concept of the TMT selection procedure

3.1. Key phases of the procedure

A selection of TMT for integrated transport planning system is composed of five interrelated phases (see Fig. 2) including:

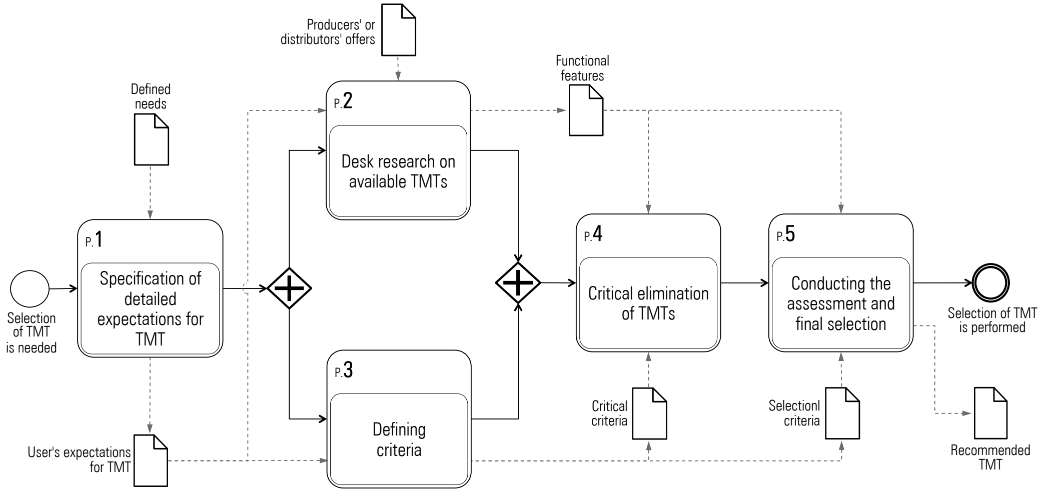

Fig. 2. Key phases of the proposed TMT's selection method

- specification of detailed expectations for TMT (phase 1 - p_1),
- desk research on available TMTs (phase 2 - p_2),
- defining evaluation criteria (phase 3 - p_3),
- critical elimination of TMTs (phase 4 - p_4),
- conducting the assessment and final selection of TMT (phase 5 - p_5).

3.2. Phase 1 – Specification of detailed expectations for TMT

In the phase 1 (p_1) a comprehensive and detailed review on target user's expectations of the trip modelling and management tool has to be extracted. At this stage several aspects have to be considered, including:

- capabilities of all TMTs available on the marketplace,
- current and predicted obligations, duties and tasks of all target TMT's user,
- a long term strategy for transport system development,
- data retrieved from the current transport system (e.g. data granularity, its adequateness and format).

As a result of this phase, a set of structured user's needs with reference to TMT is defined. It is a key input for three consecutive phases - p_2 and p_3.

3.3. Phase 2 – Desk research on available TMTs

During phase 2 (p_2) a desk research on TMTs available at the marketplace is conducted. At this stage of the procedure both, the set of structured user's needs (see p_1) and TMT's producer or distributor offers are explored. Finally, a key result of p_2 is a general set of functional features of TMT's. This result is an input for two other phases of the procedure, i.e. p_4 and p_5.

3.4. Phase 3 – Defining evaluation criteria

Phase 3 (p_3) is started with defined TMT's users expectations (see the result of p_1), and is devoted to define two separate sets of criteria. First one is composed of *critical criteria* having a crucial meaning for the users. A lack of compliance with any of critical criteria should result in rejection of TMT from further analysis. Second set, is composed of *selection criteria,* which is utilised for thorough analysis of alternative TMTs that are positively verified with critical criteria first. Selection criteria are utilised for differentiate alternative TMTs and perform a final selection.

While constructing the set of selection criteria, several practical aspects should be reflected, including:

- functional – F, all the TMT's capabilities that help the users to achieve requested decision concerning transport system,
- technical – T, which is TMT's specification that helps to communicate this tools with other facilities and data, i.e. standard cohesion, data sharing, computational technology etc.,
- financial – B, available budget, i.e. cost of TMT

acquisition and its maintenance.

The set of selection criteria should also reflect both aspects, the presence of multiple users (possibly different purposes of TMT use), and the context of TMT as a main component of more complex system - ITPS.

It should also be noticed, that some criteria from the considered set are maximised type and others are minimised. A criterion is called a maximised when with the increased value of the criterion a preference is increased too. On the other hand a criterion is minimised when the higher value means lower preference.

3.5. Phase 4 – Critical elimination of TMTs

This phase is devoted to very first evaluation of alternative TMTs and its result is elimination from the further analysis all alternatives having a conflict with at least single critical criterion (see p_3). To recognise such a conflict a set of functional features of all considered TMTs is necessary (see p_2).

3.6. Phase 5 – Conducting the assessment and final selection

The last phase of the procedure (p_5) is concentrated on a detailed evaluation of alternative TMTs and making the final selection. This phase is based on several inputs generated before, including set of functional features (see p_2) and a set of the selection criteria (see p_3). In the phase p_5 a final recommendation for TMT selection is produced as a final result of the whole procedure.

The key assumption of this phase is to achieve the comparable measures in the set of considered selection criteria. It is done using normalisation of each criterion into the interval (0, 1). Based on that a final assessment of i-th alternative TMT is performed using measure $\mathcal{K}_i$, see eq. (1).

$$\mathcal{K}_i = \frac{1}{\mathcal{W}} \sum_{j=1}^{J} w_j \left(\overline{c}_{ij} + \underline{c}_{ij} \right), \forall\, i = 1,2,\dots,I \qquad (1)$$

where:

- i – index of alternative TMT ($i = 1,2,\dots,I$),
- j – index of the criterion ($j = 1,2,\dots,J$),
- w_j – weight of j-th criterion's,
- $\overline{c}_{ij}$ – value of j-th maximised criterion for i-th alternative TMT and transformed to interval (0, 1),
- $\underline{c}_{ij}$ – value of j-th minimised criterion for i-th alternative TMT and transformed to interval (0, 1);

and

$$\mathcal{W} = \sum_{j=1}^{J} w_j \qquad (2)$$

A transformation of the real value of j-th maximised type criterion for i-th alternative TMT into interval (0, 1), denoted as $\overline{c}_{ij}$, is calculated using formula (3), as:

$$\overline{c}_{ij} = \frac{g_i(c_j) - g^-(c_j)}{g^+(c_j) - g^-(c_j)} \qquad (3)$$

where:

- $g_i(c_j)$ – value of j-th criterion for i-th alternative TMT which is expressed in its natural scale,
- $g^-(c_j)$ – the lowest value of j-th criterion, expressed in its natural scale,
- $g^+(c_j)$ – the highest value of j-th criterion, expressed in its natural scale.

A transformation of the real value of j-th minimised type criterion for i-th alternative TMT into interval (0, 1), denoted as $\underline{c}_{ij}$, is calculated using formula (4), as:

$$\underline{c}_{ij} = \frac{g^+(c_j) - g_i(c_j)}{g^+(c_j) - g^-(c_j)}, \qquad (4)$$

The graphical interpretation of an original value transformation into the interval (0, 1) is presented on the Fig. 3.

Since the aim of this procedure is to evaluate how each alternative TMT is good for the specific needs, most of the criteria c_j are usually constructed with hierarchy structure. It means a final value of such a criterion $g_i(c_j)$ is a result of aggregation certain subcriteria, and is calculated using the formula (5), as follows:

$$g_i(c_j) = \sum_{l=1}^{I} \sum_{k=1}^{K} g_i(c_{jlk}), \quad \forall\ i = 1,2,\ldots,I;\ j = 1,2,\ldots,J \tag{5}$$

where:

$g_i(c_{jlk})$ – an aggregated value of j-th criterion with respect to its sub-criteria at l-th ($l = 1,2, \ldots, L$), or k-th ($k = 1, 2, \ldots, K$) level of hierarchy, if applied, for i-th alternative TMT; value is expressed in its natural scale (it is assumed the same scale at different level of hierarchy for a single j-th criterion).

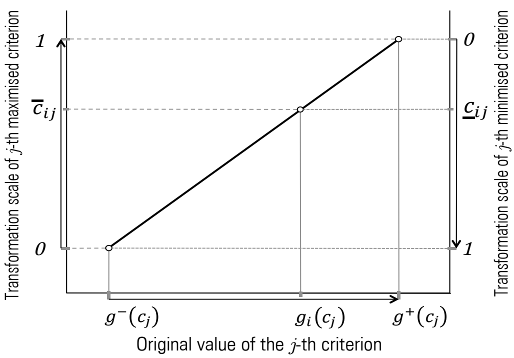

Fig. 3. Transformation of original value into the interval (0, 1) for j-th maximised (left) and minimised (right) criterion

4. Computational results

4.1. General assumptions

The exemplary application of the proposed procedure for a selection the most adequate TMT for integrated transport planning system is performed for the Regional Rail Carrier (*Łódzka Kolej Aglomeracyjna* Sp. z o.o. – ŁKA) and The Office of the Marshal of the Łódz Province (*Urząd Marszałkowski Województwa Łódzkiego* – UMWŁ), a statutory owner of the ŁKA. For their individual expectations an application of the selection procedure is detailed characterised and presented in the following sections of this chapter.

4.2. Phase 1 – Specification of detailed expectations

Based on analysis of a documentation of statutory task of both target ITPS's users, i.e. ŁKA and UMWŁ, and mutually discussing their needs, a group of 8 categories of expectations have been identified. The following set of functionalities is expected from target TMT (Fierek et al., 2015):

- A view of complex transportation system landscape, including: transportation infrastructure and coincidence of different modes, reporting on technical status of a infrastructure and passenger applied flow, location of interchange nodes and its current status, identification of bottlenecks and other malfunctions on the network, modal split status, profitability of the system and its lines, time vs. cost competitiveness of specific lines, transport accessibility for specific trip generators.
- A global view on impact of external factors (e.g. economy, sociology, psychology etc.) on specific global characteristic of a transport system, such as: modal split, passenger behaviour, and others.
- A simulation of results produced by transport system, including: changes on the network (e.g. quality improvement of the infrastructure, temporary speed restrictions, etc.) and organisational changes (e.g. ticket price, city access fee, new location of trip generator etc.).
- A matching analysis of the feeder transport with reference to the main lines, including modelling of time components of the journey (transfer time and riding time), generation of timetables of the feeder transport with respect to the main line schedule, timetables optimisation etc.
- Reporting mechanism on the cause-and-effect analysis in transport system for a specific time horizon.
- An analysis on dependencies between development of transport system and land use, including modelling key functions of the region (i.e. investment, building and commerce), and prediction of development intensity.
- Passenger traffic forecast calculations mechanism, including prediction of traffic with reference to the social and economic factors and result of wide spectrum of other research, on-line update of key input for modelling procedure (e.g. tariffs, fuel price, current status of the transport system).
- Ability of the TMT for a further extensions and setting up other functionalities of ITPS.

4.3. Phase 2 – Desk research on available TMTs

In the phase 2 (p_2) of the procedure a market recognised TMTs have been taken into consideration. There are at least few major software vendors and or distributors offering some tools to build and manage traffic model now. Using available information one can say that none of the tool is definitely best or worst. Although, the tools of this type (analysed software) are manufactured by different entities and they have a number of common features and components used both in the construction and management of a trip model.

As a result of market research six alternative tools have been selected (see Table 1). A common set of the characteristics of all those TMTs is composed of the following issues:

- mapping of the transport network (including several points, lines and zones, road and rail transport, local, agglomeration and regional transport),
- modelling of the demand and supply,
- assignment procedures,
- modelling of friction factor,
- construction and management of different scenarios,
- static and dynamic traffic distribution,
- modelling of the network parameters,
- use of geographic information system - GIS,
- interface for script-based applications,
- creating analyses, statistics and reports typical for management of the transportation system.

Table 1. Alternative TMT solution

No.	TMT	Manufacturer of TMT (Country)
1.	Aimsun	Transport Simulation Systems (E)
2.	Cube	Citilabs (USA)
3.	Emme	INRO (CDN)
4.	Minnerva	OmniTRANS (NL)
5.	TransCAD	Caliper (USA)
6.	Visum	PTV AG (D)

Source: Fierek et al., 2015

4.4. Phase 3 – Defining of evaluation criteria

According to the key assumption of phase 3 of the selection procedure, both critical and selection criteria are defined. The set of critical criteria is composed of 2 fundamental aspects, i.e.:

- sales representatives and after-sales support should be located in Poland,
- a producer or distributor of TMT have to declare an interests of sell their product to the considered users, i.e. for both, rail carrier - ŁKA and marshal office - UMWŁ.

In the next step, the set of selection criteria for detailed evaluation of considered TMTs has been constructed. In this step 19 evaluation criteria have been defined, within 3 key evaluation contexts, including:

- functional aspects $F = \{c_1, \dots , c_{13}\}$,
- technical aspects $T = \{c_{14}, \dots, c_{18}\}$,
- financial aspect $B = \{c_{19}\}$.

The list of all selection criteria is presented in Table 2. Some of the criteria have their sub-criteria (43 items) and some of the sub-criteria are described more detailed, i.e. they have another level of decomposition (23 items).

4.5. Phase 4 – Critical elimination of TMTs

Using the set of critical criteria defined at phase p_3, for further evaluation a few alternative TMTs have been extracted. Only those tools having sales representatives and after-sales support located in Poland on the one hand, and expressed interests of sell their product (TMT) for ŁKA and UMWŁ, on the other, have been considered for further evaluation. Thus, 3 out of 6 TMTs have been extracted, i.e.:

- Aimsun,
- Emme,
- Visum.

4.6. Phase 5 – Conducting the assessment and final selection

Using the set of selection criteria (see result of phase p_3), all 3 alternative TMTs have been evaluated accordingly. To achieve an objective opinion on functionality of each TMT a sequence of experimental modelling activities on reference transport system - RTS have been performed (see Fig. 4). Based on *ex post* assessment the value of each criterion has been determined and the results of all experiments, expressed in its natural scale, are presented in Table 3.

Table 2. The set of selection criteria, sub-criteria and sub-sub-criteria

Hierarchy			Description	Original scale
c_j	c_{jl}	c_{jlk}		
Subset of functional aspects of TMT – *F*				
c_1			Availability of transport system modelling, with respect to	(0, 5)
	$c_{1,1}$		private transport mode, including	(0, 3)
		$c_{1,1,1}$	passenger cars,	0 ∪ 1
		$c_{1,1,2}$	pedestrians,	0 ∪ 1
		$c_{1,1,3}$	bicycles,	0 ∪ 1
	$c_{1,2}$		public transport mode, including	(0, 2)
		$c_{1,2,1}$	rail (train, tram),	0 ∪ 1
		$c_{1,2,2}$	road (long-distance, feeder transport).	0 ∪ 1
c_2			Availability of defining attributes of transportation network components, i.e.	(0, 9)
	$c_{2,1}$		for ways, including	(0, 5)
		$c_{2,1,1}$	maximum speed	0 ∪ 1
		$c_{2,1,2}$	capacity,	0 ∪ 1
		$c_{2,1,3}$	journey time,	0 ∪ 1
		$c_{2,1,4}$	travel cost,	0 ∪ 1
		$c_{2,1,5}$	temporary shutdowns (e.g. road repairs, events etc.),	0 ∪ 1
	$c_{2,2}$		for facilities, including	(0, 4)
		$c_{2,2,1}$	capacity,	0 ∪ 1
		$c_{2,2,2}$	time to reach the node,	0 ∪ 1
		$c_{2,2,3}$	riding time to node,	0 ∪ 1
		$c_{2,2,4}$	cost of transfer.	0 ∪ 1
c_3			Availability of parameters defining mechanism for transport lines, including	(0, 6)
	$c_{3,1}$		timetables for each line,	0 ∪ 1
	$c_{3,2}$		time parameters, including	(0, 3)
		$c_{3,2,1}$	boarding,	0 ∪ 1
		$c_{3,2,2}$	leaving,	0 ∪ 1
		$c_{3,2,3}$	transferring,	0 ∪ 1
	$c_{3,3}$		ticket price, including	(0, 2)
		$c_{3,3,1}$	average price,	0 ∪ 1
		$c_{3,3,2}$	price per carrier.	0 ∪ 1
c_4			Availability of traffic assignment mechanism.	0 ∪ 1
c_5			Availability of demand forecasting mechanism.	0 ∪ 1
c_6			Availability of infrastructural scenarios construction and evaluation mechanisms.	0 ∪ 1
c_7			Availability of mechanism to work in GIS-environment.	0 ∪ 1
c_8			Availability of timetable generation mechanism, including	(0, 2)
	$c_{8,1}$		generation of the feeder lines timetables with respect to the main line	0 ∪ 1
	$c_{8,2}$		optimisation of timetable subject to minimal travel time from origin to destination.	0 ∪ 1
c_9			Availability of reporting transport network changes, with respect to	(0, 4)
	$c_{9,1}$		defined period of time,	0 ∪ 1
	$c_{9,2}$		type of change performed on transport system,	0 ∪ 1
	$c_{9,3}$		passenger's preferences,	0 ∪ 1
	$c_{9,4}$		other profile types.	0 ∪ 1
c_{10}			Availability of transport system changes evaluation mechanism, with respect to	(0, 5)
	$c_{10,1}$		land use planning,	0 ∪ 1
	$c_{10,2}$		modelling of different aspect of regional development, including	(0, 4)

Table 2. The set of selection criteria, sub-criteria and sub-sub-criteria (cont.)

Hierarchy c_j	c_{jl}	c_{jlk}	Description	Original scale
		$c_{10,2,1}$	investment,	$0 \cup 1$
		$c_{10,2,2}$	housing,	$0 \cup 1$
		$c_{10,2,3}$	commerce,	$0 \cup 1$
		$c_{10,2,4}$	other characteristics.	$0 \cup 1$
c_{11}			Availability of demand modelling mechanism with respect to different aspects, including	(0, 5)
	$c_{11,1}$		population,	$0 \cup 1$
	$c_{11,2}$		transport behaviour,	$0 \cup 1$
	$c_{11,3}$		economic structure of inhabitants,	$0 \cup 1$
	$c_{11,4}$		sociological structure of inhabitants,	$0 \cup 1$
	$c_{11,5}$		other characteristics.	$0 \cup 1$
c_{12}			Clearness and intuitiveness of user's interface, with respect to	(0, 4)
	$c_{12,1}$		model design,	$0 \cup 1$
	$c_{12,2}$		analytical process,	$0 \cup 1$
	$c_{12,3}$		a way the graphics are generated from results,	$0 \cup 1$
	$c_{12,4}$		a way the tables are generated from results.	$0 \cup 1$
c_{13}			Availability of calibration process support mechanism, including	(0, 2)
	$c_{13,1}$		standard calibration of the trip model,	$0 \cup 1$
	$c_{13,2}$		origin-destination matrix optimisation.	$0 \cup 1$
Subset of technical aspects of TMT – *T*				-
c_{14}			Availability of the Polish version, with respect to	(0, 2)
	$c_{14,1}$		user's interface,	$0 \cup 1$
	$c_{14,2}$		TMT user's manual.	$0 \cup 1$
c_{15}			Availability of automatic data acquisition (incl. import) mechanism, in terms of	(0, 4)
	$c_{15,1}$		ticket prices,	$0 \cup 1$
	$c_{15,2}$		fuel prices,	$0 \cup 1$
	$c_{15,3}$		transport means occupancy,	$0 \cup 1$
	$c_{15,4}$		other type of data.	$0 \cup 1$
c_{16}			Possibility of TMT's customisation with respect to user's demand changes, by	(0, 2)
	$c_{16,1}$		macros design,	$0 \cup 1$
	$c_{16,2}$		scripts design.	$0 \cup 1$
c_{17}			Possibility of further TMT's functionality extensions, especially in terms of	(0, 3)
	$c_{17,1}$		new libraries,	$0 \cup 1$
	$c_{17,2}$		new modules,	$0 \cup 1$
	$c_{17,3}$		another options, e.g. add-ins.	$0 \cup 1$
c_{18}			Possibility of data and results sharing with other model standards, including	(0, 2)
	$c_{18,1}$		data sharing with other macroscopic models,	$0 \cup 1$
	$c_{18,2}$		data sharing with other lower-level models, e.g. microscopic.	$0 \cup 1$
Subset of financial aspects of TMT – *B*				-
c_{19}			Net unit price of one-year licence for two independent users, with respect to	(0, 1)
	$c_{19,1}$		maximum 400 zones [thous PLN]	value
	$c_{19,2}$		maximum 1.000 zones [thous. PLN]	value

Source: based on Fierek et al., 2015

Table 3. Value of selection criteria

Criteria c_j and sub-criteria c_{jl} and c_{jlk}	Unit[b]	Alternatives[a] A_1	A_2	A_3
c_1	**pts.**	**5**	**5**	**5**
$c_{1,1}$	pts.	3	3	3
$c_{1,1,1}$	pts.	1	1	1
$c_{1,1,2}$	pts.	1	1	1
$c_{1,1,3}$	pts.	1	1	1
$c_{1,2}$	pts.	2	2	2
$c_{1,2,1}$	pts.	1	1	1
$c_{1,2,2}$	pts.	1	1	1
c_2	**pts.**	**9**	**9**	**9**
$c_{2,1}$	pts.	5	5	5
$c_{2,1,1}$	pts.	1	1	1
$c_{2,1,2}$	pts.	1	1	1
$c_{2,1,3}$	pts.	1	1	1
$c_{2,1,4}$	pts.	1	1	1
$c_{2,1,5}$	pts.	1	1	1
$c_{2,2}$	pts.	4	4	4
$c_{2,2,1}$	pts.	1	1	1
$c_{2,2,2}$	pts.	1	1	1
$c_{2,2,3}$	pts.	1	1	1
$c_{2,2,4}$	pts.	1	1	1
c_3	**pts.**	**6**	**6**	**6**
$c_{3,1}$	pts.	1	1	1
$c_{3,2}$	pts.	3	3	3
$c_{3,2,1}$	pts.	1	1	1
$c_{3,2,2}$	pts.	1	1	1
$c_{3,2,3}$	pts.	1	1	1
$c_{3,3}$	pts.	2	2	2
$c_{3,3,1}$	pts.	1	1	1
$c_{3,3,2}$	pts.	1	1	1
c_4	**pts.**	**1**	**1**	**1**
c_5	**pts.**	**1**	**1**	**1**
c_6	**pts.**	**1**	**1**	**1**
c_7	**pts.**	**1**	**1**	**1**
c_8	**pts.**	**2**	**0**	**2**
$c_{8,1}$	pts.	1	0	1
$c_{8,2}$	pts.	1	0	1
c_9	**pts.**	**4**	**4**	**4**
$c_{9,1}$	pts.	1	1	1
$c_{9,2}$	pts.	1	1	1
$c_{9,3}$	pts.	1	1	1
$c_{9,4}$	pts.	1	1	1
c_{10}	**pts.**	**5**	**5**	**5**
$c_{10,1}$	pts.	1	1	1
$c_{10,2}$	pts.	4	4	4
$c_{10,2,1}$	pts.	1	1	1
$c_{10,2,1}$	pts.	1	1	1
$c_{10,2,1}$	pts.	1	1	1
$c_{10,2,1}$	pts.	1	1	1
c_{11}	**pts.**	**5**	**5**	**5**
$c_{11,1}$	pts.	1	1	1
$c_{11,2}$	pts.	1	1	1
$c_{11,3}$	pts.	1	1	1
$c_{11,4}$	pts.	1	1	1
$c_{11,5}$	pts.	1	1	1
c_{12}	**pts.**	**4**	**4**	**4**
$c_{12,1}$	pts.	1	1	1
$c_{12,2}$	pts.	1	1	1
$c_{12,3}$	pts.	1	1	1
$c_{12,4}$	pts.	1	1	1
c_{13}	pts.	**1**	**1**	**2**
$c_{13,1}$	pts.	1	1	1
$c_{13,2}$	pts.	0	0	1
c_{14}	pts.	**0**	**0**	**1**
$c_{14,1}$	pts.	0	0	1
$c_{14,2}$	pts.	0	0	0
c_{15}	pts.	**4**	**4**	**4**
$c_{15,1}$	pts.	1	1	1
$c_{15,2}$	pts.	1	1	1
$c_{15,3}$	pts.	1	1	1
$c_{15,4}$	pts.	1	1	1
c_{16}	pts.	**2**	**2**	**2**
$c_{16,1}$	pts.	1	1	1
$c_{16,2}$	pts.	1	1	1
c_{17}	pts.	**3**	**3**	**3**
$c_{17,1}$	pts.	1	1	1
$c_{17,2}$	pts.	1	1	1
$c_{17,3}$	pts.	1	1	1
c_{18}	pts.	**1**	**1**	**2**
$c_{18,1}$	pts.	0	0	1
$c_{18,2}$	pts.	1	1	1
c_{19}	-	-	-	-
$c_{19,1}$	thous. PLN	238.0	76.5	198.6
$c_{19,2}$	thous. PLN	452.2	153.0	340.5

[a] A_1 – Emme, A_2 – Aimsun, A_3 – Visum
[b] pts. = points

Using formulas for transforming original values of each criterion into an interval (0, 1), i.e. formula (3) and (4) for maximised and minimised criteria, respectively, value of each criterion c_j, for $j = 1, \dots, 19$, has been achieved. A result of this calculation is presented in Table 4.

Assuming an equivalence of each criterion, i.e. a value of each criterion is the same ($w_j = 1$, for $j = 1, \dots, 19$), the value of $\mathcal{K}_i$ and its partial values, i.e. $\mathcal{K}_i^F$, $\mathcal{K}_i^T$ and $\mathcal{K}_i^F$ for each alternative TMT, have also been calculated. All these results are presented in Table 4, as well.

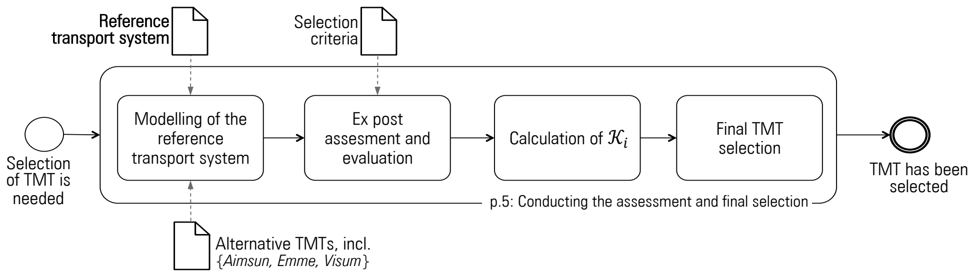

Fig. 4. A concept of TMT's assessment using reference transport system

A comparison among all three alternative TMT and its comparison to ideal profile of TMT is presented on Fig. 5.Taking this result into account, one can say the most recommended TMT is Visum (A_3), which is around 16% better than two other TMTs, i.e. Emme and Aimsun (17,9 vs. 15,0 points) and is only 6% worst than ideal profile of TMT (i.e. 17,9 vs. 20 points).

Table 4. The normalised value of criteria [points]

Criteria c_j			Alternatives[a]		
subset	name	type[b]	A_1	A_2	A_3
F	c_1	max	1	1	1
	c_2	max	1	1	1
	c_3	max	1	1	1
	c_4	max	1	1	1
	c_5	max	1	1	1
	c_6	max	1	1	1
	c_7	max	1	1	1
	c_8	max	1	0	1
	c_9	max	1	1	1
	c_{10}	max	1	1	1
	c_{11}	max	1	1	1
	c_{12}	max	1	1	1
	c_{13}	max	0	0	1
	$\mathcal{K}_i^F$	-	**12**	**11**	**13**
T	c_{14}	max	0	0	0.5
	c_{15}	max	1	1	1
	c_{16}	max	1	1	1
	c_{17}	max	1	1	1
	c_{18}	max	0	0	1
	$\mathcal{K}_i^T$	-	**3**	**3**	**4.5**
B	c_{19}	min	0	1	0.4
	$\mathcal{K}_i^B$	-	**0**	**1**	**0.4**
F, T, B	$\mathcal{K}_i$	-	**15.0**	**15.0**	**17.9**

[a] A_1 – Emme, A_2 – Aimsun, A_3 – Visum
[b] *max* – maximised criterion, *min* – minimised criterion

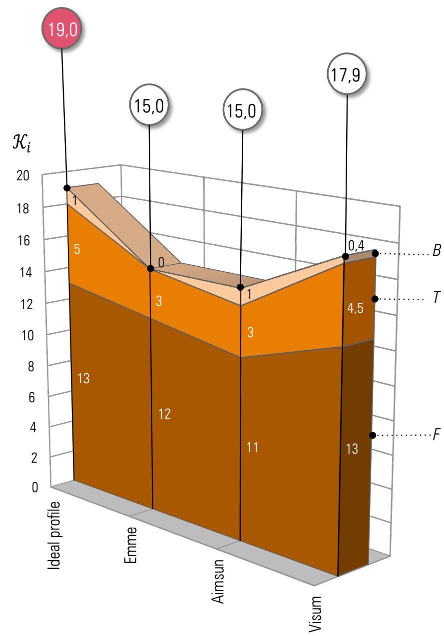

Fig. 5. Partial evaluation and final selection based on value $\mathcal{K}_i$ (F – financial, T – technical and B – financial context)

A better position of Visum compared to both Emme and Aimsun results from having:

- mechanism supporting calibration process (c_{13}), including standard calibration of the trip model and O-D matrix optimisation,
- Polish version (c_{14}), including user's interface,
- data and results sharing with other model standards (c_{18}), including both macro- and microscopic models.

What is more, Visum is better than Aimsun in having timetable generation mechanism (c_8), including generation of the feeder lines timetables and optimisation of timetable subject to minimal travel. In this matter Visum is equivalent with Emme.

On the other hand a difference between Visum (17.9 pts.) and ideal profile (19.0 pts.) results from lack of Polish manual (see sub-criterion of c_{14}), and relatively high price of one-year licence for two independent users (c_{19}).

Based on this result both users considered in this case, i.e. ŁKA and UMWŁ have been received Visum as the most adequate TMT for more complex integrated transport planning system.

5. Conclusions

The paper presents a result of constructing a selection procedure for the most suitable TMT, in a presence of multiple users and taking into account TMT as a part of a more complex integrated transport planning system (ITPS). This procedure is composed of five phases, including specification of detailed expectations of all identified users, research on available TMT, defining evaluation criteria (both, critical and selection one), critical elimination, and conducting final selection.

In the paper an exemplary application of this procedure is presented. The authors have defined 2 critical criteria and a set of 19 selection criteria divided into 3 main subsets, describing functional, technical and financial context of selection process, respectively. Using this procedure 3 out of 6 market recognised TMTs have been extracted using critical criteria. Next, all 3 alternatives have been evaluated based on its application to the reference transport system. As a result a single TMT, Visum, has been selected and recommended for implementation to ITPS as a more complex system.

The selection procedure presented in the paper is universal method and it can be applied more widely for selection of specialised software. Further research the authors are planning to curry out will be concentrated on application this method, its development and comparison of results.

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References

[1] AYAĞ, Z. and ÖZDEMİR, R.G., 2007. An intelligent approach to ERP software selection through fuzzy ANP. International Journal of Production Research, 45(10), pp. 2169–2194.

[2] BANDOR, M.S., 2006. Quantitative methods for software selection and evaluation. Technical Note CMU/SEI-2006-TN-026, Carnegie Mellon University.

[3] BIEŃCZAK, M., FIEREK S., KICIŃSKI M., KWAŚNIKOWSKI, J. and SAWICKI, P., 2015a. Planowanie zrównoważonego rozwoju transportu publicznego w oparciu o regionalny model podróży. Prace Naukowe Politechniki Warszawskiej: Transport, 105, pp. 5-20.

[4] BIEŃCZAK, M., GAWRON, P., KICIŃSKI, M. and KWAŚNIKOWSKI, J., 2015b. Zrównoważone planowanie publicznego transportu zbiorowego w ramach jednostek terytorialnych. Spójna metodyka oparta na metodach optymalizacji. Logistyka, 4, pp. 90-98.

[5] DOWLING, R., SKABARDONIS, A. and ALEXIADIS, V., 2004. Traffic analysis toolbox Volume III: Guidelines for applying traffic microsimulation modeling software. http://trid.trb.org/view.aspx?id=794930#.VswgpWybBqk.mendeley

[6] DOWNLING R., HOLLAND J. and HUANG A., 2002. Guidelines for applying traffic microsimulation modelling software. California Department of Transportation. Dowling Associates, Inc.

[7] FIEREK, S., BIEŃCZAK, M., KICIŃSKI, M., SAWICKI, P., JAKUBEK, A. and ZMUDA-TRZEBIATOWSKI, P., 2015. Metodologia dla cyklu badań i projektów w zakresie transportu publicznego w regionie łódzkim, ze szczególnym uwzględnieniem transportu kolejowego, jako transportu niskoemisyjnego, dla potrzeb aplikacji w ramach RPO WŁ perspektywy 2014-2020. Dokument metodyczny i założenia do funkcjonowania systemu informatycznego. 05/51/PRJG/3399, Poznań.

[8] LAI, V. S., WONG, B. K. and CHEUNG, W., 2002. Group decision making in a multiple criteria environment: A case using the AHP in software selection. European Journal of Operational Research, 137(1), pp.134-144.

[9] LAI, V.S., TRUEBLOOD, R.P. and WONG, B.K., 1999. Software selection: a case study of

the application of the analytical hierarchical process to the selection of a multimedia authoring system. Information & Management, 36(4), pp. 221-232.

[10] LEE D.H. (ed.), 2004. Urban and regional transportation modelling. New dimensions in networks. Edward Elgar Publishing Ltd, Northampton, MA, USA.

[11] MACIEJEWSKI, M., 2010. A comparison of microscopic traffic flow simulation systems for an urban area. Problemy Transportu, 5, pp. 27-38.

[12] MARR, B. and NEELY, A., 2003. Automating the balanced scorecard - selection criteria to identify appropriate software applications. Measuring Business Excellence, 7(3), pp. 29-36.

[13] PANORAMA CONSULTING SOLUTIONS, 2016. ERP software selection. http://panorama-consulting.com/services/erp-software_selection/ [23.02.2016].

[14] SAI, V., 2004. COTS acquisition evaluation Process: Preacher's practice. CMU/SEI-2004-TN-001, ADA421675. Pittsburgh, PA: Software Engineering Institute, Carnegie Mellon University, 2004 (http://www.sei.cmu.edu/publications/documents/04.reports/04tn001.html [23.02.2016].

[15] SEJM RP, 2011. Ustawa z dnia 16 grudnia 2010r. o publicznym transporcie zbiorowym (Public Transport Act). Dz.U. 2011 nr 5 poz. 13.

[16] SPENCER, B. and JOHNSTON R., 2014. Best practice steps to software selection. EVP K2 Enterprises,http://www.accountingsoftwareworld.com/articles-white-papers/selection-steps [23.02.2016].

[17] YAZGAN, H.R., BORAN, S. and GOZTEPE, K., 2009. An ERP software selection process with using artificial neural network based on analytic network process approach. Expert Systems with Applications, 36(5), pp. 9214-9222.