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THE TRAFFIC INTENSITY PREDICTION IN TRANSPORT NETWORK BY MEANS OF REDUCTS SET

Summary. The paper discusses several aspects of traffic modelling; with its unpredictable controlling processes. The subject of the analysis comes from the rough sets theory implemented for the transportation processes description. The key problem of the analysis can be found in the traffic intensity prediction, for junctions of the network graph's arches description, using not necessarily complete data of the observable network part.

PRZEWIDYWANIE NATĘŻEŃ RUCHU W SIECI TRANSPORTOWEJ NA PODSTAWIE ZBIORU REDUKTÓW

Streszczenie. Artykuł przedstawia omówienie pewnych aspektów modelowania ruchu drogowego; z uwzględnieniem nieprzewidywalnych stanów sterowania siecią. Przedmiotem analizy są też różne aspekty zastosowań teorii zbiorów przybliżonych. Kluczowym problemem, zreferowanym w pracy, jest modelowanie procesów przewidywania natężeń ruchu w sieci drogowej, niezbędnych do opisu grafu sieci transportowej i atrybutów łuków grafu sieci. Problem dotyczy w szczególności sieci nie kompletnie zidentyfikowanej, jak we fragmentach pozbawionych sprawnych detektorów pojazdów.

1. INTRODUCTION

The introduced contribution discusses several aspects of traffic modelling; the very unpredictable controlling processes. The subject of analysis comes from the rough sets theory implemented for the transportation processes description.

The key problem of this analysis can be found in the traffic intensity prediction, for all junctions of the network graph's edges description, using the available (not necessarily complete) data of the observable network part.

Unlike existing solutions, which base on summing up traffic volumes on intersection, proposed here method consider all the intersections of network at the same time. This approach allows to decrease accumulated error.

The model description principles were predicted by short comments of rough sets theory fundamentals. There were introduced expressions used in further description of the transportation model.

2. THE ROUGH SETS INFORMATION MODEL

In rough sets theory the specific objects universe U existence was assumed, such as: object $x \in U$, assigned by set Q of attributes' values. The set of all values W, as can assign these attributes, bounded by a sum of all attributes sets:

$$W = \bigcup_{q \in Q} W_q \tag{1}$$

where: each attribute $q \in Q$ can be equal to value $w \in W_q$.

The universe description, containing its characteristic values, is the ordered four, as:

$$SI = (U, Q, W, \rho)$$

The three first sets were defined above. The information function ρ: $U \times Q \rightarrow W$, assigns functions indicating pairs: object – attribute, adequate to these relations.

The decision system of the control unit assigns the ordered five, such as:

$$SD = (U, C, D, W, \rho)$$

The attributes set, of the decision unit, was divided into two sub-sets C and D. The subset C contains conditional attributes. The elements of the sub-set D are attributes of the decision output.

The conditions of the conclusion were introduced in the decision table 1, where headers of rows define each objects $x_i \in U$. The columns headers assign attributes of objects $c_j \in C$, $d \in D$

Every table should have it's own title. Tables and figures numbering must me continuous through the whole paper.

Table 1

The decisions table example

Universe elements	Attributes			
	Conditional			Decision
	c_1	c_2	c_3	d
x_1	$w_{x1,c1}$	$w_{x1,c2}$	$w_{x1,c3}$	$w_{x1,d}$
x_2	$w_{x2,c1}$	$w_{x2,c2}$	$w_{x2,c3}$	$w_{x2,d}$
x_3	$w_{x3,c1}$	$w_{x3,c2}$	$w_{x3,c3}$	$w_{x3,d}$

If the two elements (objects) x_i, x_j, of the decision-making unit, have the same value for all $q \in P \subset Q$, then the state are P- indistinguishable.

The relationship of these indiscernible states, in the decision-making system, can be defined by the expression:

$$x_i \tilde{P} x_j \Leftrightarrow \underset{q \in P}{\forall} \rho(x_i, q) = \rho(x_j, q) \tag{2}$$

The relationship of the *P*-indiscernible states divides the universe into the equivalence classes:

$$[x_i]_{\tilde{P}} = \{x \in U : x\tilde{P}x_i\} \tag{3}$$

In the rough sets theory, the equivalence classes define a specific elementary sets. Suppose we have a certain set of elements of universe $X \subset U$.

P-lower; $\underline{\tilde{P}}X$ approximation, of the set *X* is called the sum of these elementary sets that completely belong to the set *X*.

$$\underline{\tilde{P}}X = \left\{x \in U : [x]_{\tilde{P}} \subset X\right\} \tag{4}$$

P-upper; $\overline{\tilde{P}}X$ approximation, of the set *X* is called the sum of these sets which give non-empty intersection with the *X* set.

$$\overline{\tilde{P}}X = \left\{x \in U : [x]_{\tilde{P}} \cap X \neq \phi\right\} \tag{5}$$

Suppose you have a specific *SI* information system, and that the universe of this system is a set of points in the plane. The indiscernibility relationship of this information system elements divides the universe into elementary sets, illustrated by puzzles in Fig. 1.

The elements of the lower approximation is totally included in *X* and but the upper approximation elements have at least one common point with the set *X*.

Therefore, the approximated *X* set of elements produce pairs of sets ($\underline{\tilde{P}}$X, $\overline{\tilde{P}}$X), forming the upper and lower approximation products.

Anticipation (prediction) of the traffic intensity in the network, one can describe by the approximation formulas. Finding an independent (minimum) set of the control system attributes, at the selected controlling area, concerns searching the reducts of the complete information system description.

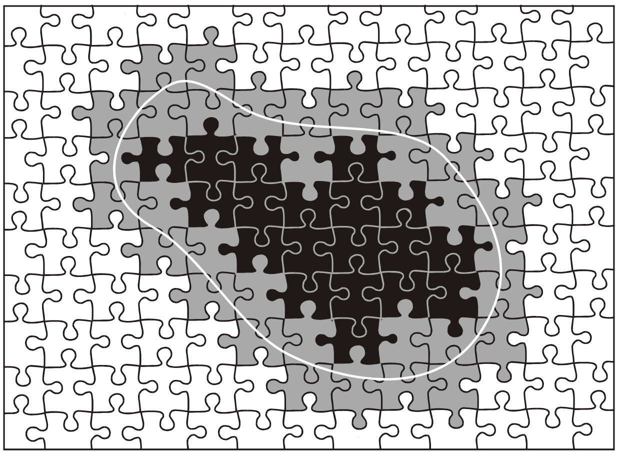

Fig. 1. The lower (black) and upper (gray) approximation of *X* collection (by white line) of information system
Rys. 1. Dolne (czarne) i górne (szare) przybliżenie zbioru *X* (biała linia) w systemie informacyjnym

We say that a set P_1 of attributes, of an information system, is an independent, if for any subset of attributes $P_2 \subset P_1$ discernibility relations generated by these two sets are different:

$$Q \supset P_1 \text{ is independent } \Leftrightarrow \underset{P_2 \subset P_1}{\forall} \tilde{P}_1 \neq \tilde{P}_2 \tag{6}$$

The information system reduct we call each of the minimum set of attributes of an information system, which describe an independent set of attributes $P \subset Q$ that generates the same relationship as the entire set of indistinguishable attributes $\tilde{P} = \tilde{Q}$.

It is also necessary to define the concept of a core set of attribute information system:

$$core(Q) = \{q \in Q : \tilde{Q} \neq \tilde{P}, P = Q \setminus \{q\}\} \tag{7}$$

Core consists of attributes that belongs to all reducts.

3. THE CURRENT TRAFFIC DATA ENTRY

The data assigning the current traffic on each inlet of the network is entered into the universe illustrating the all registered states (attributes) of the network. Traffic on the network can be expressed in integers from 0 to approximately 2 000 VPH, for which the presumed number of network-states has very large sizes. Evaluation of parameters of traffic with great accuracy is not necessary when estimation of vehicles number we produce in terms of the rough sets theory.

To simplify the network model the approximate description was introduced, where only four intensities (levels of service) of the traffic are considered; from the set {LOS I, LOS II, LOS III, LOS IV}.

The decision function of such a system allocates a couple: state - connection, the appropriate value of LOS.

$$S = (U, Q, W, \rho)$$

where:

U — is the universe of objects, which in this case are the network statuses,

Q — is a set of attributes that describe the objects (here intensities on the network connections, assigning the network states),

W — is a set of attributes values (determining the level of freedom of movement on the network connections),

ρ — is an information function $\rho : U \times Q \rightarrow W$ assigning the pair: status/link particular attribute value

4. TRAFFIC INTENSITIES PREDICTION BASED ON THE DETERMINATION OF REDUCTS

In the above model each crossing of the network is equipped with motion detectors, signaling the passing vehicles. We also assume that the crossing is located inside the transport network. On each inlet of the crossing the pipe of vehicles appears, registered previously in another (preceding) crossroads of the network.

In every real networks, of the urban layout, the road junctions model is more complex, where are crossings without traffic lights without traffic detectors. At the junctions sometimes are less than 4 inlets, and other specific topologies.

We also cannot assume that the road always meets at angle 90°, creating regular layouts between main intersections. The road network topology is more complex and irregular.

The introduces above, traffic modeling method will be effective for specific, theoretical cases. It can also be assumed that it is not required to know the intensities of the traffic on all sections of the network to uniquely determining the status of the network [9].

The traffic density on the monitored road parts will be a function of traffic intensity in other, monitored pathways, the more for rough modeling approach. Using the data histogram on current vehicles streams, in a number of measuring points, one can approximate the road traffic status. It is the reasonable assumption for slow and random processes, such as road transport.

This data can be processed in accordance with the rules of the rough sets theory. The product of this processing will be a knowledge base for the conclusion concerning a current traffic intensity at crossings without vehicles detectors.

The controlling procedures are defined on the basis of data from a model of predicting states, coming from the states of junction equipped with traffic detectors.

In Fig. 3 is an example of the transport network, in which the cases described above were introduced.

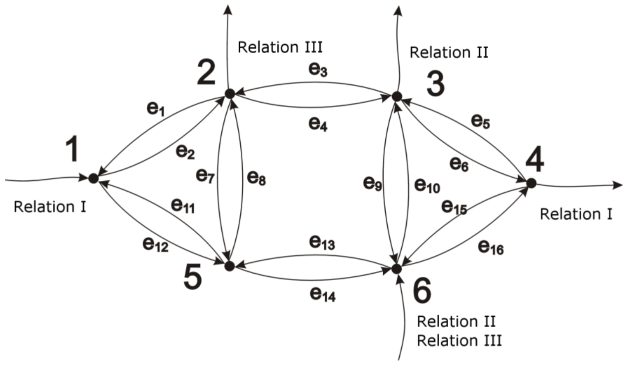

Fig. 2. Example of a transport network
Rys. 2. Schemat sieci transportowej

Three relations have been assumed In traffic Network. Relation I starts in intersection 1 and goes to intersection 4. Traffic participants can randomly choose their route.

Table 2

The example traffic intensity [VPH]

	Relation 1	Relation 2	Relation 3
Case 1	770	420	420
Case 2	1100	600	600
Case 3	1210	660	660
Case 4	1350	560	810
Case 5	1650	440	990
Case 6	1500	400	900
Case 7	500	960	960
Case 8	400	1080	1080
Case 9	400	1200	1200

Also 9 cases of traffic intensities have been assumed. The table 2 shows an example data, describing the intensities of these states of the road traffic load, with three relationships of the traffic in the network.

For the selected connections in the network, several random intensities of the traffic was defined; similarly to models presented in the literature [5], [9] with traffic intensities corresponding to real transportation network.

The calculations were made on the basis of the routes choice algorithm, in accordance with the second Wardrop’s principle [6], for minimisation of costs per unit. The route is designated into each traffic participant (from a possible combinations) in accordance with the journey lowest cost criterion. The costs evidence of the route is expressed by the time dimension t_0, according to the traffic capacity c in a free driving. The cost of the route section designates the formula:

$$t_{u,v}(x_{u,v}) = t_{0u,v} \cdot \left(1 + \alpha \left(\frac{x_{u,v}}{c_{u,v}}\right)^{\beta}\right) [\mathrm{s}] \tag{8}$$

where:

$t_{0\,u,v}$ — duration of the free driving traffic,

$x_{u,v}$ — traffic intensity on the road unit [VPH]

$c_{u,v}$ — capacity (throughput) of the road section [VPH]

α, β — calibrating parameters (α = 0,15; β = 4).

The free driving time defines the ability to cross the distance, with any speed. It means that the vehicle's speed in not decreased by any predicting traffic participant.

The attention could concern the possibility of simplifying the traffic description model that assumes a constant value of the capacity between intersections. At the algorithm calculation the measure of the road section capacity the inlet parameters of the crossing has been adopted.

Table 3

The example parameterisation of the transportation network

Links	Capacity [VPH]	Time t_0 [s]
$e_1, e_2, ..., e_6$	900	40
e_7, e_8	500	60
e_9, e_{10}	700	50
$e_{11}, e_{12}, ..., e_{16}$	300	80

The real capacity also depends on the volume of traffic at other inlets of the crossing, which significantly complicates the calculation.

Although in Fig. 3 an ideal network part has been discussed it can be easy modified into reality dimensions, by introducing all physical parameters in the network description graph.

In table 3 an example description part of the real traffic model has been presented. Parameters values of each junction of traffic network have been assumed.

With assumed parameters values of network links and using formula (8) for cost per unit calculation the traffic assignment has been made. The example assignment of the transportation network has been presented in table 4.

Table 4

The traffic intensity assignment

State/ Link	e_1	e_2	e_3	e_4	e_5	e_6	e_7	e_8	e_9	e_{10}	e_{11}	e_{12}	e_{13}	e_{14}	e_{15}	e_{16}
1	I	II	I	II	I	II	I	I	I	IV	I	I	I	I	I	I
2	I	IV	I	IV	I	IV	I	I	I	IV	I	I	I	I	I	I
3	I	IV	I	IV	I	IV	I	I	I	IV	I	I	II	I	I	I
4	I	IV	III	IV	I	IV	I	I	I	IV	I	I	I	I	I	I
5	I	IV	III	IV	I	IV	I	I	I	IV	I	II	III	II	I	II
6	I	IV	III	IV	I	IV	I	I	I	IV	I	I	II	I	I	I
7	I	I	I	I	I	I	I	II	I	IV	I	I	IV	I	I	IV
8	I	I	I	I	I	I	I	IV	I	IV	I	I	IV	I	I	IV
9	I	I	II	I	I	I	I	IV	I	IV	I	I	IV	I	I	IV

Further columns correspond to the network links. Rows define the traffic intensities. In the fields of this table the values (one from the four) of the levels of service, in the network nodes, were indicated.

The next algorithm step is the determination of reducts in decision system. For this purpose the RSES 2.0. [1] software package was used. The package allows us the analysis using the exhaustive search method, covering all elements of the network.

Table 5

The transport network states assigned by three attributes of reducts

a)

State/ Link	e_2	e_3	e_8	e_{13}
1	II	I	I	I
2	IV	I	I	I
3	IV	I	I	II
4	IV	III	I	I
5	IV	III	I	III
6	IV	III	I	II
7	I	I	II	IV
8	I	I	IV	IV
9	I	II	IV	IV

b)

State/ Link	e3	e4	e8	e13
1	I	II	I	I
2	I	IV	I	I
3	I	IV	I	II
4	III	IV	I	I
5	III	IV	I	III
6	III	IV	I	II
7	I	I	II	IV
8	I	I	IV	IV
9	II	I	IV	IV

c)

State/ Link	e3	e6	e8	e13
1	I	II	I	I
2	I	IV	I	I
3	I	IV	I	II
4	III	IV	I	I
5	III	IV	I	III
6	III	IV	I	II
7	I	I	II	IV
8	I	I	IV	IV
9	II	I	IV	IV

Finally we obtained three reducts shown in tables 5: a) b) and c); each with four attributes. The links e_3, e_8 and e_{13} belong to all the obtained reducts, i.e. are the so-called core information system; necessary for identifying the traffic status.

5. CONCLUSIONS

The worked out method enables us to reduce set of attributes that are necessary to describe the status of the transportation network. It also allows specifying the traffic on the inlet junctions that is not equipped with traffic detectors.

The determined representation of the transportation network states (covered by all needed reducts), allows us to reduce significantly the number of necessary attributes describing the network status. The overworked algorithms extract the necessary attributes from a complete set of attributes assigning the transportation network statuses.

If for specified attribute $q \in Q$ exists reduct $R_i \subset Q$, such that $q \notin R_i$, the attribute q value can be calculated on the basis of the values of other attributes belonging to the reduct R_i. If the attribute $q \in Q$ belongs to the reduct R_i then the designation of the q value of the attribute is not possible, on the basis of other attributes, belonging to reduct R_i . Then we has to use another reduct R_j , such that $q \notin R_j$.

The minimum number of attributes of the reducts' will uniquely identify the status of the network. The attributes belonging to the core of the system are necessary to determine the status of the network.

The attribute value $q \in \text{core}(Q)$ cannot be determined because the reduct $R \subset Q$ such as $q \notin R$ does not exist.

The data entered into the information system describes the network states, where vehicles' movement was observed. The determined reducts are not describing the network states, with interference. The method for the reducts determining, works for cases of regular transport network. For more complex networks the algorithms of reducts finding is remarkable more complicated.

The conclusions rules' base, generated by the reducts set may return incorrect results, when the network will reduce the capacity of one or more sections of the road. It is therefore necessary to supplement the existing information system of the network states, where the traffic capacity, on certain routes of the network, has been reduced.

The historical data acquisition of the network, in which a reduction of the traffic capacity at the road sections was noticed cannot only be difficult but also not very reliable. The expected good solution is available in simulation methods, assessing the effects then entering them into the network model.

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