Intelligent recognition of the preference structures for multi-criteria management and traffic control methods in ITS systems

INTRODUCTION

The transportation systems are complex socio-technical systems embedded in an active operational environment created by interconnected complex of physical/virtual networks called SupNet. This SupNet through wide spectrum of complex interactions influences the key internal operational and behavioural environment of transportation processes [12-19]. The specific features concerning the transportation processes to be fundamental ITS systems operational determinants are as follows:

- Existence of complex interactions operational and behavioural type (inter: SupNet→ITS; intra: ITS system heterogeneous modes, users, common resources, operational specifications of available transportation resources; human behavioural anisotropy, existing ITS systems operational specifications, multi-institutional interactions) [7-9][12-15].
- Multi-scale complex phenomena (uncertainty, randomness, fast non-linear dynamics, high sensitivity to instabilities, blockings and unpredictable traffic congestion propagation, existence unpredictable traffic incidents, traffic situational dependent level of service).
- Generation of various types negative impacts: safety, environmental, social, energy waste.

In the above context the proposals of adequate solutions in the form of professional ITS systems development are fundamental. The ITS systems crucial functional specifications concerns:

- Open system professional solution (development methodology, obligatory TRIADS: I-E-U principles, advanced dedicated DSS computer tools supporting the ITS system development) with FBP (Future Big Picture) future functionalities extensions, adaptations perspective.
- Hierarchical multi-layer functional integrated system structure (i.e. interactive multi-time horizons, multi-objectives, system multi-tasks decomposition with system wide perspective guarantee of compatibility, interoperability and functional flexibility system-wide actions).
- Integration system specifications offer (in available resources context) wide spectrum of cooperative responses to full range of dedicated demands specifications (users/modes/regions).

Intelligence system specifications form first of all the remedies for uncertainty, randomness, instability, special events, behavioural interactions, negative impacts. The very important intelligence application area concerns the intelligent supervision and monitoring of then ITS system 2-D (time-space) processes (detection symptoms, recognition and diagnosis events, understanding processes and mechanisms). The dedicated intelligent supporting activities of these ITS system layers (management and coordination, adaptation, optimisation and direct control) in a crucial way conditioning both the functional efficiency and productivity of the individual layers (e.g. enabling proper estimation/prediction of tasks specifications) as well as by intelligence generated integration premises similar operation of the whole system. Very important practical aspects are related with guarantee of applicability of the professional methods, models and computer tools, dedicated to intra/inter layers functionalities. The proposed advanced system platform HITS [18] enables complex system tasks related, adequate inter-layers coherent reactions and co-operative actions. The fundamental question concerning the operational ITS systems adequacy/flexibility/multi-users oriented efficiency and productivity in response to above presented transportation processes features. Some necessary conditions supported by modern enabling technologies and professional tools are important:

1 AGH University of Science and Technology, Institute of Automatics and Bio-Engineering, Al. Mickiewicza 30, Kraków 30-059, Poland
2 the Cracow University of Technology, Faculty of Civil Engineering, ul. Warszawska 24, 31-155 Kraków, Poland Tel. 126283094, heldak@pk.edu.pl
The ITS system multi-layer hierarchical structure with exploration of intelligent supervision and system data and knowledge perspective is presented in Fig.1 [7-9][12-14]. The presented Intelligent Supervisor (IS) is embedded in the ITS system coordinated hierarchy and functioning in the information and knowledge rich operational environment. The ITS system archives the available information from different data sources to databases and preparing it for data mining purposes. Integrated hierarchical management, surveillance and control structures of ITS multi-layer systems create among others the base for completely new capabilities [18-19):

- Integrated recognition and stimulating beneficial synergistic effects by system-wide solutions.
- Intelligent real-time opportunity based efficient management strategies selection/update.
- Real-time multi-criteria intelligent "control by opportunity" and robust control modes.

New features include: high efficiency (due system components inter-operability) and productivity (multi-criteria dynamic approach), flexibility (modularity, expandability, intelligent preference structures selections for system activities) and transparency (sophisticated expert systems and visualization tools). The implementation of effective management and control strategies requires continuous monitoring and intelligent surveillance i.e. real-time assessment and diagnose of network components (intersection (IM)/artery (AM)/ sub-area (SM) modules) operating conditions based on real-time traffic data. The assessment of operating conditions requires for example robust recognition and diagnosis of traffic modes and theirs dynamic transitions in time-space arena. Traffic operational modes are represented by traffic situations related markers to be an appropriate transformations of representative traffic variables into network components performance measures e.g. for arterials delays, stops, queue lengths and travel times [9][13]. The response to uncertainty, differentiated dynamics, behavioural conditioning aspects are high requirements respectively, in terms of decision robust features, multi-time horizon activities compatibility and intelligent recognition of behavioural patterns [13]. Very interesting are nowadays technological premises: information technologies with communication revolution and computer technology advances which create the formal base for improvements of ITS systems functionalities [19]. In particular, the modern ICT (Information and Communication Technologies) enables to implementation of more intelligent and integrated approaches to ITS systems. In general the network common 2-D resources (i.e. physical infrastructure, traffic intersections) are used by different users modes with various individual 2-D requirements under dynamic network-wide obligatory constraints of being safe, environmentally acceptable and cost-effective. The dynamically changing the network 2-D (space-time) operational environment require the similar system reactions to balance obligatory constraints and offering efficient dedicated services [17][20]. Therefore, we need to be able to recognize and diagnose the traffic situations using the respective data, information and knowledge for users information services and implementation adequate management and control system-wide actions.
The high importance of information in operation of ITS systems becomes the norm however the lack of coherence between various systems functionalities balancing competing needs of different modes and policy goals calls for more sophisticated integrated and intelligent solutions. The available ICT technologies and v-v/v-i communicating systems in natural way support the above modern ITS systems premises. The capability of rapid collection real-time processing and dissemination of data and information for different ITS system layers calls for solution of sophisticated tasks. The availability high quality data (e.g. from sensor technologies vehicles tracking information on location, speed and travel times, video-cameras, vehicle probes) enables the generation of information and knowledge to be useful for different ITS system tasks. The computing technologies and vehicle platforms offer new capabilities of monitoring and intelligent supervision of the above processes using the task-representative 2-D data and theirs dedicated automatic dissemination to task-related areas directly or in the form of dedicated information/ knowledge. The basic ATIS users services of high quality can be offered by electronic displays, tracking of vehicles (GPS, GSM/GPRS, v-v, v-i), internet and mobile phones. At the upper management and coordination ITS system layer the potential
The power of these new approaches concerns the strong understanding of the strategic goals for the system and ways of resolving the inevitable trade-offs by intelligent recognizing the preference structure. The role of integrated transport management is to realize those aspects of transport strategy that require management (ATMS) and information (ATIS) as well as lower layers supporting actions.

Fig. 2. The preference structure for multi-criteria control problem recognition
To illustrate of the ITS system multi-layers co-operative activities we allocate the following general activities to the system layers. Optimisation Layer: After updating the optimisation specifications (preferences, constraints, parameters) the corresponding criteria and performance measures are selected and preference cones for multi-criteria PIACON control method are recognized and implemented for solution of these problems. Intelligent Surveillance and Monitoring Layer: In this layer the real-time monitoring of the system environment is realized and modern multi-media technologies are used for the ATIS visualization, warning and alarm generation purposes. Intelligent surveillance diagnoses these abnormal situations and support the ITS system remedial actions. In consequence wide spectrum of professional anticipative and preventive actions practically on all layers of the proposed system can be realized. Direct Control Layer: Depending on diagnosed situations the multi-criteria robust control problem is solved with additional capability of selection more adequate to a given traffic situation Pareto solutions from Compromise Set e.g. multi-criteria PIACON (Polyoptimal Integrated/Intelligent Adaptive CONtrol) real-time control method with traffic delay and capacity control modes and recognized preference cone for solutions from Pareto Set. PIACON traffic control method for urban areas meet the most of needs of real traffic decision making and control processes. ([9-11],[18]). The multi-criteria traffic control approaches in natural way are embedded into ITS systems structures. The crucial problem is connected with adequate recognition/diagnosis of the control preference structures (see Fig. 2 preference cones) which selects the adequate control measures/performance criteria for diagnosed traffic situations.

Tab.1 Ranking of criteria (RQ); alternatives w.r.t. to individual criteria A/Qi and final FR

<table>
<thead>
<tr>
<th>A/Q1</th>
<th>A/Q2</th>
<th>A/Q3</th>
<th>A/Q4</th>
<th>A/Q5</th>
<th>A/Q6</th>
<th>FR/LP</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4192</td>
<td>0.0255</td>
<td>0.4030</td>
<td>0.0281</td>
<td>0.0408</td>
<td>0.1834</td>
<td>0.0359</td>
</tr>
<tr>
<td>0.1284</td>
<td>0.0641</td>
<td>0.1750</td>
<td>0.0859</td>
<td>0.2300</td>
<td>0.2343</td>
<td>0.1967</td>
</tr>
<tr>
<td>0.1936</td>
<td>0.0427</td>
<td>0.2431</td>
<td>0.0573</td>
<td>0.1778</td>
<td>0.1279</td>
<td>0.1574</td>
</tr>
<tr>
<td>0.0782</td>
<td>0.3460</td>
<td>0.0629</td>
<td>0.3444</td>
<td>0.0664</td>
<td>0.0466</td>
<td>0.0781</td>
</tr>
<tr>
<td>0.1333</td>
<td>0.3418</td>
<td>0.0298</td>
<td>0.3108</td>
<td>0.0664</td>
<td>0.0411</td>
<td>0.0781</td>
</tr>
<tr>
<td>0.0473</td>
<td>0.1798</td>
<td>0.0861</td>
<td>0.1734</td>
<td>0.4186</td>
<td>0.3666</td>
<td>0.4536</td>
</tr>
</tbody>
</table>

The hierarchical structure of premises for evaluations of traffic situations have both quantitative operational markers (e.g. traffic volumes, lengths of vehicle queues) as well as quantitative markers (e.g. social aspects of offered LoS – Level of Service). The AHP-E methods options are a multi-criteria decision-making methods that uses a main goal related hierarchical structure of the constitutive elements to solve such complicated problems and integrating different measures into a single overall score for ranking of decision alternatives. In this paper the proposal of synthetic recognition of traffic multi-criteria real-time control preference structures are realized in two steps; the recognition of adequate communication systems offering the representative information from the point
of view of traffic parameters estimation and prediction tools (see Tab.1 AHP, LP methods) and in the second step recognition of control, preference structure for the PIACON multi-criteria control method (see Fig.2 and Tab.2) by max-plus algebra dedicated tool. As can be seen the recognized preference structure is represented in Fig. 2 as delay, capacity and queue control modes ([5][9-11]).

Tab.2 Ranking of criteria (RQ); alternatives w.r.t. to individual criteria A/Qi and final FR

<table>
<thead>
<tr>
<th>RQ</th>
<th>A/Q1</th>
<th>A/Q2</th>
<th>A/Q3</th>
<th>A/Q4</th>
<th>A/Q5</th>
<th>A/Q6</th>
<th>FR/MAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.3840</td>
<td>0.0238</td>
<td>0.4361</td>
<td>0.0251</td>
<td>0.0527</td>
<td>0.1666</td>
<td>0.0398</td>
<td>0.1086</td>
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<tr>
<td>0.1597</td>
<td>0.0692</td>
<td>0.1473</td>
<td>0.0937</td>
<td>0.2285</td>
<td>0.2403</td>
<td>0.2007</td>
<td>0.1235</td>
</tr>
<tr>
<td>0.2304</td>
<td>0.0406</td>
<td>0.1841</td>
<td>0.0484</td>
<td>0.1632</td>
<td>0.1155</td>
<td>0.1688</td>
<td>0.0880</td>
</tr>
<tr>
<td>0.0768</td>
<td>0.3350</td>
<td>0.0839</td>
<td>0.3500</td>
<td>0.0653</td>
<td>0.0385</td>
<td>0.0946</td>
<td>0.2356</td>
</tr>
<tr>
<td>0.1108</td>
<td>0.3350</td>
<td>0.0383</td>
<td>0.3018</td>
<td>0.0653</td>
<td>0.0385</td>
<td>0.0946</td>
<td>0.2172</td>
</tr>
<tr>
<td>0.0384</td>
<td>0.1965</td>
<td>0.1104</td>
<td>0.1811</td>
<td>0.4249</td>
<td>0.4005</td>
<td>0.4015</td>
<td>0.2272</td>
</tr>
</tbody>
</table>

2 ILUSTRATIVE EXAMPLES

Driving, it possible to meet not optimal usage of road traffic capacity. When traffic pattern or mode is not recognised, traffic control system work wrong. The incidents are the examples of situation when road resources are not optimally used. The figure 3 presents example of intersection blocking, figure 4 shows the incident after the intersection, which make the lower saturation of intersection, etc. Our Aimsun model presents same negative effects the incidents and their reduction by intelligent and regular determination of optimal traffic control plan.

Fig. 3. The example of incident detection (a) and Aimsun model (b)

AIMSUN model ([22]) represents road network area with typical traffic condition and set of traffic control parameters (column T in tab. 3). Then there was modelled the incident in left turn arrival flow of traffic stream, which reduce real saturation for this stream (column I2 in tab. 3) and similar incident in straight flow of traffic stream (column I1 in tab. 3). For new traffic parameter The actuated set of traffic control parameters was determined and the results of the simulations are presented in in column
R1a and R1b (tab. 3) for the incident I1 and R2a, R2b for the incident I2 (tab. 3) as the intelligent system reaction for new traffic condition. The R1a/R2a represents optimal control plan for maximal flow and R1b/R2b – gating methods. AIMSUN model works for one hour period and the table 3 presents the results of this experiment. The propagation of disturbances for the others traffic streams generate so poor road network quality for drivers (example in fig. 4)

![Fig. 4. The incident I1 (a) and I2 (b) detection in Aimsun model.](image)

The measuring system allow to recognize new traffic condition, then the optimal traffic control plan is establish basic on clique methods ([21]). Decision support system uses fuzzy rules for establishing optimization criteria $J_c$ and boundary conditions according current criteria:

- **Minimal intergreen time**
- **Maximization of the intersection capacity per cycle**
- **Maximization function:**
  \[
  J_{c2} = \sum_{i=0}^{r} s_i g_i = \sum_{i=1}^{r} s_i \sum_{k=1}^{K} u_i^k \tau^i
  \]

- **Determine the signal plan:**
  \[
  u(*) = (u, \tau)^T
  \]

- **Minimal intergreen time**
  \[
  J_{c1} = \tilde{\tau}_{ij} = t_{ij}^p - t_{ij}^e + t^p + t^g
  \]

$x$ – control plan definition

- **Minimal delay**
  \[
  J_c = 0.9 \sum_{k=1}^{K} \sum_{i=1}^{E(p)} \left( \alpha_{pse}^1 + \left( \sum_{k=1}^{K} (1 - u_p^k) \tau^k \right)^2 + \frac{\alpha_{pse}^2}{(\sum_{k=1}^{K} u_p^k \tau^k)^2} - \frac{\alpha_{pse}^3}{(\sum_{k=1}^{K} u_p^k \tau^k)^3} \right)
  \]

Where:
- $\sigma = \{ \sigma_1, \sigma_2, \ldots \sigma_N \}$ – The set of traffic stream:
- $q = \{ q_1, q_2, \ldots q_N \}$ – The set of flow volume vectors
- $D_n$ – Matrix: n-signal group definition
- $E = \{ D_1, D_2, \ldots D_N \}$ – Set of control states
- $\tau = \{ \tau_1, \tau_2, \ldots \tau_N \}$ – Time vector for each control set
- $u(*) = [(u1 \tau_1)^T, (u2 \tau_2)^T, \ldots]$ – Set of controls, Signal plan – control variables determines used plan
  \[
  a_{pse}^1 = \frac{q_{pe} s_{pe}}{2(q_{pe} - s_{pe})}, \quad a_{pse}^2 = \frac{c^2 q_{pe}}{2s_{pe}} \quad a_{pse}^3 = \frac{c^3 q_{pe}}{s_{pe}}
  \]
CONCLUSION

The Intelligent Supervisor Layer embedded in ITS system is potentially able to offer many important ITS system integrated operational advantages. Through a knowledge generation and exploration, we can provides cohesive tool for handling a wide variety of knowledge-based system activities or support the activities in terms of similar to programming paradigms: rule-based, object-oriented and procedural. Developing this paradigms in intelligent supervisor and monitoring layer in ITS systems offer high improvements in the recognition of multi-criteria system activities preferences, representative information service to estimation and prediction problems and give professional recommendations to intelligent co-operation actions between different system layers conditioning very effective and productive of the ITS hierarchical system functionalities. The importance of the inter-layers intelligent interactions (i.e. interfaces between layers) in a crucial way determines the features of the whole system operation. Recently available technologies and wide-area intelligent network
analysis and management tools supported by high quality real-time information and knowledge availability creates new capabilities for ITS systems development and beneficial modifications.

Abstract
High complexity of the external interactions from the operational environment of ITS systems SupNet and internal demand-limited resources interactions determine the similar features of transportation processes, uncertainty, randomness, varied non-linear dynamic and users behaviour. The adequate recognition, diagnosis and prediction of the traffic situations is a crucial for implementation of efficient system activities. In this paper the proposal of dedicated ITS system option which explore the intelligent supervision layer for recognition of preference structure dedicated to multi-criteria traffic control method PIACON is presented. The upper ITS system layers based on control specifications recognize by AHP and LP methods the preference structure for representative data sources and communication systems but bottom layers based on traffic situational markers recognize by max-plus-algebra method the structure of preferences for multi-criteria traffic control and adequate compromise set for selection of control solutions by PIACON method. The illustrative examples confirm the high practical importance of proposed approach.

Inteligentne rozpoznawanie struktury preferencji dla wielokryterialnego zarządzania i sterowania ruchem w ramach ITS systemów

Streszczenie
Złożoność oddziaływań zewnętrznych z otoczenia operacyjnego ITS systemu SupNet oraz wewnętrznych wynikających z interakcji popytu z ograniczonością zasobów, determinują podobne cechy procesów transportowych, nieokreśloność, losowość, zróżnicowana nieliniowa dynamika i zachowania użytkowników. Właściwe rozpoznanie, diagnoza i predykcja sytuacji ruchowych ma więc kluczowe znaczenie dla określania efektywnych działań systemowych. W artykule zaproponowano dedykowaną opcję ITS systemu eksponującą warstwę inteligentnego nadzoru oraz wykorzystano ją dla rozpoznawania struktury preferencji dedykowanej dla metody PIACON wielokryterialnego sterowania ruchem drogowym. Górné warstwy ITS systemu w oparciu o specyfikację problemu sterowania wyznaczają przy pomocy metod AHP i PL preferencje dla reprezentatywnych źródeł danych i systemów łączności. Dolne warstwy w oparciu o markery sytuacji ruchowych rozpoznają przy pomocy metody max-plus-algebra strukturę preferencji dla wielokryterialnego sterowania oraz adekwatny zbiór kompromisów z którego będą wybierane sterowania przez metodę PIACON. Przykłady ilustrujące potwierdzają duże praktyczne znaczenie proponowanego podejścia.

REFERENCES