ADVANCED SYSTEMS ENGINEERING METHODOLOGY IN REGARD TO ITS EDUCATION

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Summary

The basic thesis of this paper and background research is that Systems Engineering represents a core methodological competence for transport and traffic professionals. Therefore, advanced Systems Engineering methodology has to be included in under-graduate and graduated education in the ITS (Intelligent Transport Systems) branch. A systemic framework for the definition and development of ITS solution is illustrated by the traffic dependent route guidance system. Further development of advanced complex system methodology is suggested. Since Systems Engineering is based in English it is possible to organize more easily the transfer of knowledge and student and academic staff mobility.

Key Words: *ITS education, Systems Engineering methodology, transfer of knowledge*

1. Introduction

The principles of transportation have been evolving for many millennia and at the beginning of 21st century the ITS paradigm is accepted as the new approach for solving the growing transport, traffic and logistic (TTL) problem. **[2]** Transport faculties have to be included in scientific research and innovation in transport system development and therefore students, academic staff and professionals should be qualified to define, develop and deploy ITS solutions. Basic methodological know-how includes Systems Engineering approach, methods and tools.

This paper reviews basic competences of ITS students as they are defined in the new *ITS and Logistics Curriculum* at the Faculty of Transport and Traffic Sciences at the University of Zagreb. A systemic framework for ITS development is illustrated by the example of dynamic route guidance system. **[3]**
Since ITS encompasses a large number of functional process, adequate functional classification is very important for effective and efficient development of ITS solutions.

2. Competence of completed under-graduate and graduate students

Basic competences defined in the proposed *ITS and Logistics Curriculum* are as follows **[5] [6]**:

a) For under-graduate studies

- Definition of ITS context and systems
- Identification of ITS functions and in transportation and logistics systems
- Explanation of the basic interactions between the components of intelligent network, infrastructure, intelligent vehicles and humans as components of the transportation system
- Explanation of logistics chains and purchase and supply management systems

- Application of the basic engineering knowledge of ITS and logistics systems modeling
- Explanation of connections between production, transportation and logistics process
- Statistically monitoring and adaptation of appropriate logistics services
- Analysis and design of pre-travel and travel information supply
- Identification of incident traffic situations
- Calculation of logistics capacities

b) For graduate students

- Strategic planning of ITS and its interfaces development
- Strategic planning of the logistics systems and processes
- Development and introduction of integrated ITS services
- Systems analysis and design of Dynamic Route Guidance
- Establishment of transportation and logistics chains
- Management of complex transportation and information processes
- Optimization of logistics processes
- Solving the problems of ITS physical, functional and institutional interoperability
- Creative implementation of the basic engineering knowledge in ITS and logistics
- Control of complex logistics processes
- Organization and consolidation of goods and information flows
- Organization of purchase and supply management systems

3. Definition of Systems Engineering

According to INCOSE Systems Engineering is a discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the user and stakeholders needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire life cycle. Systems Engineering is responsible for creating outputs and also a process for producing these outputs in concrete context. **[4]**

The systems engineers' outputs (products) are:

- Mission and concept statement
- Drawing of system boundaries
- Stakeholders requirements specification
- Description and classification of functions and objects
- Figures of merit
- Test plan
- Interface control document
- Listing of deliverables, models
- Sensitivity analysis
- Tradeoff study
- Risk analysis
- Life cycle analysis
- Description of physical architecture
- Description of logical architecture
- Description of institutional architecture.

The requirements should be validated and system functions should be mapped to the physical components. The mapping of ITS functions to physical components can be one to one or many to one. But if one function is assigned to two or more physical components, then a mistake might have been made and it should be investigated. One valid reason for assigning a function to more than one component would be that the function is preformed by one component in a certain mode and by another component in another mode. **[4]**

Figures of merit, technical performance measures and metrics are all used to assess performance of a system. Figures of merit are used to quantify user or stakeholder requirements in the tradeoff studies. They usually focus on the product or service. Technical performance measures are used to mitigate risk during design and manufacturing. Metrics (including user satisfaction comments, usability, number of problem reports, etc.) are used to help manage processes. Measurement and tradeoff of costs and performance is the key. The basic rule is that if you cannot measure it, you cannot control it. If you cannot control it, you cannot improve it.

Important resources such as volume, price, time, communications bandwidth and power consumption should be managed. Each subsystem is allocated a portion of the total budget and the project manger is allocated a reserve. These resource budgets are managed throughout the system life cycle which can be very long for infrastructure systems. **[2] [4]**

4. Systematic framework for development of ITS solutions

To display system methodology we can use concrete ITS applications such as anticipatory Dynamic Route Guidance system. Anticipatory quality means that the system estimates and predicts (expects) the current and future traffic conditions, and takes action to prepare for them. The anticipatory Dynamic Route Guidance system has to be realized as an integral part of broader transport and traffic network management system (as a separate functional area in ITS architecture). To achieve anticipatory quality, there are different approaches related to data, information and knowledge processing. It is very important for students and developers to distinguish between raw data and information which includes semantics and pragmatics. Centralized or decentralized architectures are possible. **[1] [3]**

A description of the purpose or top-level function is the starting point in the development process. The concept of operations must be defined and the most mandatory and preferred requirements must be identified.

Integrated solution for Dynamic Route Guidance should provide the following basic functionalities:

- Data collection (historical and real-time inputs)
- Estimation of traffic conditions,
- Predictions of network flow patterns (over the near and mid-terms),
- Routing information to drivers and trip makers.

The system continuously interacts with multiple sources of real-time information such as:

- Drivers
- Traffic (loop) detectors,
- Roadside sensors,
- Weather monitors,
- Vehicle probes, etc.

Basic input-output system description with functional and physical relations between components of anticipatory Dynamic Route Guidance system is represented in Fig. 1. Basic input includes static and real-time components. Outputs are provision of real-time driver information and anticipatory guidance solutions.

Users or drivers who receive guidance information may change their routes according to recommendations or follow specific behaviors related with aversion to switching routes, perceptual factors, etc. The quality of consistency will be achieved if the traffic behaviors which result from the drivers' reactions to it are the same or very similar to those which had been anticipated when generating them.

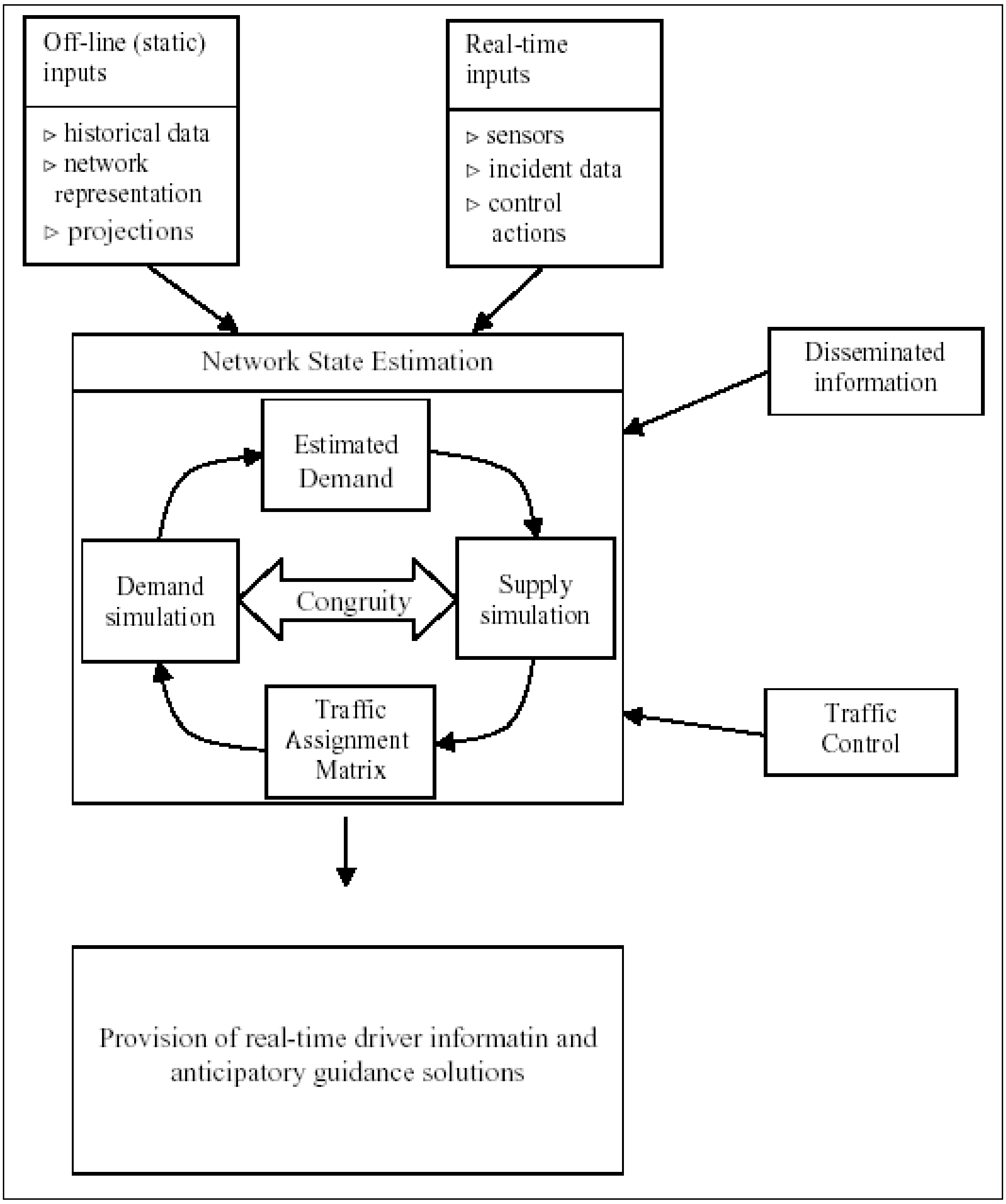

Fig. 1: *Basic framework for ITS application development*

Dynamic Route Guidance functionalities can be classified as shown on fig.2. It is an example of classical hierarchical decomposition of functions. Complex systems description also includes another type of decomposition. **[2]**

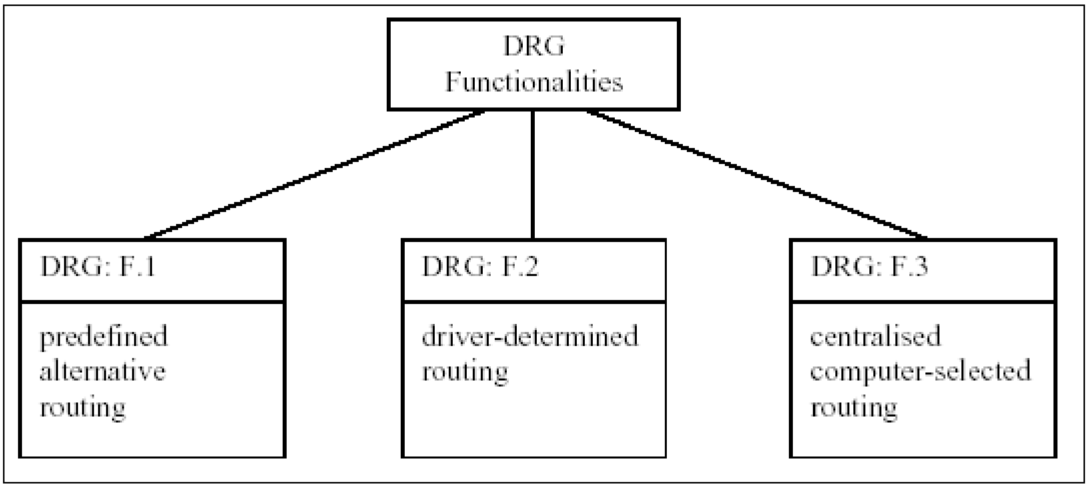

Fig. 2. *Classification of DRG functionalities*

Detailed illustration of development process is given in Bibliography. **[3] [7]**

5. Description of dynamic network behavior

Description of dynamic network behavior is a very complex task which requires a new methodological support. A new approach to solving complex problems must grow from problem reduction and minimization to inclusion of the problem totality. It includes classical hard optimization and new soft optimization systems concept and procedures.

Proposed methodology for solving a defined problem (example system of Dynamic Route Guidance) in real environment includes two categories of interrelated procedures:

1) Network assignment modeling
2) Traffic simulation modeling

with several associated support functions. **[1]**

Basic illustration of modeling framework is given on Figure 3.

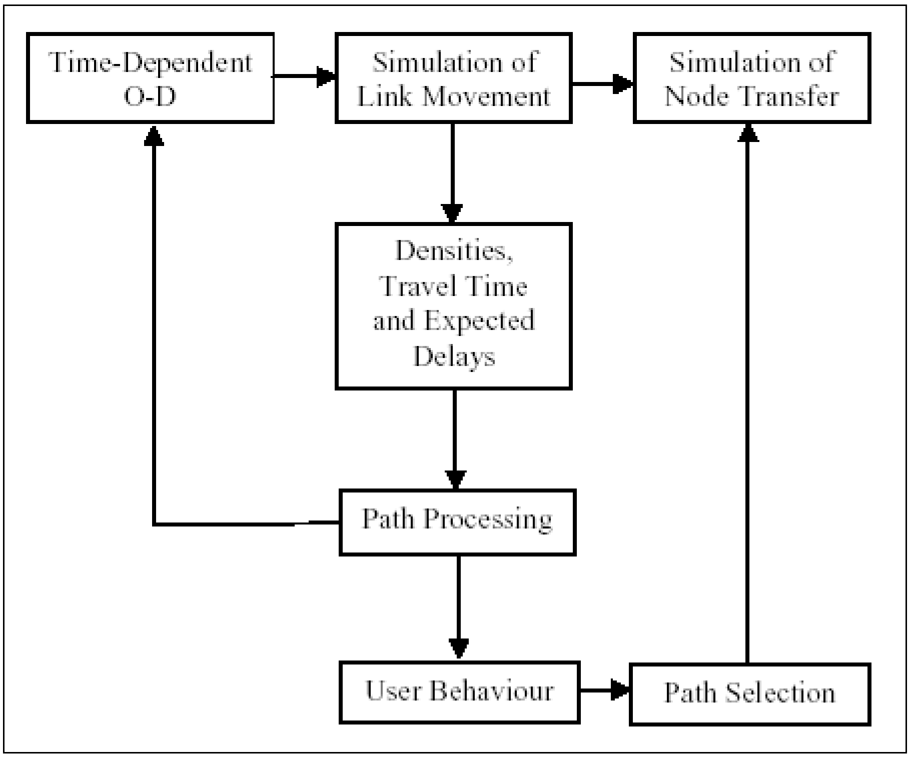

Fig. 3 *Example of DRG problem solving*

The adapted traffic simulation logic combines a microscopic level of representation of individual drivers with a macroscopic description of the interactions in traffic flows. In the simulation-assignment procedure, vehicles are generated according a time-dependent O-D matrix and assigned to routes according to specified rules. The simulation procedures take a time dependent loading pattern and process the movements of vehicles on links and the transfers between links/nodes according to specified control actions. The transfers between links require instructions (from TMC) that direct vehicles approaching the downstream node. User behavioral components represent individual trip-making decisions for path selection, both at the trip origin and en-route. **[1] [3]**

In real environment we can assume the set of local controllers distributed in the network where every controller extract only limited raw data from network detectors. The control rules have to be operational under different scenarios of spatial and temporal data availability. The *local area* is defined as the set of links and nodes with scope less than or equal to a pre-specified number *K*.

6. Conclusion

ITS is an important approach to solving the growing transport, traffic and logistic problems. Adequate Systems Engineering methodology is required for under-graduate and graduate level of education in ITS.

New complex Systems Engineering must grow from the problem reduction and minimization to design hard or soft optimization based on unified systems concept and models. Real experience suggests that ITS applications such as real time driver information and guidance systems require new methodological approach based on new *complex system methodology*.

Since complete Systems Engineering methodology is based on the English language, the new subject of Systems Engineering can represent a good basis for cooperation of transport faculties.

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Acronyms:

DRG - Dynamic Route Guidance
DTNA - Dynamic Traffic Network Assignment
ITS - Intelligent Transport Systems
TMC – Traffic Management Center