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STRAFF

...simulate traffic

Simulation of Traffic and Transportation Systems

White Paper

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1. Congestion in Europe [4]

Congestion has becoming a problem in Europe since the 90s and currently it threatens economic competitiveness in the continent. Paradoxically, congestion in the centre goes hand in hand with excessive isolation of the outlying regions, where there is a real need to improve links with central markets so as to ensure regional cohesion within the EU. In the 1993 White Paper a serious warning was made on growth, competitiveness and employment emphasizing that traffic jams are not only exasperating but they also cost Europe a lot in terms of productivity. As networks are crucial for markets and therefore competitiveness, the malfunction is reflected in lost opportunities to create new markets and hence in a level of creation of new workplaces.

Thus a serious risk of the lost of economic competitiveness of Europe arouses. The most recent study on the subject showed that the external costs of road traffic congestion alone amount to 0.5 % of Community GDP. Unless something is done, road congestion will increase significantly by 2010. The costs attributable to congestion will also increase by 142 % to reach EUR 80 billion a year, which is approximately 1 % of Community GDP.

Partially the problem comes from the fact that transport users do not always cover the costs they generate. The costs of infrastructure, congestion, environmental damage and accidents are not reflected in the price structure. Poor organization of Europe's transport system and failure to make optimum use of means of transport and new technologies is also one of the elements of the poor situation. Saturation on some major routes is partly the result of delays in completing trans-European network infrastructure. On the other hand, in outlying areas and enclaves where there is too little traffic to make new infrastructure viable, delay in providing infrastructure means that these regions cannot be properly linked in.

Since the mobility of people and goods seem only to increase, the problem of congestion will simultaneously increase with them and that will cause constant lost of money and time and unnecessary emissions.

2. Simulation of Traffic and Transportation Systems

Simulation as a method of imitation of operations in a real-world processes and systems can be used to describe and analyse the behaviour of an existing and conceptual systems especially in traffic and transportation. Hence this can also be a fruitful method for searching optimal solution by integrating with efficient algorithms and a part of a system supporting decision making.

The main purpose of STRAFF Working Group was to join the activities of organisations interested in this field and prepare a research in the area less isolated. Better co-ordination of work would help to generate a "critical mass" both in research and development as well as in applications.

The goals for this group were defined as[12]:

- to analyse which design and management problems of traffic can be addressed by simulation technology
- to survey state of the available technologies and their current application
- to promote the use of simulation and make potential users aware of its benefits
- to identify needs and options for future research and improved applications
- to stimulate RTD projects addressing the identified needs

3. Simulation of Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) describes any system or service that makes the movement of people or goods more efficient and economical, thus more "intelligent" [11]. ITS create new ways to provide necessary transport services for users. The new transport technology combines communications and information technology with transport, opening up new possibilities for the development of the transport system and logistics and for safe and sustainable transport and travelling. ITS services can significantly improve the performance and service ability of existing and new transport networks, and enable the realisation of new investments within the confines of the available resources. The benefits from ITS implementation in city infrastructure are shown on fig. 1.

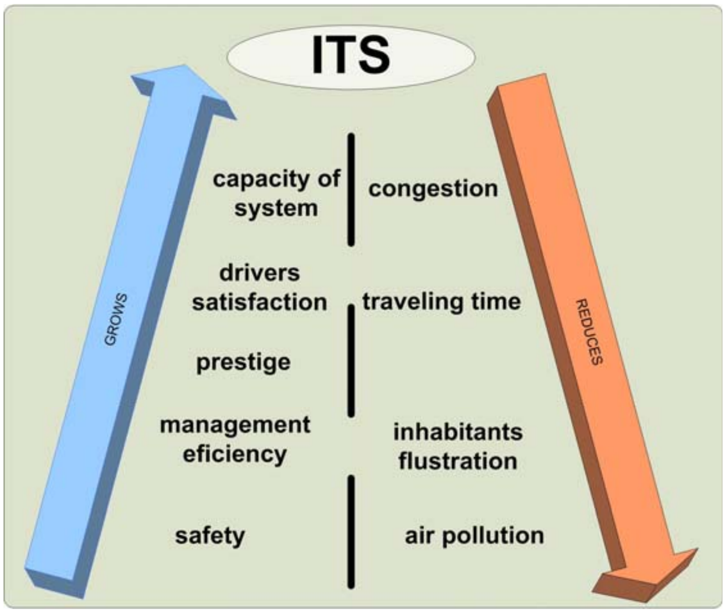

Fig. Benefits from ITS

As the ITS advantages are evident and confirmed of this technology in other fields such as the defense and aerospace industries it is strongly needed to quantify potential benefits prior to any major investment in development and deployment. The use of traffic simulation is regarded inevitable in this are, at present at least. Simulators are sufficient either to assess the benefits of ITS in a planning mode or to generate scenarios, optimize control, and predict network behavior at the operational level. Unfortunately comprehensive research tools for quantifying the expected benefits from ITS are either still absent or in their infancy[1].

Although a number of traffic simulators are currently under development, covering wide ranges of complexity, comprehensiveness, and potential usefulness, these simulators have to be closely calibrated and evaluated before their results can be locally applied. In this regard three major obstacles are encountered while researching the models[1]:

- the unavailability of a network/corridor of a manageable size and that is adequately instrumented with functioning vehicle detectors to supply the necessary data,
- the absence of a comprehensive test bed that is capable of modeling and testing a variety of ITS components and of acquiring real-time traffic data, and
- the unavailability of a non-limiting traffic simulator that is easy to use and yet capable of ITS modeling in a corridor/network environment of any realistic size. Non-limiting refers to being capable of handling large networks.

The prime objective of traffic simulators to be used within an ITS context is when they are to serve as tools for dynamic transport management. More specifically, simulators can play two distinct roles:

- as an off-line evaluation/ design tool,
- as an on-line control/guidance tool.

Both roles mentioned above are described in paper[1] in contexts of numerous ATMIS applications which functionality covers: provision of traveler information and route guidance, a wide variety of surface street and freeway adaptive control (adaptive signal control, adaptive ramp metering, lane use control, etc.), incident detection and management, automated toll collection, and assessment of environmental impact of transport design and management, to name but a few. The off-line role is the easier one in comparison to the on-line. Simulators which are fast enough could be used for both functions - off-line and on-line.

Centralized management seems necessary to ensure proper functioning of transportation networks. This is due to dynamic nature of this networks relative to supply, performance and demand. Given such centralized management unexpected events can be handled more efficiently. It may also lead to a greater motivation of drivers to change their behavior. For example, they may adjust their routes - within the day, or from day to day. Similarly they may adjust departure times in response to the dynamically changing supply conditions. Any simulator to be useful for dynamic transport management, it should be capable of [1]:

- Capturing the dynamics of supply, in terms of the detailed configuration of the transportation network and its performance in response to demands and Transportation Management Center (TMC) control functions implementation.
- Capturing the dynamics of demand, in terms of dynamic user behavior in response to observed supply, either directly or via traveler information systems.
- Capturing the complex dynamic interaction between supply and demand.
- Performing faster than real-time to allow for proactive (based on predicted conditions) rather than reactive (based on observed conditions) dynamic transport management.

4. Traffic Simulation Approaches

4.1. Discrete event simulation

Fig. Discrete Event model of Wroclaw City Center [source: CAMT]

Discrete-event simulation supports hierarchical modular model construction, distributed execution, and therefore affords a basis to characterize complex, large-scale systems using formulation of components and their interactions. It is used to simulate components which normally operate at a higher level of abstraction than components simulated by continuous simulators. Within the context of discrete-event simulation, an event is defined as an incident which causes the system to change its state in some way - a new event is created whenever a simulation component generates output. A succession of these events provide an effective dynamic model of the system being simulated. The events in a discrete-event simulator can occur only during a distinct unit of time during the simulation - events are not permitted to occur in between time units. This feature of discrete-event simulation separates it from continuous simulation which is generally less popular in traffic simulation because it is usually slower and does not provide a reasonably accurate approximation of a system's behavior, especially, flowing elements.

4.2. Microscopic simulation

Microscopic simulation is the technique which provides a realistic measure of traffic flow on a network as well as the variety of type and number of vehicles. In the past describing the traffic was possible using macroscopic approach which perceived the traffic as a fluid flowing along the carriageway. Microscopic approach allows to study the traffic flow by modeling the motion of a particular vehicle. The mathematical models used in it are called car following models.

Since each vehicle could be autonomous, the realism of each vehicle’s behavior could correspond to the geometry of the road network as well as each vehicle’s and its driver’s behavior could be determined by individual set of mathematical rules according to its type. Car-following and overtaking as well as driver’s awareness and aggressiveness could be modeled in this way. The crucial aspect of any microscopic simulation model is a calibration of parameters describing vehicles and the environment.

4.3. Agent based simulation

Agent based approaches are widely used in network applications and they are currently one of the most attractive and rapidly evolving software technologies. An agent concept is used to describe the concept of an entity that automates some tasks. It emerged from a specialized class of distributed artificial intelligence. Agents can be perceived as autonomous, proactive and reactive entities that can exhibit the ability to learn, co-operate and move. In order to use agents in traffic simulation, agents must be able to migrate from node to node in network and interact with their environment. Agent-based solutions are suitable for management of transportation systems with logic embedded to its elements.

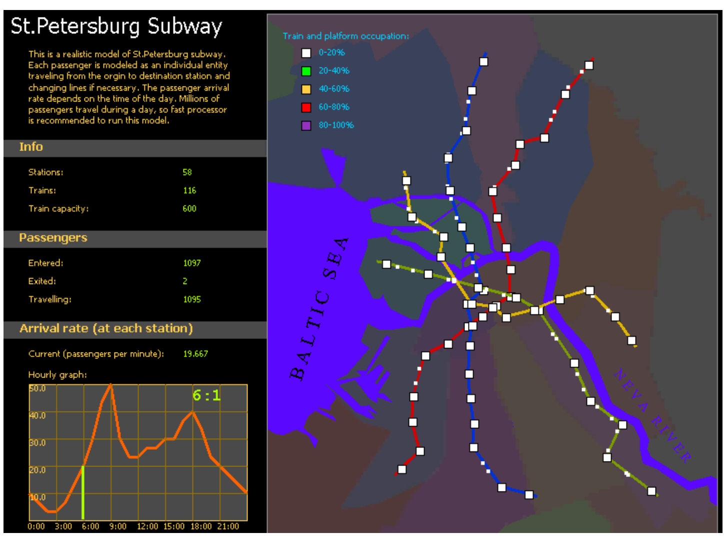

Fig. Agent based model of St. Petersburg [13]

4.4. Cellular automata simulation

First cellular automata (CA) was developed in the 1940 as a simple spatial processing model in the early architecture of digital computers.

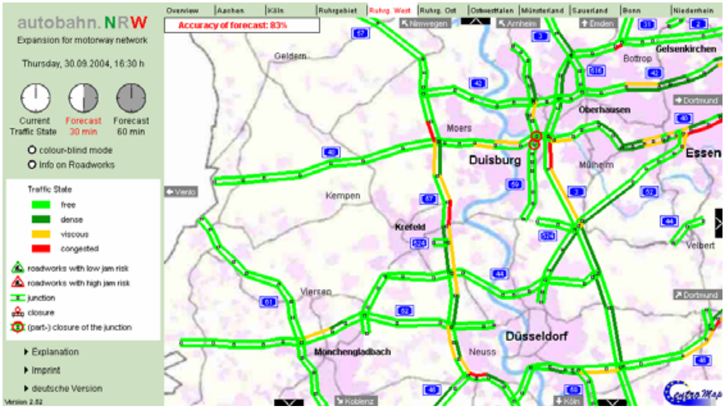

Fig. Cellular Automata simulation model of Westphalia [source: Duisburg Essen University] [12]

CA is associated with complexity theory and has been used to investigate ideas about operation of real urban systems from a controlled experimental environment within computer software. Urban applications of CA range from traffic simulation and regional-scale urbanization to land-use dynamics, historical urbanization, and urban development. Models of CA are conceptually simple and therefore can use a set of simple CA rules to produce complex behavior, e.g. interacting traffic pattern behavior. Cellular Automata is useful in simulating of complex and adaptive systems such as people movement and traffic flow.

4.5. Generalized Nets

Generalized Nets (GNs) as the extensions of Petri nets was developed by Krassimir Atanassov. GNs model provides a simple graphical representation of hybrid systems and takes advantage of the modular structure of the nets in giving a compact description of the system which is characterized by their static structure, dynamic elements, global temporal components and memory. Because of specificity of this approach it will be described in a special white paper.

4.6. Parallel traffic simulation

Solving real problems requires complex model containing many details of real world. When the different simulation approaches gave opportunity to match the problem, the computation time is often to long. In such situation parallel simulation is recommended. Its aim is an application of parallel computing techniques in order to decrease the computation time by engaging different processors of a multiprocessor system or different computers of a network[3]. The method involves dividing the network into regions and simulating each region under a separate instance of the program. Suitable interprocess communication techniques are employed to exchange data between different regions and synchronize time among the different regions.

5. CASE STUDIES – REVIEW

5.1. Street Pollution Modelling [1]

Street pollution modeling covered the microscopic traffic simulation model and the traffic simulation. The former was used to predict the special pollution distribution within a street, while the latter to model the flow of vehicles in realistic traffic conditions on a real road network. This produces details of the amount of pollutant produced by each vehicle at any given time. The integration of individual components provides a practical street canyon pollution model which simultaneously gives isoconcentrations of pollutant within the road topography.

5.2. Determining The Number Of Servers In Situations With Peaks [7]

The aim of the study of the system was to make it work under different configurations of the service stations which were needed to cope with the peaks and the following are: firstly, to search for the satisfying alternatives (in order to obtain that a set of constant flow simulations was run), secondly, to obtain the optimum alternative (and in order to obtain that the model was run with real flows). For its best results, the presentation, based on standard queuing theory terminology, includes the example of a design of a pay toll booth in a highway with the highly seasonal incoming traffic

In order to design systems that suffer short periods of very high peaks a methodology was presented based on both queuing theory and simulation modeling which uses a five-step procedure that includes obtaining the input flow and the service time distributions, a simulation model that is run both with constant and real flows and a double-graph summary tool.

The successfulness of the double simulation seems to be immediately proven as the time spent in running the model was very small compared to the time spent in collecting the data and developing the model. After the validation of the model, it was used for a thorough experimentation and finally led to a strong-based conclusion.

Thus to validate the methodology, a real-life example of a paytoll system in a highway is put forward. The limits on the number of booths are set quickly and the simulation runs help to make the final decision. Therefore, the combination of experimentation via simulation models with quantitative queuing analysis has been proven as an interesting tool to treat situations with peaks that incorporates both management input and intensive collection of data.

5.3. Process Simulation Approach To Design And Evaluation Of Toll Plaza With Etc Gates [9]

The paper referring to an overview of ETC system aims at showing a process simulation-based approach to traffic jams in toll plaza of expressways with ETC gates. Firstly, the article clarifies the issue of traffic jams in toll plaza of Japanese expressways and prohibits the process of ETC system. Secondly, it presents the process simulation model developed in this study as well its internal procedures as far as simulation of the traffic jams are concerned. The result of simulation provides two kinds of solution to traffic jam issues. One is to determine the appropriate time in gate change for combination gates while the other is to study the layout redesign of toll plaza to achieve more efficient performance. Using the result of simulation, feasibility of the approach will be discussed. Since the goal of the study is to propose a practical solution to the traffic jam issues which prohibits the progress of ETC system, this paper also shows the results of simulation of a case study and discusses what the simulation-based approach can provide.

This paper describes the overview of ETC system in Japan, and points out critical issues of traffic jams around expressway toll plaza to be solved to achieve the better performance of toll gates with ETC system. Simultaneously the article presents the process simulation-based approach, describing the definition and internal procedures, and presented some result of process simulation to analyze the traffic jams which occur in toll plaza of expressways with ETC gates. The paper also shows that the model developed in this study can support estimation of appropriate time in gate change in combination gate, and also consideration of layout redesign of toll plaza to achieve better performance. Since the goal of the study is to propose a practical solution to the traffic jam issue which prohibits the progress of ETC system, this paper also shows the results of simulation of a case study and presents what the simulation-based approach can provide. Conducting much more case studies in actual toll plaza, we would like to work on further studies to increase the quality of the model, and to propose more practical solutions to enhance the progress of ETC systems.

5.4. *Urban Traffic Modeling* [5]

Urban traffic simulation model based on Nagel-Schreckenberg's cellular automata model (NaSch model) and its modification is presented in the article. Although these NaSch models have been constructed for simulation of traffic on highways and freeways, they have tried to modify this approach to obtain a model of urban traffic. The development is based on an object oriented approach.

The designed model is based on the Nagel-Schreckenberg cellular automata model with VDR and anticipation that have been tested several times in other projects or smaller research works. Thus there is certainty that the simulation based on this model is close to reality. The solution of crossroad dynamics is one of the most detailed that is used in cellular automata models and at the same time it allows a very simply way to pass the vehicles through the crossroad. It involves a possibility of changing the inner dynamics by changing the permitted directions on the crossroad or simply the addition of any new testing of other interesting features during passage through the places at the crossroad. The leading head algorithm is an easy and flexible way showing how to move vehicles through and between segments. The crossroad, the road and the roundabout are mostly the same for this algorithm. Finally, it should be noticed that the main goal of the designed model is to make an easily extendable one for big applications that will be able to configure the simulation automatically from the urban traffic data that is obtained from city measurements.

5.5. *Applications Of Gns For Transport Processes Modeling*

The GNs in the modeling of the public transport

The public transport has been modelled by means of the Generalized Nets. The notion "A transport system" referes to the set consisting of a transport net in a given unbanized region, all vehicles and passengers, and other active or passive participants in the public traffic of the same region. A transport net is characterized by its geometry, topology and organization. Its aim is to realise vehicle or pedestrian connection between all points which are to be connected in a given region. The transport nets involving public transport (busses, trams, trolley-busses etc.) has been described by using GNs.

GN-models of international transport

For the international transport market is a complicated dynamical system developing under the influence of a number of factors, its study is connected with creating different models which give a visual aspect of the processes and afterwards make it possible to determine the ways of improving them in practice. The modelling concerns the activities of the forwarding agent and the transporting firm. The GN-models could be used not only for simulation of concrete processes, but also for management (in combination with expert systems) and control in real time.

5.6. *Simulation Of Turning Rates In Traffic Systems* [6]

Although certain variables of dynamic system cannot be measured they, however, play an important role for control system strategies thus in such a situation the approximation, computer based simulation of these variables could be useful for further techniques. Using a certain knowledge of some estimation methods which can determine the traffic flow in a traffic network, the simulation of the turning rates can be made. The paper treats the simulation of split rates in the traffic systems modeled in terms of linear time varying system using different filtering approaches. Three methods for simulation of turning rates in a basic traffic network is suggested in the paper. First the unconstrained Kalman filtering, and second the algorithm that has been developed for traffic systems and based on the unconstrained and constrained Moving Horizon Estimation(MHE). The constrained MHE problem for traffic systems is modeled in terms of linear time varying system and solves the split rate estimation process. The estimation is subjected to equality and inequality constraints. A numerical example is chosen to demonstrate the Moving Horizon Estimation of split variables.

The article summarizes the Moving Horizon Estimation approach for a simple traffic system i.e. an intersection. In traffic engineering the estimation of split variables is significant for further optimal traffic light control strategies. The MHE optimal estimation method shows a possible way for including constraints into the design procedure. One could possibly extend the state estimation, based on MHE algorithm with some additional constraints in inequality form on states, noise or other variables. the good approximation of arrival cost. What influences the performance of the estimation is the selection of weighting matrices and estimation horizon. A numerous examples have been shown to demonstrate how to apply the Moving Horizon technique to split rate observation. The general MHE technique could be applied to nonlinear processes which will be in the focus of our traffic system estimation research.

5.7. *A Framework Combining Cellular Automata and Multi-Agents in a Unified Simulation System for Crowd Control* [8]

Controlling crowds in airports, train terminals, sporting events, etc. is a complex problem. This problem has a great deal of interaction between the entities and the crowd with the environment in which the crowd is placed. The complexity of this system can be described in the researched area of artificial life. By combining Cellular Automata (CA) with agents, they can construct a system to capture and control the ebb and flow of a crowd, including the particular characteristics of the individuals in it. Prototype crowd control simulation system have been developed as a test case for this sort of problem. The imbedded CA provides a framework for flow of people, much like traffic models, while the agent reproduces the behavior of a crowd, including subgroup behaviors, interactions, stochastic decisions of single units, etc.

The study demonstrates the effectiveness of modeling public facilities using both Cellular automata (more basic/complex moving rules) and agents (for behavior attributes) to improve services in a museum setting. Clearly this framework is extendable to model many events, such as sporting events, shopping malls, rail stations, airports, etc. Additionally, this framework may be applicable to other complex systems such as network reliability, supply chain management, and management logistics.

5.8. *Biologically Inspired Discrete Event Network Modeling* [10]

This paper describes a biologically inspired discrete-event modeling approach for simulating networks. It introduces a synergistic modeling approach by incorporating key attributes of honeybees and their societal properties into a set of simulation models described in the Discrete Event System Specification. Particular emphasis is given to the model of the behavior of the honeybees and their cooperation as discrete event models. The simulation models and their experimental results are presented and discussed.

This paper proposed a discrete-event modeling approach for networks. The models are devised based on biologically-inspired routing mechanisms to tackle the scalability aspect of large-scale networks. The approach and its implementation are promising for handling models composed of hundreds to thousands of components. The routing strategy, which is based on the behavior of beehives, is robust and exhibits similar or better performance compared to the contemporary routing RIP technique. This research suggests that the proposed modeling approach can be used for the design and development of robust and scalable network systems.

6. Summary

Simulation methods of imitation of operations in a real-world processes and systems can provide an important knowledge based on experiments of an existing and conceptual systems, especially in traffic and transportation. By integration simulation tools both with data sources and tool propagating data from simulators it becomes a useful tool in transport management - a tool supporting decision making in transport centres. The effectiveness of different simulations approaches are proved by many projects realised by different organisation. After all, the improving further effectiveness of simulation needs integration. According to traffic simulation approaches it is needed to join different methods. However many information were collected, it is still without answer how to make the simulation popular and common tool in decision making processes and concepts evaluation.

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