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A Critical Review on the Development of Urban Traffic Models & Control Systems

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Abstract— Modeling and development of control systems to deal with the congestion at intersection in urban traffic is a critical research issue. Several approaches have been used to develop the modeling and controlling phenomenon in the said problem. These approaches include, Petri net, Fuzzy Logic, Neural Network, Genetic Algorithms, Activity Theory, Multi Agent Systems and many more. This paper is a survey on the development of Urban Traffic Control Systems using techniques discussed above in the last decade.

Index Terms— Fuzzy Logic, Neural Network, Genetic Algorithms, Multi Agent Systems, Activity Theory, Petri Nets.

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1 Introduction

The development of control systems to deal with the congestion at the intersection in urban traffic is a critical research issue. The prime requirements of the developed system are, the signal must not allow the ambiguous movement to the traffic and it must be clear that how/when the indication of signal shown to be changed. Two other aspects to be handled are to take decisions about signal indication sequence in the control system to make the system well optimized and development of control logic for signal generation.

This paper has been divided into 6 subsections. In section 2, Petri net based modeling has been studied and revised. Section 3 contains the review of multi-agent systems in urban traffic control systems. Neural Network based approaches are discussed in Section 4. Section 5 contains the fuzzy logic based approaches in Traffic Control Systems. Several hybrid approaches of fuzzy logic, neural network, petri nets are discussed in section 6. Section 7 contains various other approaches for the traffic control systems, like activity theory, complex network theory, incident and real time traffic control etc.

2 Petri Net Model Based Approaches

Petri Nets [1] are also known as a place/Transition Net or P/T net. It is the mathematical modeling language for the description of Discrete Event Systems (DES). PN theory is developed in 1962 by Carie Asam Petri. These are highly applicable in graphical modeling, Mathematical modeling, simulation and real time control by the use of places and transitions.

Different variations of the Petri Nets are applied in the modeling and control of traffic systems.

A Colored Timed Petri net (CTPN) model has been used for validating a Urban Traffic Network in [2].

A model for real time control of urban traffic networks is proposed in [3]. A modular framework based on first order hybrid Petri nets model is developed. The vehicle flows by a first order fluid approximation, in this approach. The lane interruptions and the signal timing plan controlling the area are developed by the discrete event dynamics integrated with timed Petri nets.

A new hybrid Petri net model for modeling the traffic behavior at intersection is developed in [4]. The important aspects of the flow dynamics in urban networks are interpreted very well.

A new approach of continuous Petri nets with variable speed (VCPN) is proposed in [5]. The analysis and control design in urban and interurban networks is done.

A network model via hybrid Petri nets [6] is used to demonstrate and implement the solution of the problem of coordinating several traffic lights. It aims the improvement in the performance of some classes of special vehicles, like public and emergency vehicles.

A model of TCPN (Timed Control Petri Nets) is used to demonstrate and solve the problem of coordinating several traffic lights in [7]. The analysis of the control TCPN models is done by Occurrence Graphs (OG) techniques.

A Colored Petri Net Model of an urban traffic network for the purpose of performance evaluation is demonstrated in [8]. The subnets for the network, the intersections, the external traffic inputs and control are discussed.

A Urban Traffic Simulation has been done using petri net in [9]. This approach is based on generating producer consumer network and grid simulation of petri nets.

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3 Multi Agent Systems

A multi-agent system (MAS) [10] is a system consists of multiple interacting intelligent agents. Multi-agent systems can be used to solve problems that are possible to be difficult or impossible for an individual agent or a monolithic system to solve. Intelligence may include few methodic, functional, procedural and algorithmic searching, finding and processing techniques.

A multi agent system approach to develop distributed unsupervised traffic responsive signal control models, has been developed in [11]. Each agent in the system is a local traffic signal controller for one intersection in the traffic network. The first multi agent system is identified using hybrid soft computing techniques. Each agent employs a multistage online learning process to update and adapt its knowledge base and decision-making procedure. The second multi agent system is produced by integrating the simultaneous perturbation stochastic approximation theorem in fuzzy extended neural networks (NN).

An approach to model the traffic of an important crossroad in Mashhad city using intelligent elements in a multi-agent environment and a large amount of real data, has been developed in [12]. The overall traffic behavior at the intersection was first modeled by the Bayesian networks structures. Also, the probabilistic causal networks are used to model the effective factors.

Among the several ITS applications is the notion of Dynamic Traffic Routing (DTR), which involves generating "optimal" routing recommendations to drivers with the aim of maximizing network utilizing. In [13], it has been presented that the feasibility of using a self-learning intelligent agent to solve the DTR problem to achieve traffic user equilibrium in a transportation network. The agent then learns by itself by interacting with the simulation model. Once the agent reaches a satisfactory level of performance, it can then be deployed to the real-world, where it would continue to learn how to refine its control policies over time.

The integration of cooperative, distributed multi-agent system to improve urban traffic control system is proposed in [14]. Real-time control over the urban traffic network is done through an agent-based distributed hierarchy traffic control system. This system cooperates with dynamic route guidance system. Cooperative system framework and agent structure are discussed in this work.

A new framework of hybrid control system for UTC is presented in [15], in which any optimal control strategy can be adopted. By the interface D-S and interface C-S namely cooperation model, the hybrid system of UTC is divided into three layers including digital control loop, discrete event module, and Group Decision-making Support System (GDSS). By integrating GDSS consisted of central agent and intersection agents, real time control and coordinate control with the characteristics of self-decision, cooperation, and intelligence are implemented.

An approach of modeling the urban traffic flow system is discovered for combining the global and local model information for the whole city net in [16]. It is assumed that traffic digraph consists of several nodes and those nodes are linked with routes lines. The proposed system uses the random walk theory. Vehicle flow density and driver strategy independence are also the important factors in this approach.

An agent-based approach to model the individual driver behavior under the influence of real-time traffic information is proposed in [17]. The driver behaviour models developed in this work are based on a behavioural survey of drivers. This survey was conducted on a congested commuting corridor in Brisbane, Australia. Based on the results obtained from the behavioural survey, the agent behaviour parameters which define driver characteristics, knowledge and preferences were identified and their values determined.

4 Neural Network Based Approaches

An artificial neuron is a computational model inspired in the natural neurons. Natural neurons receive signals through synapses located on the dendrites or membrane of the neuron. When the signals received are strong enough (surpass a certain threshold), the neuron is activated and emits a signal though the axon. This signal might be sent to another synapse, and might activate other neurons. The network developed on this theory in called Artificial Neural Network (ANN) [18]. The ANNs are highly applicable in the design of models for traffic control systems.

An intelligent model consists of two levels of neural network [19] for the traffic control system. The first level is a traffic flow neural network model to predict the traffic flow changes in road tunnel, the result of predicting will be used as an input of the second level neural network which is used to describe an intelligent model of urban road ventilation system, through the different states of predicted traffic flow, to establish an intelligent model of urban road tunnel ventilation system based on multi-level neural network.

A neural network model is proposed for forecasting crossroads traffic flow using back propagation (BP) neural network in [20]. The work gives a new reliable and effective way of forecasting short term traffic flow of crossroads in urban road network.

A commonly used macroscopic dynamic deterministic traffic flow model for traffic control is analyzed in [21]. The neural network model for the urban expressway traffic flow is established and the urban expressway multi-variable neural control strategy with both the on-ramp control and the road speeds control is implemented.

MTL (Multi Task Learning) based neural networks are used for traffic flow forecasting in [22]. For neural network MTL, a back propagation (BP) network is discovered by incorporating traffic flows at several contiguous time instants into an output layer. Nodes in the output layer can be seen as outputs of different but closely related STL tasks.

A back propagation artificial neural network model, which utilizes the characteristics of urban signalized intersections for occurrence prediction of intersection - related traffic crashes, along with its application for crash reduction, are proposed in [23]. With the ANN model, a proposed decision-making scheme for intersection rehabilitation was suggested.

A commonly used macroscopic dynamic deterministic traffic flow model is analyzed in [24]. The 1.5-layer feed-forward network modeling for the urban expressway traffic flow is implemented.

A novel intelligent identification method is proposed in [25] to reduce the computation cost and to improve the identification rate. The proposed method combines principal component analysis (PCA) method with higher-order Boltzmann machine (BM). PCA is applied to reduce the dimension of input feature space. It can not only reduce the computation cost but also filter noise of the source data. BM is a kind of stochastic network that is used to get the global optimum solution. Higher-order BM without hidden units can save lots of computation cost without decreasing modeling power. The trained higher-order BM is used to identify traffic state.

Short-term forecasting of traffic parameters such as flow and occupancy is an essential element of modern Intelligent Transportation Systems research and practice. An advanced, genetic algorithm based, multilayered structural optimization strategy that can help both in the proper representation of traffic flow data with temporal and spatial characteristics is presented in [26]. After that, it evaluates the performance of the developed network by applying it to both univariate and multivariate traffic flow data from an urban signalized arterial.

5 Fuzzy Control Approaches

Fuzzy logic [27] is a form of many-valued logic; it deals with reasoning that is approximate rather than fixed and exact. In contrast with traditional logic theory, where binary sets have two-valued logic: true or false, fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy Logic Theory is highly applicable in the design strategies for modeling traffic control systems.

The coordination of Urban Traffic Flow Guidance System (UTFGS) and Urban Traffic Control System (UTCS) can give decision support to navigation and signal timing at the same time. It realizes basic information sharing and to get the optimal results from the point of system integration. A combined model of traffic assignment and signal control is presented in [28], with the object to minimize congestion degree both at links and intersections. To avoid the complexity and difficulties in solving the optimal model, a fuzzy control algorithm is put forward, the input collected traffic data is described. Then the fuzzy control rules are listed in table to get the optimal link volumes.

The automated urban traffic control systems [29] are based on deterministic algorithms. They have a multi-level architecture. To achieve global optimality, hierarchical control algorithms are generally employed. An alternative approach is to use a fully distributed architecture in which there is effectively only one (low) level of control. These systems are aimed at increasing the response time of the controller and, again, these often incorporate computational intelligence techniques.

A new route choice model taking account of the imprecision and the uncertainties lying in the dynamic choice process is proposed in [30]. This model makes possible a more accurate description of the process than those (deterministic or stochastic) used in the literature. It is assumed that drivers choose a path all the more than it is foreseen to have a lesser cost. The predicted cost for each path is modeled by a fuzzy subset which can represent imprecision on network knowledge (e.g. length of links) as well as uncertainty on traffic conditions (e.g. congested or uncongested network, incident).

6 Hybrid Approaches

Sometimes, the approaches like, neural network fuzzy logic, petri net are hybridized to develop the model for urban traffic control systems.

A hybrid model for single point short term traffic flow forecasting in an urban traffic network is proposed in [31]. The hybrid model consists of two main modules: a fuzzy input fuzzy output filter (FIFO-filter) and a multi-layer feed-forward artificial neural network architecture optimized using evolution strategies (MLFN-ES). The FIFO-filter does the data clustering operation and results in a rough forecasted prediction value based on the input data to the MLFN-ES associated with each cluster for modeling the input–output relation to provide accurate short term forecast value.

A hybrid adaptive model, based on a combination of colored Petri nets, fuzzy logic and learning automata has been studied in [32].

An original method using high level petri nets for the specification and design of interactive systems is presented in [33]. An agent oriented architecture based on the classic components of an interactive application (application, dialogue control, and interface with the application) is demonstrated.

An approach of intelligent urban traffic control is developed in [34], using the neuro-genetic petri net approach. In this approach genetic algorithm is used to provide dynamic change of weight for faster learning and converging of neuro-petri nets.

7 Other Approaches

7.1 Incident based traffic jam

Effective control strategies are required to disperse incident based traffic jams in urban networks. In [35], such a control strategy has been developed and their effectiveness in dispersing incident-based traffic jams in two-way rectangular grid networks is presented. The spatial topology of traffic jam is proposed for propagation, the concept of vehicle movement ban is implemented, which is frequently adopted in real urban networks as a temporary traffic management measure.

7.2 Real time Traffic Control

A vehicle routing problem in dynamic urban traffic network with real-time traffic information is presented in [36]. Both re-current and non-recurrent congestion are handled in the problem. A method to solve the problem by combining the initial routes arrangement with the real-time route adjustment has been implemented. The genetic algorithm is also integrated in this work.

The prediction of traffic situations is a vital issue in modern Intelligent Transport Systems (ITS). A situational algorithm of real time traffic is proposed in [37].

7.3 Survey Work

Urban transportation system consists of surface-way networks, freeway networks, and ramps with a mixed traffic flow of vehicles, bicycles, and pedestrians. In [38], a survey has been carried out for control and management of recurrent and non-recurrent congestion in traffic network using computational intelligence techniques.

7.4 Optimization Complex Network Theory

The three factors are important for tuning the network traffic system: (i) the topology of underlying infrastructure; (ii) the distribution of traffic resources; (iii) the routing strategy. The optimization of network capacity based on complex network theory is done in [39]. The optimization method of network traffic in several situations corresponding to the real cases has been studied, also.

7.5 Dijkestra Algorithm

Route network model, construction of route network database and optimization route algorithm has been studied in [40]. Theurban route network model, which includes direction, crossing delay and restraint of urban traffic is introduced. The resolution to optimization route of turning delay and restraint is presented based on improved Dijkstra algorithm and programs the algorithm.

7.6 Model Based

Some advanced model-based control methods for intelligent traffic networks are discussed in [41]. Specifically, we consider model predictive control (MPC) of integrated freeway and urban traffic networks. The basic principles of MPC are presented for traffic control including prediction models, control objectives, and constraints. The proposed MPC control approach is modular, allowing the easy substitution of prediction models and the addition of extra control measures or the extension of the network.

7.7 Other developments for UTCS approaches

The mathematical model was formulated in [42] to describe the effectiveness of traffic jams information under the assumption of simple network and linear cost function. The impact of traffic congestion information on congestion propagation was discovered by using two models namely stochastic and deterministic user equilibrium assignment.

In [43], the problem of efficiently collecting and disseminating traffic information in an urban setting is discovered. The traffic data acquisition problem and explore solutions in the mobile sensor network domain while considering realistic application requirements is formulated.

In the last decade, economic approaches based on computational markets have been proposed as a paradigm for the design and control of complex socio-technical systems, such as urban road traffic systems. The control problem of an urban road traffic system can be modeled as a distributed resource-allocation problem to apply market-based techniques as solution methods. A competitive computational market is designed in [44], where driver agents trade the use of the capacity inside the intersections with intersection manager agents.

Traffic congestion in urban road and freeway networks leads to a strong degradation of the network infrastructure and accordingly reduced throughput, which can be countered via suitable control measures and strategies. A comprehensive overview of proposed and implemented control strategies is provided for three areas: urban road networks, freeway networks, and route guidance has been discussed in [45].

The automation of highways as part of the intelligent vehicle highway system (IVHS) program is seen as a way to alleviate congestion on urban highways. The concept of lane assignment in the context of automated highway systems (AHS) is discussed in [46]. Lane assignments represent the scheduling of the path taken by the vehicle once it enters an automated multilane corridor. The classification of lane assignment strategies is developed into non-partitioned (totally unconstrained, general, and constant lane) and partitioned (destination monotone, origin monotone, and monotone) strategies. An optimization problem is also formulated with the performance criterion being a combination of travel time and manoeuvre costs.

A congestion propagation model of urban network traffic is proposed in [47] based on the cell transmission model (CTM). The proposed model includes a link model, which describes flow propagation on links, and a node model, which represents link-to-link flow propagation. A new method of estimating average journey velocity (AJV) of both link and network is developed to identify network congestion bottlenecks. A numerical example is studied in Sioux Falls urban traffic network.

Intelligent transportation systems (ITS) is effective on solving the problem of traffic jam in cities. Prediction of crossroads' traffic volume is the key technology in ITS. In [48], BP neural network is universally used in prediction of crossroads' traffic volume.

In reality, the individual's day-to-day route choice behavior is a long-time evolution process, and travelers choose their traveling routes according to the combination of historical experience and real-time traffic information. Considering two classes of users, one equipped with advanced traveler information systems (ATIS) and the other without, the travel efficiency under two different information feedback strategies, namely, travel time feedback strategy and mean velocity feedback strategy, has been investigated in [49].

A discrete-time, link-based dynamic user-optimal route choice problem using the variational inequality approach is formulated in [50]. The proposed model complies with the dynamic user-optimal equilibrium condition in which for each origin-destination pair, the actual travel time experienced by travelers departing during the same interval is equal and minimal.

7.8 Activity Theory Based

Activity Theory is more of a descriptive meta-theory or framework than a predictive theory. It considers entire work/activity system that includes teams, organizations, etc., beyond just one actor or user and accounts for environment, history of the person, culture, role of the artifact, motivations, complexity of real life action, etc.

A conceptual activity-based and time-dependent traffic assignment model is proposed in [51]. The temporal utility profiles of activities are employed to formulate the temporal activity choice behavior of individuals as a multinomial logic model. Route choice behavior is then described as the ideal dynamic user equilibrium condition.

A model for urban traffic control has been proposed in [52], which integrates the model driven engineering and activity theory. It is also extended with fuzzy logic to deal with issues of uncertainty.

Conclusion & Future Scope

The development of models and control systems for Urban Traffic is an important research issue. Several problems and research issues have been identified in this field. To deal with these issues, several approaches and models have been proposed and implemented using Fuzzy Logic, Neural Network, Petri Net, etc. These approaches have been reviewed in this paper.

In future, the authors are interested in the development of urban traffic control systems using satellite based and global positioning systems.

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