PRESENTATION OF EXISTING METHODS BASED ON MULTI AGENT SYSTEMS WITH THE PURPOSE OF ROAD PLANNING

DOI: https://doi.org/10.18485/arh_pt.2024.8.ch8

_ Julijan Jurak

Assistant, Faculty of Transport and Traffic Sciences, Zagreb, Croatia,
https://www.fpz.unizg.hr/zgp/index.php/djelatnici, jjurak@fpz.unizg.hr

_ Krešimir Osman

PhD, Research Assistant, Department of Electrical Engineering,
Zagreb University of Applied Sciences, Zagreb, Croatia,
https://www.tvz.hr/odjeli/elo, kresimir.osman@tvz.hr

_ Matija Sikirić

Assistant, Faculty of Transport and Traffic Sciences, Zagreb, Croatia,
https://www.fpz.unizg.hr/zgp/index.php/djelatnici, msikiric@fpz.unizg.hr

_ Ljupko Šimunović

PhD, Full Professor, Faculty of Transport and Traffic Sciences, Zagreb, Croatia,
https://www.fpz.unizg.hr/zgp/index.php/djelatnici, ljsimunovic@fpz.unizg.hr

ABSTRACT

In this review paper, a presentation of existing methods and simulation programs based on multi agent systems algorithms for road planning in transportation engineering is given. The focus of this paper is on recent microsimulation approaches based on multi-agent systems, where decisions and negotiations are made during transportation. In traffic engineering, they are defined for dynamic interaction and behave thanks to different strategies. In such cases, the transportation network is represented by dynamic graphs that can evolve as a function of time.

KEYWORDS _ *Microsimulation, Multi-agent, Road Planning, Transportation*

INTRODUCTION

In today's modern society, fast and safe mobility is one of the most important basic needs. To achieve this, people use various means of transportation such as cars, subways, and bicycles. Of all these modes of transportation, cars are still the most prevalent due to their convenience and practicality. However, with the growing population, the number of vehicles is also increasing, especially in big cities. Consequently, traffic jams on city streets become a burning and unavoidable problem. The above problem is solved by transport engineers, and for this purpose several methods and computer programs have been developed. All of these have been developed to help vehicle users plan an efficient route in an environment that changes dynamically over time. To achieve this, time-varying parameters such as equipment failures, traffic accidents, congestion, and uncertainties in the road network must be considered. Simulations developed to optimize and improve the throughput of urban roads are also very useful. In the existing literature, various methods and simulation programs based on the macro approach can be found. Recently, however, programs have also been developed that are limited to the micro-level of microsimulation. Existing traditional approaches to solving traffic problems assume of statistical correlation between various parameters. In addition, work related to the cellular automata approach, rule-based methods, and the application of evolutionary algorithms is also applied in this research. More recent approaches, such as those based on multi-agent systems, rely on causality, i.e., how decisions and negotiations are determined during transport. Such model describes its actors and infrastructure with autonomous agents. They are defined to interact dynamically and behave thanks to different strategies. In this case, the transport network is represented by dynamic graphs that can evolve as a function of time. The aim of this paper is to present the existing microsimulation methods and computer programs for solving traffic problems in cities, focusing on methods and programs based on the simulation of multi-agent systems. Microsimulations are used whenever greater accuracy is required in the research being conducted. However, their major disadvantage is that they are therefore expensive and sometimes too accurate, which is not necessary. As an alternative, macrosimulations can be used, which again give a less accurate calculation.

PRESENTATION OF EXISTING METHODS

This type of algorithm is used to simulate more complex behaviour in road planning. For this purpose, micro simulators are used in which such behaviour can be implemented or integrated into traffic components (Figure 1). In the following, the section is organized according to different application areas in traffic engineering.

OPTIMIZATION OF AN ISOLATED INTERSECTION

In the paper, authors Fujii et al (2017) prove the thesis for urban sections that a streetcar lane near a station in Okayama city, Japan, could be useful and would not interfere with the ongoing traffic of cars and vehicles. To this end, a vehicle, streetcar, and pedestrian simulation environment was created and applied to this problem to identify issues with traffic signals. In the work of Lindorfer et al (2017), an isolated traffic intersection was studied. For this purpose, the program TraffSim is used to simulate four different traffic control strategies: fixed, mirrored, cyclic and self-optimized. In their work, 60 hours of traffic are simulated, with the number of simulated vehicles ranging from 540 to 1080 vehicles/hour. The contribution of this work is the optimization of traffic light circuits with the possibility of their extension.

THE USAGE OF AN AGENT SYSTEM IN THE CREATION OF TRAFFIC FLOWS AND BEHAVIOURS

The authors Bonhomme et al (2016) performed a simple simulation of a small road network. The experiment, called "TraFigen", focused on the generation of traffic flows by agents that could behave in different ways. The NetLogo simulator was used, while the road network was created using OpenStreetMap. The paper, authored by Singh et al (2017), investigates various aspects of traffic flow using data from a loop coil near an intersection. The objective is to measure the time lost due to the warm-up time during a traffic change. The simulation was performed using the SUMO simulator. It has been shown that during the evening peak calibrations of green waves, the warm-up time can be reduced, which in turn can reduce the travel time per vehicle by up to 37 %. Mizuta (2015) analysed the influence of traffic flows. He focused on slowing traffic near the intersection. He introduced "ghost" vehicles that drive in front of cars near intersections. The real car in the simulation uses a model that follows the car, which causes the vehicle to behave more naturally near intersections. Similar behaviour can be used in traffic congestion, where cars in the simulators brake too suddenly and unnaturally. The experiments were conducted with a simulation duration of 13 hours, 891,335 knots (Tokyo Bay Area), and approximately 4,900,000 vehicles.

DEPLOYMENT OF AN AGENT SYSTEM IN NEW STRATEGIC TRAFFIC LIGHT SYSTEMS

The work of Raphael and Sklar (2017) describes a comparative analysis of three traffic light systems: FIXED, SCOOT (the most popular traffic system in the world) and SUPRL (a reinforcement learning system). The SUMO simulator is used to analyse different traffic signal management approaches for three different urban traffic flows, such as structured, unstructured, and sport events. All simulations were tested using maps of the cities of Phoenix and Portland in the United States. Each sample was computed 30 times, and the result showed that SUPRL performs better than SCOOT by two times for unstructured flows and by 7 % for the sporting event in Phoenix. However, for structured flows, SCOOT performs better by about 0.5 %. In Portland, SURPL performed better than the SCOOT strategy for all types of traffic flows, especially sporting events. In the work of Manolis et al (2018), the comparison of traffic management systems is studied. The authors use the AIMSUN simulator and perform several experiments to compare centralized and decentralized logic methods. The representative of decentralized algorithms - SURTRAC (Scalable Urban TRAffic Control) seems to be the most promising. Among the centralized methods, TUC (Traffic Responsive Urban Control) is an excellent but very simple technique. According to the authors, TUC performs better for congestion, but must be redesigned as a temporal, topological device each time signal control changes. Each experiment included 5400 steps and analysed the area of Chania in Greece with 13 nodes. In the work of Zhonghe et al (2015), the authors presented a new traffic control strategy called URBC (Urban Traffic Balance Control) based on the concept of state feedback. The control system can achieve a closed loop and reach a consensus on how traffic signals should behave. This technique was evaluated through a simulation in the Wangjing area of Beijing, China, using the VISSIM simulator. The area includes 19 intersections and 56 links. In addition, four traffic demands were analysed: 800, 1000, 1200, and 1500 vehicles/hour/lane. After evaluating the strategy, the authors found that regular traffic management can reduce delay time by 13-20 % and increase average speed by 8.5 %. The paper of Lee et al (2019) presents a new traffic flow management algorithm (called Atom) that reduces the waiting time in traffic flow. It simulates traffic signal operations in a network of 13 intersections and later conducts a test in the Baltimore, USA, area, which includes 137 intersections. In addition, this technique is compared with other systems such as TAPIOCA, FUZZY and WSN-ATLC (WSN-adaptive traffic signal control). Each traffic control technique was evaluated using the SUMO simulator. The result of the evaluation shows that ATOM is effective for highly congested roads. A paper by Yin et al (2019) analyses an adaptive traffic signal applied to a single-lane intersection. It investigates which of the five control methods best suits such a problem. The considered control methods are TD (temporal difference), RLS-TD (recursive least squares TD), FPS (fixed phase sequence), VPS (variable phase sequence), and APS (adaptive phase sequence). The result shows that when the vehicle saturation is high (1800 vehicles/hour), RLSTD is better than TD, because it adapts faster to the current traffic. However, the APS technique is more efficient because it can reduce the delay by up to 58 %.

OPTIMIZING WAITING TIME

Burguillo et al (2016) simulate road traffic in a grid using the NetLogo simulator. They use a varying number of organized-only intersections and analyse how this might affect the average waiting time of drivers. They found that if the number of smart intersections exceeded 50 %, waiting times would decrease compared to a traffic network with regular, fixed traffic lights. If the number of traffic light-controlled intersections is increased, waiting time is reduced even more. They also find that communication between traffic signals does not affect the quality of the solution. In the work of Ahmad Yousef et al (2019), the optimization of the average waiting time is determined using microsimulation. It was assumed that if a city has traffic data from several longer periods, the traffic data from certain periods (weeks, months) should be similar. The experiment was conducted for the 4 × 4 grid and street schemes in the city of Madison, USA. They ran simulations of 1, 2, and 3 hours and measured that the algorithm optimized the average waiting time by 18 %. Patrascu et al (2015) focus on reducing the waiting time at the intersection. For this purpose, they use Java, the JADE framework, and the SUMO program with different types of agents: an intersection controller, a traffic light, a lane sensor, and a vehicle sensor. The results show that the average waiting time can be reduced, leading to an average fuel saving of 3.06 % and an average speed increase of 9 %. In addition, the impact of emergency vehicles on traffic flow is also studied. The work of Kapusta et al (2017) proposes a preventive traffic light control. The experiment was conducted using VISSIM, which simulated an intersection in Zagreb (Croatia). In the tested scenarios, a one- hour traffic was simulated, with emergency vehicles in the 20th and 40th lanes. The tests with this condition were repeated ten times for the situation with the new algorithm. The results showed that the travel time of emergency vehicles can be reduced by 13 % without any negative impact on traffic.

BRAESS PARADOX

This traffic theory problem describes a scenario in which a new link in an urban area, created to facilitate traffic, could reduce the performance of all connected roads. On this topic, Thomas Ho and Pasi (2018) studied the impact of a new bridge in the city of Joensuu, Finland. For this purpose, MATSim was used with the city network created by OpenStreetMap. In addition, traffic flow data from the morning and evening rush hours were used. The simulation shows that the new bridge will not increase traffic congestion in the city. A similar problem was addressed by authors Kim et al (2016) in Daejeon, South Korea. Traffic congestion after the construction of a new bridge in this area was analysed. The CORSIM program was used for this evaluation, and it was concluded that the bridge would have a positive impact on the area and that only high traffic volumes would cause the phenomenon of congestion. The work of Soares et al (2013). describes an integration platform that allows the integration of Java with SUMO and possibly with another simulator. The Braess paradox was reproduced by simulating a small city network with 1900 vehicles that learned the connections and selected the optimal ones. After the learning and evaluation phase, a new path was added to the graph, and learning with evaluation was repeated. The authors observed that in 50 phases, the vehicles explored an additional road while the old roads were still heavily congested. However, in subsequent phases, the agents noticed the shorter time on road C and started to use it, resulting in severe congestion on this road. Thunig et al (2019) investigate the optimization of fixed traffic lights. The MATSim simulator was used, and 4445 agents were simulated driving through an intersection. The experiment iteratively simulated the environment with agents and optimized the traffic lights with a cyclic time extended network (CTEN) model. The result of this work shows that the travel time at an intersection could be improved from 45 to 71 %. Wang et al. addressed iterative tuning in (2016) using the example of a major road in Singapore with multiple intersections. In the experiment, traffic conditions were simulated using VISSIM and the intersections were iteratively calibrated to reduce the number of vehicles queuing in the lanes. The results showed that this technique leads to a 24 % reduction in the average delay time and a 29 % reduction in the average number of stops compared to a fixed time strategy.

Han et al (2015) study traffic signal optimization focusing on a network of small cities. They run a simulation where each intersection, road segment, and vehicle are agents. The results show that this technique can optimize the average delay time at each intersection by 6 %.

TRAFFIC OPTIMIZATION SYSTEM IMPROVEMENT

In their paper, Pavleski et al (2019) describe the improvement of the system UTOPIA (Urban Traffic Optimization by Integrated Automation), which was developed in 1984 in Turin, Italy. They describe the integration of the system with the VISSIM program and evaluate the quality of this improvement in a small urban network with seven intersections (main streets of Skopje, Macedonia). The experiment has shown that the implementation of this link allows the system UTOPIA to estimate travel time, average queue length, average number of vehicles and average number of stops before applying the changes to the actual network.

EVACUATION SIMULATION

Al-Zinati and Zalila-Wenkstern (2018) studied the problem of terrorist attacks using a road reversal mechanism in a city simulated with the MATISEE program. It is the system developed by the authors for agent-based simulations. A hierarchical agent transportation system (ATS) is described, which has three levels of agents. At the lowest level is the intersection agent, which is responsible for collecting traffic flow information. At the middle level is a zone manager, which analyses traffic flows and manages topology and bandwidth. At the highest level is a traffic manager, which initializes and reorganizes zones and receives information about road closures. The traffic manager balances the roads by adding one road at a time to each zone. Each zone should have a similar number of vehicles on the road that belongs to that zone. In the simulated environment, 3,500 vehicles try to escape from the city, and after 1,000 cycles, two explosions block two exits until the end of the simulation. Initially, the model contains four zones for 83 intersections and 145 road connections. However, the traffic manager can request a change in the size of the zone owned by the middle level zone manager if needed for evacuations. The experiment was repeated six times and showed that reversing the road negatively affects the speed of traffic flow during a terrorist attack. The work of Wolshon et al (2015) describes the flight of citizens from the Gulf of Mexico area (according to 2010 population data) during a hurricane. The experiment was conducted using TRANSIMS simulator, preparing six scenarios based on five hurricane scales. It was found that the results were almost as expected. This means that the average travel speed decreases when the demands increase due to high traffic volume. Robinson et al (2018) analyse the evacuation after a hurricane in the Norfolk region, England. Microsimulation was performed in the TransModeler application and the capabilities of the transportation system were tested during the one-day escape of 800,000 vehicles from the area. The scenario included 35-48 traffic accidents that affected traffic conditions. It was found that even if an accident increased travel time, it did not ultimately have a visible impact on the escape of the population. Alam and Habib (2019) conducted a microsimulation using the program VISSIM to evaluate the road conditions and escape options for the citizens of Halifax, Canada, during flooding. Three scenarios of water rise were examined in the experiment. In the scenarios with water rise of 2.9/3.9 and 7.9 m, 23.3, 23.7, and 31.2 % of roads were blocked, respectively. The VISSIM program simulated 65,000 vehicles on 1,784 roads. The researchers concluded that the first two scenarios were possible, but that when the water rose 7.9 m, multiple escape routes were available that were too small to allow all citizens to escape. Accident-based reactive systems: Huang et al (2016) used the AIMSUN program to develop a new control strategy for accidents blocking a road in a 7 × 7 grid. In the experiment, the traffic demands for major roads with three lanes (a fourth horizontal and a fourth vertical) were set at 500 vehicles per hour, while for other roads that have two lanes in each direction, the traffic demands were set at 325 vehicles per hour. The accident occurred in the 10^{th} minute on the main road and obstructed traffic for one hour, blocking two lanes of this connecting direction. The entire test simulates traffic conditions for 120 minutes and shows that the new traffic control policy increases average vehicle speed by 35 % (from 20 to 27 km/h) and reduces the number of stops during rush hour. The work of Smith et al (2014) also addresses accidents in traffic networks. Their experiment focused on an accident and its impact on the road network. A test was conducted using the program SUMO to simulate an accident for a vehicle that was stopped for a specified time. In seven tests, a 10 × 10 road network was used, and 3,600 vehicles per hour were simulated. In the test, the researchers measured an accident-free situation, three tests using the detour algorithm proposed by the researchers, and three tests in which the detour algorithm was not used but accidents still occurred. The detour algorithm was found to reduce travel time by up to 35 %. The authors Wang et al (2016) developed an algorithm to optimize traffic flow in network and urban network simulation. The algorithm, called 'Next Road Rerouting', was tested in four scenarios using the simulator SUMO. Each scenario simulates 30 minutes during peak traffic hours. The results lead the authors to conclude that travel time can be reduced by up to 65 %, which is nearly twice as efficient as the algorithm proposed in Smith's paper. According to a book chapter by authors Shahabi and Pan (2017), it was observed that road traffic can be slowed down by 30 % in the accident area. Another useful observation is the conclusion that congestion detection could be done offline, as it is characterized by unusually long waiting times. On the topic of accident-induced rerouting, authors Kim et al (2017) created a simulation in which an agent navigates through a city network based on its own belief and desire to reach a destination. Using the DynusT simulator, they created a Java module that planned routes for 3,102,771 vehicles in the network of the city of Phoenix, USA, during the experiment. The simulation was run during normal and congested (random) traffic, and the rerouting worked well in both situations. The rerouting method presented in the study, called EBD-I, reduced average travel time by 18 % during accidents. The authors compared the results with the base case in which the detour mechanism was not introduced. In this study 43,600 vehicles in the city were considered. Jeihani et al (2015) analysed the effects of an accident on a three-lane highway in Baltimore, USA. The experiments focused on the time required to restore traffic. In this study, 726 simulations were performed using the VISSIM program, and the researchers analysed different traffic conditions, such as accident categories (short - 20 min, medium - 40 min, long - up to 60 min), different number of lanes closed (1, 2, or 3 lanes), and different traffic intensity (light 0.25-0.5, medium 0.5-0.8, approximate capacity 0.8-1.0, where 1.0 means 2400 vehicles/hour/lane). When the value of this parameter approaches 1.0, congestion is the most difficult to solve. The closure time and the number of lanes closed have a smaller effect on the road condition than the intensity parameter. Kaddoura and Nagel (2018) focused on the problem of lack of knowledge about the response to certain accidents. In the experiments, the researchers wanted to find out whether the pricing system would help with traffic congestion caused by long- and short-term traffic accidents. The test map, representing the urban network of Berlin, was created using maps developed by HERE Technologies. The MATSim program was used to simulate the researchers' situation studies, and various scenarios were tested - perfect day, long-term impact of road works, long-term impact, and short-term impact. In addition, the road pricing system was studied in a perfect situation and in a day with road works. The researchers find that in the proposed experiments, the average travel time increases by 18 % for long-term incidents and 8 % for short-term incidents. It follows that pricing policy reduces average travel time by 17 % for short-term incidents and by up to 30 % for long-term incidents. In (2019), Elkosantini and co-authors present a new impressive traffic signal control policy that recalls the immune response of the urban network. For the evaluation, VISSIM is used with four scenarios: 4800 and 7200 vehicles/hour without accidents and two with the same vehicle parameters but in a situation where an accident occurs. In the case of a roadblock, the system can respond with actions that mitigate the situation, as the problem is analysed more carefully. The authors claim that experiments show that the application of the proposed method reduces the waiting time in the traffic network by 10 %.

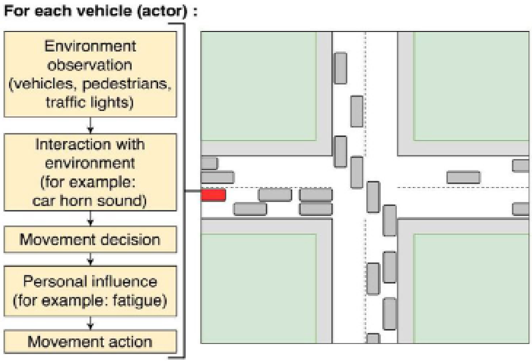

Figure 1: Presentation of the multiagent system algorithm in traffic engineering (Rydzewski and Czarnul, 2020)

CONCLUSIONS

With this paper, the authors aimed to provide an overview of existing methods and computer programs related to the problem of microsimulation in traffic engineering. The paper is intended as an overview of the work and the beginning of research in this area. In writing the paper, the authors felt that it would contribute to the research field of microsimulation methods with a focus on multiagent systems.

One of the directions of future research would be the development and application of an algorithm based on multiagent systems with the goal of solving urban traffic congestion and optimizing the road routes of vehicle movements in cities.

REFERENCES

- Alam, M.D., Habib, M.A.: 'Mass evacuation of Halifax, Canada: a dynamic traffic microsimulation modeling approach', Procedia Comput. Sci., 2019, 151, pp. 535–542
- Al-Zinati, M., Zalila-Wenkstern, R.: 'A resilient agent-based re-organizing traffic network for urban evacuations', Int. Conf. on Practical Applications of Agents and Multi-Agent Systems, Toledo, Spain, 2018, pp. 42–58.
- Bonhomme, A., Mathieu, P., Picault, S.: 'A versatile description framework for modeling behaviors in traffic simulations', Int. J. Artif. Intell. Tools, 2016, 25, (1), p. 1660006.
- Fujii, H., Uchida, H., Yoshimura, S.: 'Agent-based simulation framework for mixed traffic of cars, pedestrians and trams', Transp. Res. C, Emerg. Technol., 2017, 85, pp. 234–248.
- Han, Z., Zhang, K., Yin, H., et al.: 'An urban traffic simulation system based on multi-agent modeling'. The 27th Chinese Control and Decision Conf. (2015 CCDC), Qingdao, China, 2015, pp. 6378–6383.
- Ho, C.T., Pasi, F.: 'Multi-agent approach traffic forecast for planning urban road infrastructure'. TENCON 2018-2018 IEEE Region 10 Conf., Jeju, Korea, 2018, pp. 1795–1800.
- Huang, Y.-S., Huang, W.-P., Wu, W.-P.: 'Analysis of urban traffic jam control strategies using simulation technology'. 13th Int. Conf. on Networking, Sensing, and Control, Mexico City, Mexico, 2016, pp. 1–6.
- Ion, A., Berceanu, C., Patrascu, M.: 'Applying agent-based simulation to the design of traffic control systems with respect to real-world urban complexity'. Multi-Agent Systems and Agreement Technologies, Athens, Greece, 2015, pp. 395–409.
- Jeihani, M., James, P., Saka, A.A., et al.: 'Traffic recovery time estimation under different flow regimes in traffic simulation', J. Traffic Transp. Eng., 2015, 2, (5), pp. 291–300.
- Kaddoura, I., Nagel, K.: 'Using real-world traffic incident data in transport modeling', Procedia Comput. Sci., Porto, Portugal, 2018, 130, pp. 880–885.
- Kapusta, B., Miletić, M., Ivanjko, E., et al.: 'Preemptive traffic light control based on vehicle tracking and queue

lengths’, 2017 Int. Symp. ELMAR, Zadar, Croatia, 2017, pp. 11–16.

- Kim, S., Jang, K., Jang, I.G.: ‘Study on the quantitative effects of new bridge construction on traffic conditions’, 3rd Asia-Pacific World Congress on Computer Science and Engineering, Nadi, Fiji, 2016, pp. 47–52.
- Kim, S., Son, Y.-J., Tian, Y., et al.: ‘Cognition-based hierarchical a route planning for multi-agent traffic simulation’, Expert Syst. Appl., 2017, 85, pp. 335–347.
- Lee, S., Younis, M., Murali, A., et al.: ‘Dynamic local vehicular flow optimization using real-time traffic conditions at multiple road intersections’, IEEE Access, 2019, 7, pp. 28137–28157.
- Lindorfer, M., Backfrieder, C., Mecklenbräuker, C.F., et al.: ‘Modeling isolated traffic control strategies in traffsim’. 2017 UKSim-AMSS 19th Int. Conf. on Computer Modelling & Simulation (UKSim), Cambridge, UK, 2017, pp. 143–148.
- Louati, A., Elkosantini, S., Darmoul, S., et al.: ‘An immune memory inspired case-based reasoning system to control interrupted flow at a signalized intersection’, Artif. Intell. Rev., 2019, 52, (3), pp. 2099–2129.
- Manolis, D., Pappa, T., Diakaki, C., et al.: ‘Centralised versus decentralised signal control of large-scale urban road networks in real time: a simulation study’, IET Intell. Transp. Syst., 2018, 12, (8), pp. 891–900.
- Mizuta, H.: ‘Evaluation of metropolitan traffic flow with agent-based traffic simulator and approximated vehicle behavior model near intersections’, 2015 Winter Simulation Conf. (WSC), Huntington Beach, CA, USA, 2015, pp.3925–3936.
- Pavleski, D., Koltovska-Nechoska, D., Ivanjko, E.: ‘Development of TSCLab: a tool for evaluation of the effectiveness of adaptive traffic control systems’, ‘New technologies, development and application’ (Springer, Sarajevo, Bosnia and Herzegovina, 2019), pp. 386–394.
- Raphael, J., Sklar, E.I.: ‘Towards dynamic coalition formation for intelligent traffic management’, in ‘Multiagent systems and agreement technologies’ (Springer, Evry, France, 2017), pp. 400–414.
- Robinson, M., R., Collins, A.J., Jordan, C.A., et al.: ‘Modeling the impact of traffic incidents during hurricane evacuations using a large scale microsimulation’, Int. J. Disaster Risk Reduct., 2018, 31, pp. 1159–1165.
- Rodríguez-Hernández, P.S., Burguillo, J.C., Costa-Montenegro, E., et al.: ‘A study for self-adapting urban traffic control’. Ibero American Conf. on Artificial Intelligence, San José, Costa Rica, 2016, pp. 63–74.
- Rydzewski, A., Czarnul, P.: ‘Recent advances in traffic optimisation: systematic literature review of modern models, methods and algorithms‘, IET Intell. Transp. Syst., 2020, Vol. 14, Iss. 13, pp. 1740-1758
- Shahabi, C., Pan, B.: ‘Accident impact prediction’, 2017, pp. 39–48.
- Singh, S.K., Komolkiti, P., Aswakul, C.: ‘Impact analysis of start-up lost time at major intersections on Sathorn road using a synchro optimization and a microscopic sumo traffic simulation’, IEEE Access, 2017, 6, pp. 6327–6340.
- Smith, D., Djahel, S., Murphy, J.: ‘A sumo-based evaluation of road incidents’ impact on traffic congestion level in smart cities’, 39th Annual Conf. on Local Computer Networks Workshops, Edmonton, AB, Canada, 2014, pp. 702–710.
- Soares, G., Kokkinogenis, Z., Macedo, J.L., et al.: ‘Agent-based traffic simulation using sumo and jade: an integrated platform for artificial transportation systems’, Simulation of Urban MObility User Conf., Berlin, Germany, 2013, pp. 44–61.
- Thunig, T., Scheffler, R., Strehler, M., et al.: ‘Optimization and simulation of fixed-time traffic signal control in real-world applications’, Procedia Comput. Sci., 2019, 151, pp. 826–833.
- Wang, S., Djahel, S., Zhang, Z., et al.: ‘Next road rerouting: a multiagent system for mitigating unexpected urban traffic congestion’, IEEE Trans. Intell. Transp. Syst., 2016, 17, (10), pp. 2888–2899.
- Wang, Y., Wang, D., Jin, S., et al.: ‘Iterative tuning with reactive compensation for urban traffic signal control’, IEEE Trans. Control Syst. Technol., 2016, 25, (6), pp. 2047–2059.
- Wolshon, B., Zhang, Z., Parr, S., et al.: ‘Agent-based modeling for evacuation traffic analysis in megaregion road networks’, Procedia Comput. Sci., 2015, 52, pp. 908–913.
- Yin, B., Dridi, M., Moudni, A.E.: ‘Recursive least-squares temporal difference learning for adaptive traffic signal control at intersection, Neural Comput. Appl., 2019, 31, (2), pp. 1013–1028.
- Yousef, K.M., Shatnawi, A., Latayfeh, M.: ‘Intelligent traffic light scheduling technique using calendar-based history information’, Future Gener. Comput. Syst., 2019, 91, pp. 124–135.
- Zhonghe, H., Chi, Z., Li, W.: ‘Consensus feedback control for urban road traffic networks’, 54th Annual Conf. of the Society of Instrument and Control Engineers of Japan, Hangzhou, China, 2015, pp. 1413–1418.