Optimization and Scheduling for a Large Scale Urban Transportation System involving Human Factors

Abstract

The striking growth of cities in developing countries prevents a well-planned urban development. Many urban areas are suffering from serious traffic congestions, pollution, noises and traffic fatalities. Limited financial resources and physical space cannot guarantee the feasibility of the infrastructures expansion, which leads to seek other alternative solutions to address the above problems. This thesis focuses on solving the above issues by designing adaptive traffic signal controller for both vehicles and pedestrians and developing optimal tactics and strategies for public-transport operations incorporating passenger loading process.

Traffic congestion, as one of the most serious issues mentioned above, has made bad impacts on the mobility and accessibility in many cities. The reasons responsible for this phenomenon can be attributed by many factors: urban population increase, economic growth (rapid increase of private cars, unreasonable city development), poor road infrastructure, poor traffic management, car accidents and some special event gatherings. In view of the increasing traffic congestion in urban road networks, many models have been developed to analyse the dynamics of traffic flow at different levels, e.g., Cellular Automata Models, Headway distribution Models, Lighthill-Whitham-Richards(LWR)-type Models and Cell Transmission Models (CTM). Traffic signal control, as one of the most essential strategies to tackle this challenge, has been applied and studied over the past several decades. Adaptive traffic signal strategies have demonstrated the efficiency on fluctuated demands by tuning the signal plans on-line based on the real-time input data and its internal optimization model. However, existing traffic signals generally aim to minimize vehicle delay, but the pedestrian delay is seldom considered. This is reasonable when pedestrian volume is low, however, in CBD areas where large number of pedestrians interfere with vehicular traffic, optimizing traffic signals only for vehicles may not make good use of crosswalks and potentially create more conflicts between pedestrians and vehicles. Therefore, we develop the model to provide Traffic Light Scheduling for Pedestrian-Vehicle mixed-flow Networks (TLSPVN). Firstly, a macroscopic pedestrian "hopping" model at an intersection is developed, which inserts mixed logical constraints into the flow dynamic model and is capable of reflecting the changing capacity during one time interval resulted from the crosswalk length and pedestrian relatively lower speed. By considering drivers' psychological response to traffic signal states, a network-based vehicle flow model is adopted. Both pedestrian performance and vehicle performance are integrated together via the weighted sum method, which could be translated into monetary values for economic considerations or delay costs for efficiency evaluation. By connecting with the commercial simulator, VISSM, experiment studies are carried out to illustrate the usefulness of our proposed solution.

Nevertheless, the increase of the efficiency could be possible to alleviate the safety of the system. According to Traffic Police accident statistics, 22% of the pedestrian fatal accidents occurred at signalized pedestrian crosswalks. More than 30% of the total pedestrian fatalities can be attributed to the illegal crossing behaviour. Therefore, it is essential to design traffic signals considering both efficiency and safety. Pedestrian Flashing GREEN (FG), a time interval for pedestrians on crosswalks to safely finish crossing before the next phase occurs, may fail to clear the crosswalk in the allotted time, due to significant pedestrian non-compliant behaviour. In this manner, probability of pedestrian-vehicle exposures increases when non-

compatible vehicle flows are released at the next immediate phase. We address this issue by presenting a traffic signal control strategy for urban traffic networks that aims to minimize vehicle traveling delay (increase efficiency) as well as pedestrian crossing risk (increase safety). Specifically, we formulate a mathematical model for pedestrian crossing on a signalized intersection, whose arrival flow and leaving flow of each waiting zone are separately described in order to make the model more realistic, then the duration of Dynamic All RED phase (DAR) is obtained according to the number of illegal-crossing pedestrians via pedestrian crossing time model. By integrating with the vehicle network model based on CTM, a Pedestrian-Safety-Aware Traffic Light Control Strategy (PSATLCS) is developed with the aim to reduce both traffic congestions and pedestrian-crossing risks. Secondly, both the genetic algorithm (GA) and the harmony search algorithm (HS) with the repairing mechanism are proposed in order to meet the requirement of the real-time signal switching. Thirdly, efficiency on vehicle side is evaluated by comparing the before-mentioned adaptive signal strategy for TLSPVN problem with our proposed PSARLCS. Based on the Traffic Conflict Technique (TCT), one method used to evaluate the road risk, the safety cost under two strategies is also illustrated. Moreover, we establish quantitative standards for selecting signal strategies between the efficiency and safety in an economic evaluation framework, which provides referable suggestions for transportation professionals to make proper decisions on phase pattern selection.

Besides the traffic light control, public transportation, another effective solution to address the above issues, has also been studied for several decades due to its larger ridership and sustainability on economic efficiency, environmental justice and social equity. Especially for Singapore, a densely-populated small city-country with a total population of 5.6 million, and its main island has a land area of 648 km^2 spreading about 42 km in length and 23 km in breadth. Clearly, developing an efficient public transport system is definitely indispensable in order to solve serious traffic issues under such limited land supply and exploding transport demands. There are three major layers in public transportation system: strategic planning, tactical planning and operational planning. Strategic planning refers to the transit network design, which determines the bus line, bus stop location and types of buses. Tactical planning aims at improving the level of public service and reducing the operational cost. Operational planning refers to the short-term decision. In this thesis, we address the bus dispatching system from the tactical and operational level, with the aim to design transit timetable and schedule corresponding vehicles. Meanwhile, we take the stop-skipping control strategies into account and allow the bus-platoon dispatching to guarantee an efficient bus service. We successively developed two models, in which the model I only considers dynamics on buses and stops while the model II also incorporates the bus loading process at each stop. By introducing the bus loading process, the function which describes the relationship between the bus dwelling time and the number of loading passengers, is adopted from the literature. Besides the objectives in the model I with the aim to minimize passenger delay and bus vacancy, model II also tries to minimize the bus unpunctual delay due to the loading process. Both models consider a ring-route bus line with the stop demand dynamics and the bus demand dynamics involved. Also, passengers' perceived delay is firstly formulated by a nonlinear function, which describes the dissatisfaction of the passengers who haven't boarded after their expected bus arrival time. Moreover, we compare our method with the traditional fixed schedule and the optimized non-platoon schedule, and the simulation results illustrate the efficiency of our method.

Overall the thesis proposes three major problems faced by the researchers and policy makers in the intelligent transportation field. The suggested frameworks and guidelines can be used to help to develop an integrated, multi-modal system in order to provide citizens a more smart, safe and sustainable transportation experience.

Publication Lists

Journal Publications

Accepted

1. Y. Zhang, K. Gao and Y.C. Zhang, R. Su. "Traffic light scheduling for pedestrian-vehicle mixed-flow networks". IEEE transactions on Intelligent Transportation Systems. June 2018.

Submitted

1. Y. Zhang, Y.C. Zhang, R. Su. "Pedestrian-safety-aware traffic light control strategy for urban traffic congestion alleviation". IEEE transactions on Intelligent Transportation Systems. Major revision, March 2019.

Prepared

1. Y. Zhang, R. Su. "Optimal platoon dispatching strategies for bus operations considering passenger loading dynamics".

Conference Publications

Accepted

1. Y. Zhang, Y. C. Zhang, R. Su. "Optimization of vehicle delay and drivers' unhappiness at a signalized network: a multi-objective approach". 15th IEEE International Conference on Control and Automation (ICCA19). Edinburgh, Scotland, 2019.

2. Y. Zhang, R. Su. "Pedestrian phase pattern investigation in a traffic light scheduling problem for signalized network". 2nd IEEE Conference on Control Technology and Applications (CCTA18). Copenhagen, Denmark, 2018.

3. Y. Zhang, R. Su, and Y.C. Zhang. "A macroscopic propagation model for bidirectional pedestrian flows on signalized crosswalks". 56th IEEE Conference on Decision and Control (CDC17). Melbourne, Australia, 2017.

4. Y. Zhang, R. Su, K. Gao, Y. C. Zhang. "Traffic Light Scheduling for Pedestrians and Vehicles". 1st IEEE Conference on Control Technology and Applications (CCTA17). Hawaii, USA, 2017.

Submitted

1. Y. Zhang, R. Su, Y. C. Zhang. "A dynamic optimization model for bus schedule design to mitigate the passenger waiting time by dispatching the bus platoon". 58th IEEE Conference on Decision and Control (CDC19). Nice, France, 2019.

Collaborated works with others (Accepted)

Journals

1. K. Gao, Y. Zhang, Y. C. Zhang, R. Su, P.N. Suganthan. "Meta-heuristics for Bi-objective urban traffic light scheduling problem". IEEE Transactions on Intelligent Transportation Systems. August. 2018.

2. Y. C. Zhang, R. Su, G.G.N. Sandamali, Y. Zhang, R. Su, C. Cassandras, L. Xie. "A Hierarchical Heuristic Approach for Solving Air Traffic Scheduling and Routing Problem with a Novel Air Traffic Model". IEEE transactions on Intelligent Transportation System. September. 2018.

3. A. Sadollah, K. Gao, Y. C. Zhang, Y. Zhang, R. Su. "Management of traffic congestion in adaptive traffic signals using a novel classification-based approach". Engineering Optimization. August. 2018.

Conferences

1. Y. C. Zhang, R. Su, C. Sun, Y. Zhang. "Modelling and traffic signal control of a heterogeneous traffic network with signalized and non-signalized intersections". 1st IEEE Conference on Control Technology and Applications (CCTA17). Hawaii, USA, 2017.

2. Y. C. Zhang, R. Su, G. G. N. Sandamali, Y. Zhang. "A Hierarchical Approach for Air Traffic Routing and Scheduling". 56th IEEE Conference on Decision and Control (CDC17). Melbourne, Australia, 2017.

3. K. Gao, Y.C. Zhang, Y. Zhang and R. Su. "A Meta-heuristic with Ensemble of Local Search Operators for Urban Traffic Light Optimization". The 2017 IEEE Symposium Series on Computational Intelligence (SSCI17). Honolulu, Hawaii, USA, 2017.