Simulation and Analysis of Urban Transit Time-Tabling Under Uncertainty: A Fuzzy-Stochastic Approach.

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Typical real-world time-tabling problems are inherently bugged by uncertainties which may be due to imprecise measurements of or randomness in the data input or a combination of the two. Taking consideration of the effect of uncertainties in modeling real-world problems no doubt puts the modeling in more realistic perspectives than otherwise.

This work is aimed at modeling and simulating real-world time-tabling scenario under uncertainty as well as analyzing the effects of different shades of uncertainties inherent therein. It is part of an on-going research work on Urban Transit planning under uncertainty.

The problem is formulated as a mixed integer non-linear constrained Mathematical Programming model. The objectives of the simulation is to minimize the sum total of the Initial Passenger Waiting Times and the Total Passenger transfer Times in the network. The problem is constrained by a number of typical transit system constraints, including the range of vehicle headways, vehicle stopping times at individual stations, transfer considerations, among others. The problem being a mixed integer non-linear optimization problem is difficult to solve using classical optimization techniques by virtue of the size of the inherent variables and computational-hardness it poses. Genetic algorithm is therefore resorted to as an optimal search technique.

This work considers uncertainty in input data of the transit system. The input models are thus realized as deterministic, fuzzy, stochastic, fuzzy-stochastic (fuzzified-random) and stochastic-fuzzy (randomized-fuzzy) inputs data. Paramount model parameters that are affected by these forms of uncertainties are the network link speeds, boarding, de-boarding and transfer passenger demands and vehicle stopping times at stations. Since these are essentially a function of time, precisely that of vehicle headways in the transit system, uncertainties in their realization are influenced by uncertainties in headways of vehicles on different routes. The headways further influence the scheduled departure times between vehicles and so influences the realization the boarding, de-boarding and transfer passenger flow and time. Furthermore, the speeds on the links in the network being also a function of time, the link travel times are also realized as uncertain input parameter. The boarding, de-boarding and transfer passenger flows for the urban transit system are ideally assumed to vary from time-segments to time segments of the planning horizon, in a peak/off-peak configuration. The boarding, de-boarding and transfer passenger volumes are assumed to take to a custom-built concatenated triangular flow distribution whose configuration differ from segment to segment and may also differ from vehicle-stop to vehicle-stop depending on whether the start-up segment is a peak period or an off-peak period. The expected passenger volumes between vehicle departures are realized as areas under the flow distributions assumed. For one, a triangular distribution of arrival rate of Initial-boarding passengers is also assumed. In the distribution, considering the passengers' *a priori* knowledge of the schedule, the rate of passenger arrival increases from zero at the departure time of the last vehicle and reaches a peak at the arrival of a current vehicle, while it decreases back to zero at the departure of the current vehicle. The peak of the distribution is obtained as a function of the total volume of Initial-boarding passengers expected between departure times of vehicles. From these the initial waiting times for boarding and transfer are obtained via simulation.

For a typical vehicle station transit process, three transit-algorithms, boarding, de-boarding and transfer algorithms are simulated. The de-boarding scenario is first simulated signifying the arrival of a vehicle at a vehicle-station. In it, based on the vacancy on board, passengers are simulated as de-boarding and the existing vacancy on board is updated. Several possible scenarios of de-boarding ranging from excess de-boarding passengers to a situation of no de-boarding are handled in the algorithm and adjusted for during the current transit station loading process or at subsequent ones. From the de-boarding scenario too the transfer-simulation algorithm caters for adjudged volume of transfer passengers. Different scenarios of transfer are also painted by the transfer-algorithm, depending first on whether or not a currently considered station is a transfer station or transfer-benefiting station or both or none. If a transfer station, the algorithm updates number of passenger transferred and distributes the passengers, using in-built transfer benefit proportions for that station, to linked benefiting stations. At a transfer-benefiting station, the algorithm records the entry time and volume of transfer-passengers in order to compute their waiting time at the arrival of a vehicle to the station. Finally, the Initial-Boarding algorithm is simulated. Passengers are simulated as boarding depending on available vacancy on board, obtained from the de-boarding algorithm-simulation. The Initial- Boarding waiting queue are updated, the vacancy situation on board is also updated.

The three algorithms above are then tied using procedure-based declaration and coding of genetic algorithm optimal search technique.

The simulation as explained above are conducted under deterministic, fuzzy, stochastic, fuzzy-stochastic and stochastic-fuzzy uncertainties in input data. In the fuzzy version, a level fuzzy uncertainty of a particular input data taken a fuzzy measure of the input data is used. The analysis is conducted at various levels of fuzzy uncertainty in order to analyze the effect of that kind of uncertainty in the determination of the objectives of a transit timetable. The stochastic uncertainty-level is similarly taken as a probability measure using the expected value of the distribution as evidence. In the stochastic-fuzzy version, the input data is realized as a fuzzified random input in which the input data is regarded as triangular fuzzy number whose core and extreme points are realized from the probability distribution assumed for the data input. The analysis is carried out showing the effect of stochastic-fuzzy uncertainty in the determination of optimal objectives of the typical urban transit timetabling system. Finally, the fuzzy-stochastic version is also realized taking input data as fuzzified random input data.

The work is illustrated using a typical urban transit test-problem. Effects of various uncertainties in obtaining optimal time tables are amply demonstrated.

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