Public transport optimisation emphasising passengers' travel behaviour. - DTU Orbit
(14/06/2019)

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Passengers in public transport complaining about their travel experiences are not uncommon. This might seem counterintuitive since several operators worldwide are presenting better key performance indicators year by year. The present PhD study focuses on developing optimisation algorithms to enhance the operations of public transport while explicitly emphasising passengers' travel behaviour and preferences. Similar to economic theory, interactions between supply and demand are omnipresent in the context of public transport operations. In public transport, the demand is represented by the passengers and their desire to complete particular journeys, while the supply is the transit network and its characteristics. Changing the supply (e.g. by changing line plan configuration, stopping patterns or the timetable itself), thus makes the demand adapt accordingly. Acknowledging the interaction between supply and demand is important when transit operations are planned but also when performance is evaluated. Assessing public transport performance merely by measuring vehicle punctuality would provide an unfair picture of the level of service experienced by these passengers.

The unfair picture can be explained by the fact that passenger delays are often significantly larger than the vehicle delays responsible for the passengers to be late e.g. because passengers on a slightly delayed train may experience a large delay if they miss their desired connection. To overcome the discrepancy between the published performance measures and what passengers actually experience, a large academic contribution of the current PhD study is the explicit consideration of passengers' travel behaviour in optimisation studies and in the performance assessment. Besides the explicit passenger focus in transit planning, also the applicability to real large-scale network has been a main focus of the current thesis. Consequently, heuristic (i.e. not exact) methods are developed. The PhD study contributes to the state-of-the-art by proposing: A literature review outlining the discrepancy between planners, who focus on the vehicle operations and publish fixed vehicle schedules and, on the other hand, passengers, who look not only at the schedules but also at the entirety of their journey from the access to the waiting, the on-board travel, the transfers and the egress.

(ii) A metaheuristic algorithm to enhance the line plan configuration of a high frequent transit network explicitly taking into account passengers' travel behaviour. A heuristic algorithm to optimise stopping patterns in a railway network where passengers' adapted stop-to-stop path choice is considered explicitly. A metaheuristic algorithm minimising passengers' transfer waiting time by changing vehicle departure times from the initial stop, again passengers' route choice behaviour is considered. A methodological framework is proposed to assess the resilience of a transit network from the passengers' perspective. Empirical evidence indicates that passengers give more importance to travel time certainty than travel time reductions as they associate an inherent disutility with travel time uncertainty. This disutility may broadly be interpreted as an anxiety cost for the need for having contingency plans in case of disruptions, and may be looked at as the motivator for delay-robust railway timetables. Interestingly, passenger oriented optimisation studies considering robustness in railway planning typically limit their emphasis on passengers to the consideration of transfer maintenance. Clearly, passengers' travel behaviour is more complex and multifaceted, thus several other aspects should be considered as becoming more and more evident from passenger surveys identifying passengers' preferences when using transit systems. This literature review and in particular the finding that passengers' path choice is rarely considered in the operations planning was the main motivation for the papers in figure 1: The steps in the planning of transit operations are outlined along with the planning horizon. The arrows indicate that the outcome of a former step serves as input to a subsequent step. The current PhD study is focused around Network Route Design and Timetable Development. Although Network Route Design typically belongs to the strategic planning level, we approach the line planning and skip-stop planning on the tactical planning level, thereby making it possible to approximate passengers' travel choice with higher certainty. This is done by formulating bi-level optimisation problems, where the upper level solves the particular optimisation problem given passengers' route choice while the lower level derives passengers' route choice based on the updated network characteristics defined by the upper level. Due to its inherent complexity, these bi-level minimisation problems are extremely difficult to solve mathematically, since the analytical optimisation problem itself often is either non-convex non-linear or a mixed-integer linear problem, with passenger flows defined by the route choice model, where the route choice model is a nonlinear non-continuous mapping of the timetable. Therefore, the bi-level optimisation problems are solved heuristically. To speed up the convergence of the bi-level algorithms, the lower level problem is incorporated in the upper level problem formulation. Integrating the upper level and lower level makes the algorithm converge faster compared to the case where the two problems are solved sequentially without taking into account interdependencies.

Figure 1 - Planning public transport The PhD study develops a metaheuristic algorithm to adapt the line plan configuration in order better to match passengers' travel demand in terms of transfers as well as their waiting time experienced at boarding and transfers stations, respectively. The approach is based on swapping one part of a railway line with one part of another railway line at a station where the two lines meet. To search the solution space intelligently, a tabu search framework is applied to optimise the line plan configuration, while a passenger transit assignment model finds passengers' adapted route choices. The bi-level algorithm is validated on the suburban railway network in the Greater Copenhagen area in Denmark. Applying the improving bi-level passenger oriented line planning algorithm to this network yields a reduction of 3.83 % in railway passengers' number of transfers and 3.88 % in their waiting time. Another part of the Network Route Design is determining stopping patterns on transit lines. Travel time reductions in railways are typically costly and achieved through investments in rolling stock or infrastructure. Skipping stops, on the other hand, is a cost-effective way to reduce in-vehicle travel time for on-board passengers and at the same time reduce the heterogeneity of the railway operations, which reduces the risk of knock-on delays. A passenger assignment yields passenger flows, which serve as input to the skipstop optimisation. The updated stopping patterns and the reduced in-vehicle times then serve as...
input in the subsequent route choice calculation. The bi-level approach is applied to the suburban railway network in the Greater Copenhagen area in Denmark and yields a 5.48 % reduction in in-vehicle time, while the number of transfers and the transfer waiting time increase by 1.38 % and 1.60 %, respectively. Timetable Development is addressed by proposing a heuristic solution approach addressing the timetable optimisation from the passengers’ perspective. The idea is to change bus lines’ departure time from the initial station, and thereby reducing the waiting time passengers experience at any of the particular bus line’s transfer stops. The offset changing heuristic is built on a Tabu Search framework, which is applied for its superiority for the particular problem type and application, but also the ability of the algorithm to escape local minima, which is important in order not to let the existing timetable affect the final outcome. In the developed passenger oriented timetable optimisation heuristic (bi-level), the lower level passenger transit assignment yields passengers’ travel behaviour and thereby also their transfer choices. The solution approach is applied to the public transport network in Denmark yielding a 5.08 % reduction in transfer waiting time. The three contributions outlined above (i.e. line plan optimisation, skip-stop optimisation and timetable optimisation) all focus on optimising operational aspects of transit services with special regards to travel demand. It is important to emphasise that the improvements obtained by applying the three different optimisation models all are achieved without any investment costs. The only costs related to the improved transit operations are administrative costs such as marketing, printing new timetables etc. The last contribution of this PhD-study focuses on assessing the resilience of a transit network from the passengers’ perspective. In this paper, a model to assess the capacity degradability of a transit network is developed. The capacity degradability of a transit network is described as the number of individual train runs that can be cancelled without violating the in-vehicle capacity constraints on the remaining trains. This is practically useful for operational and tactical planning purposes e.g. in the case where a shortage of rolling stock occurs and some trips need to be cancelled. To take the interaction between supply and demand into account explicitly and to be able to derive passengers’ travel behaviour, a bi-level model is applied. In the bilevel model, the upper level determines the maximum degradable capacity by cancelling the individual train runs with the minimum maximum track segment load, while the lower level derives the individual vehicle loads by a schedule-based passenger assignment model. The explicit consideration of passengers’ travel behaviour is important to ensure the validity of the results, and thus also the real-life applicability. The capacity degradability model is tested on the transit network in the Greater Copenhagen area. Only individual train runs from the suburban railway network are subject to cancellations. From the case study it is concluded that this particular network is very resilient towards run cancellations on the suburban railway network since cancelling several transit runs only has a minor impact on passengers’ travel experience. However, the inconvenience passengers may have felt due to the forced changes in path choice and invehicle crowding is not explicitly considered as a part of their generalised travel cost. Thereby, the actual inconvenience felt by the passengers as a result of the cancelled runs, may have been underestimated. Summarising, the PhD study has given contributions to the state-of-the-art of several planning tasks that transit operators face by emphasising passengers’ adapted travel behaviour in order for the operations to be passenger oriented as possible. All methodologies are tested on large-scale transit networks and proved to enhance passengers’ travel experience. Thus by applying these methodologies in a real-life context, passengers would have a faster and less uncertain journey from origin to destination.