Towards the Goldilocks Zone of demand-responsive bus services

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This is a summary of the author's PhD thesis supervised by Kenneth Sörensen and Pieter Vansteenwegen and defended on May 15th, 2023 at the University of Antwerp. The thesis is written in English and is available from the author upon request at bryangalarza1303@gmail.com and from this repository: https://repository.uantwerpen.be/docstore/d:irua:17462.

This dissertation examines the design and optimization of new transportation services. Traditional Transportation Services (TTS) are currently the most implemented bus systems. However, these services are rigid and do not sufficiently meet the needs of passengers because they operate based on a fixed route according to a predetermined timetable. Moreover, these services are typically designed with collective, historical data. Demand-Responsive Public Bus systems (DR-PBS) bring more flexibility to the planning of the day-to-day operation of services. DR-PBS do not operate using fixed routes and timetables, but rather take into account the individual demand for transportation.

On the one hand, fully flexible DR-PBS serve demand very efficiently. On the other hand, TTS provide predictability and easier cost control. As such, the Demand-Responsive Feeder Service (DRFS) is introduced. This feeder service is semi-flexible, as it combines positive characteristics of both TTS as well as fully flexible DR-PBS. The service has mandatory bus stops which are always serviced, as well as optional bus stops, which are only serviced when there is demand for transportation nearby. A Mixed Integer Programming (MIP) model is developed to plan the operation of the buses in the DRFS. Two techniques are proposed to reduce runtimes: a separation of cycle elimination constraints and a column generation algorithm. The column generation model produces integer optimal solutions, implying that the solutions are optimal for the original model. In most cases, the column generation model outperforms the other models and can successfully solve relatively larger instances. However, to solve instances of a realistic size, a heuristic is developed. More specifically, a Large Neighborhood Search (LNS) algorithm. This method produces high-quality results in a short amount of time for 36 different instances. Optimality gaps of less than 0.2% are typically found for the 14 small and mid-size benchmark instances, with runtimes of less than a second. The 22 larger cases are typically solved in under a minute. It is found that the DRFS outperforms the traditional services by more than 60%. On average, DRFS worsens by 6% in comparison to a fully flexible variant. This is a minor increase given that this service, in contrast to the DRFS, does not serve passengers who do not have reservations.

The Feeder Service with Mandatory Stops (FSMS) is introduced to address the shortcomings of the DRFS. A novel heuristic framework is developed to optimize the performance of the FSMS. In each iteration of the heuristic's construction, solutions are constructed in a semi-random greedy manner. Construction parameters bring a balance between random and greedy constructions. This results in a high degree of variability in the generated solutions, allowing the heuristic to find feasible solutions on more strictly constrained instances. To find the best values for these construction parameters, the heuristic employs local search. For 42 different instances, this method produces high-quality results in a short amount of time. The first 15 instances are optimized for one hour using the commercial optimization solver LocalSolver (LS). When compared to solutions obtained by LS, our heuristic yields 12.42% better results on average, within a few seconds. The remaining larger instances are usually solved in less than two minutes.

The operation of the FSMS was optimized with the assumption that all requests are known ahead of time. In a realistic scenario, however, not all requests will be known in advance. Therefore, we present the dynamic FSMS (DFSMS), which optimizes the FSMS in real-time as new requests are received. A two-phase heuristic with an insertion phase and an improvement phase is developed to optimize the DFSMS. The heuristic processes each new incoming passenger request. During phase one, the heuristic attempts to adjust the existing bus routes and timetables to accommodate the new request. During phase two, the heuristic attempts to re-optimize a portion of the planning that has not yet been finalized. When compared to the static variant of the FSMS, the heuristic performs well in most cases, with an average acceptance rate of 95.1% for passenger requests and an average gap of 6.5%. A case study in Antwerp (Belgium) demonstrates that the DFSMS offers a promising alternative to the region's existing transit options. When sufficient resources are available, the DFSMS provides a service with 22% shorter average user journey times and more personalized timetables that better fit the demands of passengers.

This project was supported by the FWO (Research Foundation Flanders), project G.0759.19N.