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Developing an open-source Python-based implementation for designing a master schedule for Demand Adaptive Systems with Machine Learning enhancements

According to the United Nations, the global urban population will increase by 900 million from 2020 to 2030, reaching a total of 5.2 billion. This population increase in combination with already high congestion and traffic emissions in cities all around the world calls for novel transportation concepts to keep up with future urban travel demand. Generally, transportation systems consist of infrastructure (roads, railways, ports, etc) and services (buses, trains, trucks, private cars, taxis, metro). Services usually share infrastructure, e.g., buses and cars share roads, metros, and trains share railways, etc. In cities, oftentimes infrastructure is the limiting factor that leads to congestion and thus inefficient transportation services. Passenger transportation can be partitioned into two main categories. Personalized Transportation Services (PTS), such as private cars and taxis, are carried out for the mobility demand of a single or a small group of passengers with the same origin and destination, while Mass Transit Services (MTS) offer service for many passengers with different origins and destinations. In MTS, passengers share vehicles for part of their trips which leads to more efficient utilization of the (limited) infrastructure and lower cost of transportation compared to PTS. This effect is especially pronounced in situations with fixed routes and schedules where transportation demand is strong, e.g., there is consistently high demand over the service area in a specific time window. On the other hand, when the transportation demand is weak, e.g., low demand or low-population density, MTS with fixed routes and schedules uses more infrastructure than needed and the service becomes inefficient.

Demand Adaptive Systems (DAS) aim to combine traditional fixed-line bus services with flexible routes and schedules. To do so, a DAS bus line provides a traditional transit-line service for a set of compulsory stops. These compulsory stops are bound to a schedule with fixed time windows during which the vehicle serving the line has to leave each compulsory stop. Additionally, passengers may issue requests at so-called optional stops which are not contained in the set of compulsory stops and induce detours in the vehicle routes.

Problem Description

DAS services combining characteristics of traditional and on-demand systems require both a system-design phase and an operational, time, and user request-dependent adjustment of vehicle routes and schedules. As mentioned in Crainic et al. 2012, this type of planning is more complex than traditional transit planning because it involves not only choosing the route and stops but also determining the specific times at which mandatory stops will occur. Due to that reason, designing a DAS master schedule combines elements of strategic and tactical planning.

According to Crainic et al. 2012, the development of a reliable and efficient DAS line master schedule poses a significant challenge, requiring consideration of two essential inputs. The first input pertains to the topological design of the line, which involves determining the sequence of mandatory stops, as well as the partitioning of optional stops into segments. The second input involves analyzing the transportation demand between the stops, which is crucial for fixing time windows at each compulsory stop along the line. The process of selecting time windows for the DAS line master schedule is a complex task that involves reconciling several competing objectives. The optimal selection of time windows should balance the need for vehicles to fulfill all requests for service at optional stops while providing adequate time between compulsory stops. Furthermore, considerations related to economic efficiency, including minimizing the total time of the line, must also be taken into account. Finally, the conflicting quality-of-service demands of users on the bus and at optional stops need to be addressed, including preferences for narrow time windows to avoid delays and short travel times between compulsory stops to minimize time spent on the bus.

Crainic et al. 2012 introduce a mathematical model to address the challenge of designing a master schedule. However, this model has limitations in terms of accessibility and visual appeal. Therefore, the purpose of this thesis is to develop an open-source Python-based implementation of the mathematical model, with a focus on enhancing its accessibility and visual appeal. Additionally, this thesis aims to investigate possible enhancements to the model using Machine Learning techniques.

Aims and Scope

1. Conduct a comprehensive literature review on the challenges associated with designing a master schedule for Demand Adaptive Systems based on Errico et al. 2013.
2. Re-implement Crainic et al. 2012 in a way that is easier to understand, incorporating visualizations to aid comprehension.
3. Create an open-source Python-based project that offers a more accessible and user-friendly approach.
4. Explore potential enhancements, such as faster computation time and more accurate schedules, for the existing mathematical model proposed in Crainic et al. 2012, using machine learning techniques.

References

Crainic, T. G. et al. (2012). "Designing the master schedule for demand-adaptive transit systems." In: *Annals of Operations Research* 194.1, pp. 151–166.

Errico, F. et al. (2013). "A survey on planning semi-flexible transit systems: Methodological issues and a unifying framework." In: *Transportation Research Part C: Emerging Technologies* 36, pp. 324–338.