Converting Schedule Based Buses to Demand Responsive Transport
Extended Abstract

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1 Introduction

Recent developments in Information Communication Technologies (ICT), computational power and methods have made it possible to efficiently coordinate a fleet of vehicles to serve door-to-door requests in real time. Customers could then expect to share the ride in order to decrease the price of the trip compared to a taxi [1]. Traditionally such services are called Dial-a-Ride, and have been offered to the disabled and elderly for decades in a format where orders typically have to occur the day before or earlier [17][13][18]. Recently experiments have been made to offer the services to the wider population [16]. Real life experience and research supports that in areas with low demand density and utilization demand responsive transport (DRT) options can be more cost efficient than the schedule based conventional public transport (CPT) [11][2][14], whereas it can not compete in the dense urban settings where the utilization of buses is high. Other studies have analyzed the potential of DRT to serve as a feeder system into mass transit network [8][15] integrating the two systems. An integrated hybrid solution has been suggested to have merit [10], but to what extent and in what contexts remains largely to be quantified, specifically where the DRT is not solely a feeder system.

The aim of this study is to assess the feasibility of replacing a schedule based bus lines fully or partially with a demand responsive system. Costs and quality of service (QoS) are assessed under the assumption of conventional as well as Connected and Autonomous Vehicles (CAVs). The method is illustrated with the town of Roskilde (Denmark) as case study. As a satellite town of ~ 40000 people with a train station, surrounded by rural areas but in commuting reach of a large metropolitan area (Copenhagen) it represents a common settlement type in Europe that is neither obviously urban nor rural.

2 Methods

The current bus system in Roskilde provides a benchmark for the DRT. Costs are given by the operator for the year 2016 [12] on a line by line basis. Temporal demand patterns are modelled empirically from the Danish National Transport Survey (TU) [5]. With this information scenarios were built as input to the DRT along with the target costs the DRT would have to beat.

To analyze the performance and estimate the costs of the DRT, a dynamic Dial-a-Ride Problem (dDARP) is solved. It is similar to the Vehicle Routing Problem with Pickup and Delivery and Time-Windows (VRPPDTW) with cargo [6], [3]. The objective is then usually to minimize cost of the vehicle routes while satisfying constraints such as time windows, vehicle capacity, duration (such as a day of operations), pairing, precedence and maximum ride-times for each passenger.

The problem is solved by implementing a discrete event simulation (DES) model in `java` where a reoptimization is triggered each time a customer calls (~ 0.5 hours before). Requests are inserted into routes using a greedy best insertion heuristics minimizing the total travel time. All requests that are accepted are then subjected to be moved between routes via a move descend heuristic until their pickup visits are locked. A visit locks when a vehicle is already on it's way from previous visit in route to serve it.

Once the simulation has terminated, performance measures can be compared between the two systems. The Key Performance Indicators (KPIs) designed are as follows:

$$TATT^{\mu} = ATT^{\mu}/DTT \tag{2.1}$$

$$RR = \frac{|U^R|}{|U|} \tag{2.2}$$

$$\eta_{avg} = \frac{|U^S|}{|V| \cdot |T|} \tag{2.3}$$

$$\eta_{max} = \max_{t \in T} \frac{|U^S(t)|}{|V|} \tag{2.4}$$

$TATT^{\mu}$ is the transit auto travel time ratio between the actual travel time ATT^{μ} of mode $\mu \in \{CPT, DRT\}$ and direct travel time DTT with an automobile. RR is the rejection ratio where $U^R \subseteq U$ is the set of rejected requests. η_{avg} is the average serving efficiency; request served per vehicle hour, and η_{max} is the efficiency at the rush hour peak. $U^S(t)$ is the set of served requests at time interval $t \in T$, V set of vehicles.

3 Results

3.1 Analytical Results

A prior cost estimate showed that the dial a ride will never be cheaper if all bus lines are replaced. In Roskilde ~ 11000 passengers are served by the bus system each day, of those around half are served by two frequent and heavily utilized lines within the town. The yearly cost (2016) of all buses is ~ 89 mio. DKK, excluding the two big lines ('2big') ~ 55 mio. DKK [12] (buses within defined system boundaries). In Denmark a common hourly price for an 8 seat van is 375 DKK/hr. [9] and a low estimate for CAV would be 125 DKK/hr. (driver wages [7] taken away). The number of vehicles needed is dependent on the demand at the peak and the peak serving efficiency η_{max}, from that a cost curve for the DRT as a function of η_{max} can be derived. The analysis showed that a normal dial-a-ride could break even at $\eta_{max} \approx 30$ requests served by one vehicle per hour on average, but a low to medium estimate for CAV would break even at around $10 - 15$ req./veh.hr. respectively. Replacing all lines except the '2big' however breaks even at $\eta_{max} \approx 20$ req./veh.hr., while CAVs around $\sim 8 - 11$ req./veh.hr. To put in a taxi perspective at 10 req./veh.hr. it would need to look for, pick up and drop off each passenger within 6 min. on average and never pause to keep up. That efficiency rate can thus only be attained with ridesharing.

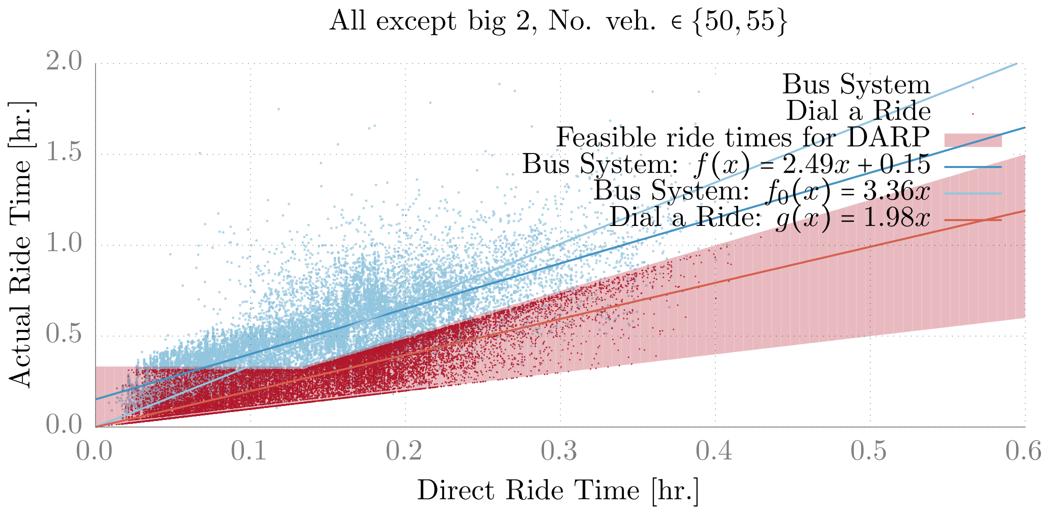

Figure 1: Expected Ride Times of Dial a Ride and Bus Systems vs Direct Ride Times, 'All except big 2' Scenario, Denial Ratio ≈ 5%, 10 instances for each no. vehicles

3.2 Simulation Results

The preliminary results presented here are from simulations run from 6 to 10 in the morning, modelling the morning peak in order to find the vehicle requirement which serves as main input to the cost estimates on the macro level. Two OD-demand pattern scenarios were defined; UNI, any address is equally likely to serve as an origin or destination; and T50, 50% probability of heading to Roskilde Station in the morning. Since analytical results showed that replacing all lines would be infeasible two other scenarios were defined; 'aBig2', all lines replaced except '2big'; 'rural', rural lines replaced and only trips to/from rural zones accepted.

Figure 1 shows a comparison between ATT of the different modes, for scenario 'aBig2' with T50 OD-distribution for a number of 50-55 vehicles allowing $RR \approx 5\%$. As can be seen by the definition of the maximum travel time ($MTT = max(20min, 2.5 \cdot DTT)$ the QoS with relation to DRT is much better than for CPT. The best fitted lines indicate the TATT values. It can be seen than that it takes average 70% longer to travel by bus than DRT ($3.36/1.98 \approx 1.70$). The constant 0.15 in function $f(x)$ of the bus system is due to walking time to/from stops. Figure 2 for the same scenario shows the capacity utilization throughout the period avg. no. passengers per vehicle around 2.5-3.2 depending on the instance for the peak. As can be seen a large portion ~ 30% of the vehicles stand idle at any given time after 8:30 approx.

Cost estimates for 'abig2' normal dial a ride was 120 mio. DKK and 40-62 mio. DKK for low to medium CAV estimates given avg. of 16 operational hours per day. Rough adjustment with relation to idle vehicles could drop the costs to ca. 35-50 mio. DKK. Contrast this to 55 mio. DKK for the current 'aBig2' bus lines or 28 mio DKK given 50% reduction in costs if busses are autonomous too [4]. Rural scenario has comparative results.

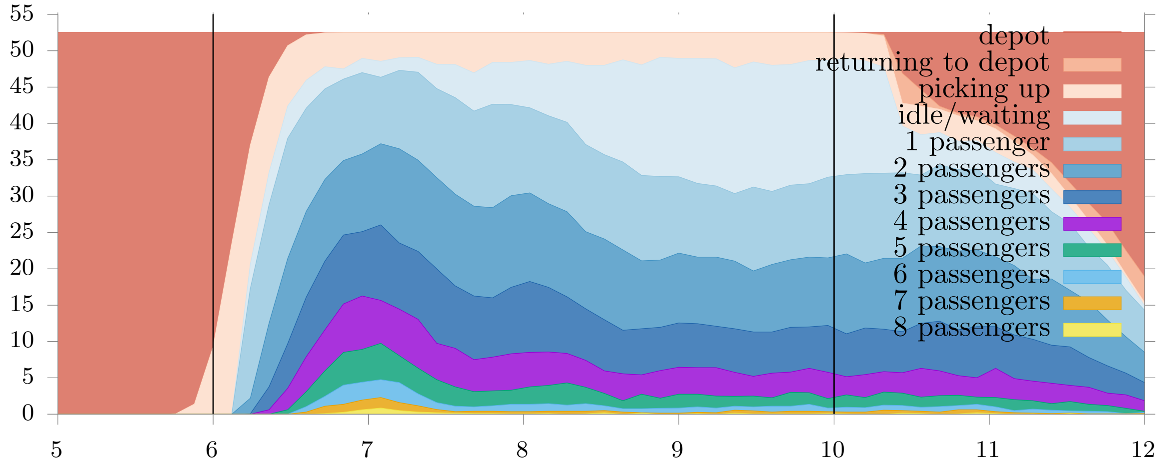

Figure 2: State of vehicles, T50 OD-locations, 'aBig2' Scenario, pickup time windows active between 6:00 and 10:00

4 Discussion and Conclusion

Results clearly indicate that a simple dial a ride would be approximately 2 times the cost of a current bus system and therefore not a competitive alternative for replacement. CAVs designed for ridesharing however will be cheaper or comparative to the current bus system excluding the two high frequency lines in the area, but if buses are assumed to be driverless too they become cheaper again (20%-40%). The QoS however will be substantially better (70% on average for 'aBig2' scenario) with regard to travel time. The service will furthermore be door-to-door providing increased accessibility for the whole area rather than only addresses within proximity to bus stops.

Current limitations include that Rejection Ratio should be 0 for DRT since CPT guarantees that a customer can go from served stop to stop (excluding accidents etc.). This will increase the price of DRT. Demand patterns are also simplified and current work includes using stop to stop demand data from the operator for demand modelling.

Wider implications of this study is that CPT is not going anywhere anytime soon. The two most utilized bus lines were far from feasible to replace, even for driverless vehicles. This implies that in the cities of the future buses, trains and other means of schedule based public transport will continue to be a dominant cheap option for travelers even in suburban areas. DRT will however replace less utilized lines as it gets cheaper, and will in a wider context prove cheaper than private vehicles providing competitive QoS attracting users from those modes. These different modes of transportation will co exist in the future with CPT still providing the cheapest option but DRT attracting users willing to pay for higher QoS.

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