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Assessing impact of replacing public transport with demand-responsive transport in Canberra

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1. Introduction

Demand Responsive Transport (DRT) is a flexible mode of transportation that enables passengers to request rides based on their specific needs, rather than relying on a fixed timetable. DRT has been suggested as a potential alternative to Public Transport (PT) services in areas with low demand. Recent research has highlighted the advantages of introducing DRT as a flexible transportation option in urban and rural areas (Daniels and Mulley, 2012). Dytckov et al. (2022) conducted a study where they replaced local bus routes with DRT in rural regions, revealing that DRT proved to be a more sustainable mode of transport for serving low-demand areas. Calabrò et al. (2022) showed that fixed PT routes benefits from integrated DRT systems as a feeder for initial or end legs of a passenger's trips in rural areas. In a similar research, Coutinho et al. (2020) showcased that replacing PT with DRT in low-demand regions resulted in reduced empty vehicle running, improved environmental impact, and increased service capacity. Moreover, Mulley and Daniels (2012) quantified the role of flexible transport services in enhancing access to PT by redesigning PT networks with a new trunk fixed scheduled bus route supplemented by flexible transport services as a feeder. The findings demonstrated that flexible services provided significantly higher accessibility to PT and the potential for increased frequency without requiring additional subsidies. Beyond its operational benefits, DRT has also proven effective in catering to the transportation needs of individuals with disabilities, highlighting its potential as a valuable social service. Despite these advantages, it is important to note that several existing DRT systems have fallen short of meeting their financial expectations (Currie and Fournier, 2020, Enoch et al., 2006). Therefore, it is crucial to evaluate DRT systems before implementing them and to find ways to optimise their efficiency to ensure their long-term sustainability.

This study aims to investigate the potential impacts of DRT services as a substitute for local PT in order to gain a better understanding of its financial impact. While it is essential to clarify that this research does not have intention to recommend replacing single fixed bus route with the DRT, for performance analysing purposes, three different real-life scenarios from a local bus route in Canberra, Australia are investigated. The efficiency of DRT is compared to the existing PT, using operational performance indicators obtained from the simulation, including number of required vehicles, travelled distance, service duration, operational cost, fuel consumption, passengers' travel time. The findings suggest that replacing PT with DRT can have positive effects on the environment and passengers' convenience, although its cost-effectiveness is not fully established. The cost-effectiveness of DRT depends on the level of demand it faces, as it proves to be a cost-effective option for low demand scenarios, while becomes less efficient as demand increases.

2. Methodology

To evaluate the potential effects of replacing PT with DRT in an actual setting, a simulation analysis is conducted. In this simulation, DRT is modelled as a Dial-a-Ride Problem (DARP). The standard DARP involves serving a set of requests with a given number of vehicles with limited capacity. These requests include pick-up and drop-off locations, desired arrival or departure times, and limits on visiting time (known as time window), maximum ride time, and tour duration. The usual objective of this problem is to minimise the required total travel distance for serving all the requests (see Cordeau and Laporte (2003) for more information and a problem description). To perform this comprehensive simulation and find an optimised plan for DRT, the study uses the deterministic annealing algorithm developed by Braekers et al. (2014).

In the post-processing of the simulation, the simulated DRT's performance is evaluated against the existing PT service from three perspectives: operational cost, environmental impact, and passenger inconvenience. The cost efficiency of the modelled DRT and PT is compared using the operational cost explained in equation (1), which includes distance-based costs and driver costs of running the system. As the focus is on the operational costs for running services over the examined period of time, the vehicle procurement costs are not included in this objective.

$$Operational\ cost = (Travel\ distance \times Fuel_{con} \times Feul_{price}) + \ (shift_{hour} \times Driver_{cost}) \quad (1)$$

The first component of equation (1) is associated with the cost of travel. In this equation, $Travel\ distance$ is equal to total travel distance of each system. $Fuel_{cons}$ and $Fuel_{price}$ denote the fuel consumption per 100 kilometer and fuel price, respectively. The fuel consumption of the systems is based on the average reported consumption of 12-seat vans (8.5 litre/100 Km) and urban buses (28.12 litre/100 Km) (Toyota, 2023, Transport Canberra, 2023a). The reported value for fuel price is the average fuel price in the city of Canberra on November 2022 (Australian Institute of Petroleum, 2022). The second component pertains to the drivers' expenses, where $Shift_{hour}$ and $Driver_{cost}$ represent the shift duration, and drivers' payment per hour, respectively. The cost of hiring drivers is estimated according to the opening job advertised for hiring bus drivers in the city of Canberra on the date this simulation analysis starts (Transport Canberra, 2023b). The environmental impact of DRT and PT is compared based on the fuel consumption of the system (first component of equation (1)). Finally, the passengers' inconvenience is compared based on the average passengers' travel time.

3. Case study and data preparation

Canberra serves as the capital city of Australia with the population of 452,672 individuals in 2021, covering an area of 393 square kilometre. Canberra stands out as a sparsely populated city owing to its abundant open space and nature reserves within the city. The population density of Canberra is almost 1152 individuals per square kilometre, which is significantly lower than other major cities in Australia, such as Sydney and Melbourne with 2,141 and 2,880 population densities, respectively (Australian Bureau of Statistics, 2021).

The PT network in Canberra comprises 66 routes that serve various destinations throughout the city and surrounding areas, consisting of a light rail line, nine rapid bus routes that offer inter-suburb services, and the remaining routes are local bus routes that provide more direct connections to specific neighbourhoods. Despite the well-developed PT network in Canberra, it often encounters low-demand scenarios in suburbs, which can reduce its overall productivity and efficiency. Consequently, this study aims to replace a local bus route in one of the suburbs of this city with DRT and compare their respective performance.

In order to achieve this objective, route 45 is selected to be replaced as the busiest outbound PT local route in the Canberra (out of city centre), carrying over 12,000 passengers per month, on average. The data utilised in this study was obtained from the passengers' tap-on and tap-off "My-Way" cards. Based on the available data from August 2020 to the end of July 2021.

Figure 1: Approximate location and map of route 45, Canberra (https://www.transport.act.gov.au).

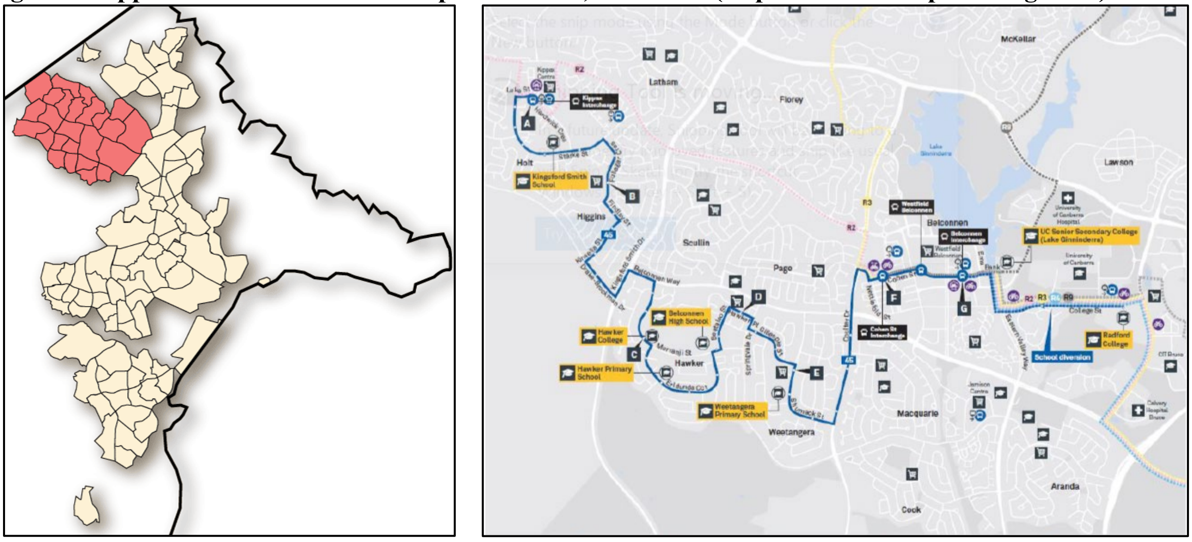
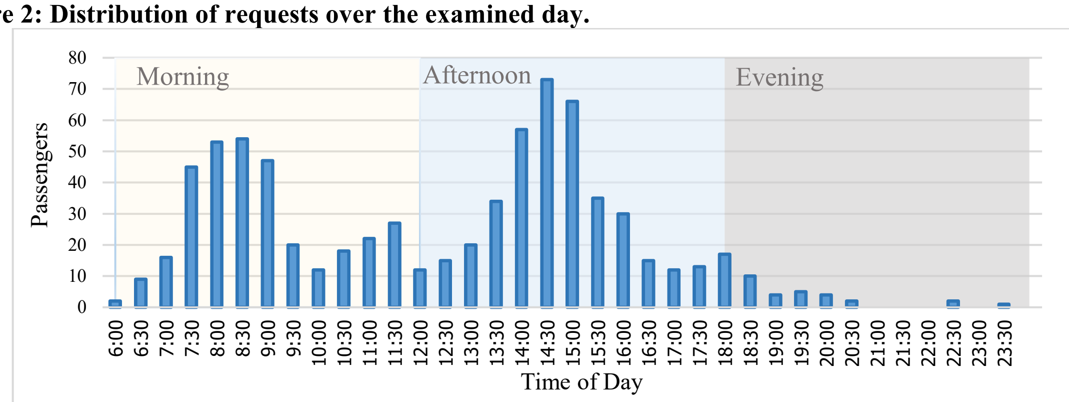


Figure 1 shows the location and map of the selected local bus route for this study. Route 45 has 32 stops and operates almost every 30 minutes (except during late evenings when the frequency changes to 60 minutes) with an average travel time of 30 minutes between the two terminals. For the simulation, the busiest weekday over the period of data, with 752 passengers transported by this service route. To account for driver shifts in the modelled DRT, three scenarios were created: morning, afternoon, and evening scenarios. Separating examined day to three shifts scenario also help us to evaluate potential impact of demand change on the performance of systems, where the morning scenario has 325 passengers, the afternoon scenario has 382 passengers, and the evening scenario has 45 passengers. Figure 2 shows the distribution of requests throughout the examined time period for each scenario. The highest request density can be observed during the afternoon scenario, with a maximum ratio of 140 passengers per hour, while it is equal to 104 and 27 for the morning and evening scenarios, respectively.

Figure 2: Distribution of requests over the examined day.



Several assumptions are made during the conducted simulation in this study to implement the identical situation for DRT in the simulation process according to the operational characteristics of the replaced bus route. Firstly, only current demand is considered, and the potential impact of replacing existing systems on demand is not considered. Additionally, all requests are assumed to be known in advance. The tap-on and tap-off locations are used as the origins and destinations of requests. Furthermore, the tap-on and tap-off times are assumed to be the desired arrival or departure time of the request. For half of the randomly selected passengers, the time window is set to their origin, while for the other half, it is set to their destination. The time window width is set based on the headway and frequency of the most replaced fixed bus route over the examined day, which is set to 30 minutes ($\pm$ 15 minutes from passengers tap on/off time). This approach guarantees that DRT's passengers' waiting time does not exceed the maximum possible waiting time experienced by passengers of the regular bus service and DRT pick up/drop off passengers in their specified time windows. Additionally, the ride time is set as the travel time between the terminals of the selected route, which is equal to 30 minutes. For consistency and fairness, simulated DRT's fleet of vehicles start/end their tours from/at the selected bus route's terminal. The maximum duration of a tour is specified as the maximum shift hours for the drivers, which in this study is set to 6 hours.

4. Results

The performance of PT and simulated DRT are compared by the required number of vehicles, total distance travelled, total tour duration, operational costs, fuel consumption, and average passengers' travel time. The performance of the PT is calculated based on the actual operational characteristics of the replaced service (Transport Canberra, 2023c), whilst the DRT's performance is evaluated using the optimised operational plan obtained from the adopted method, as discussed in Section 2. Figure 3 presents comparison between DRT and PT across all scenarios.

Plot a illustrates that the required number of vehicles for PT is lower than or equal to DRT in all scenarios. In the low demand scenario (evening), both systems require the equal number of 4 vehicles. As demand increases, required number of vehicles for DRT to fulfill the requests increases to 5 and 10 vehicles for morning and afternoon scenarios, respectively, while it remains fixed for PT and equals to 4 vehicles.

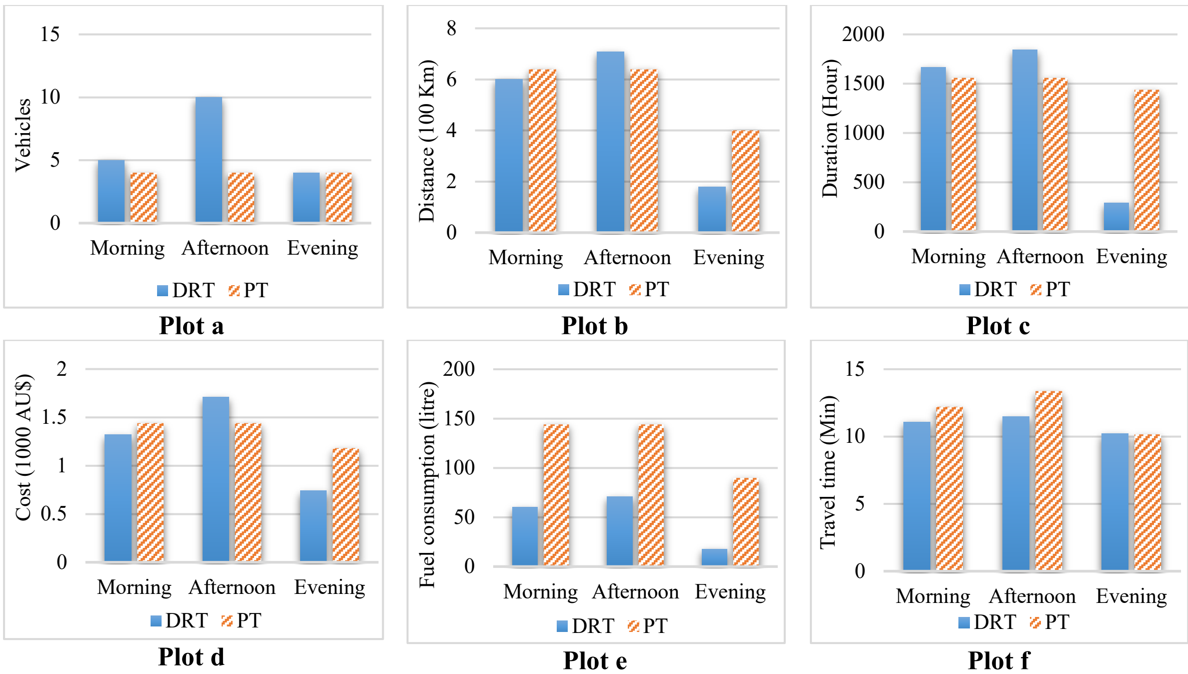
Based on Plot b and Plot c, in the low demand scenario, the travelled distance and total duration time for the DRT system are significantly lower than those for PT. In evening scenario, the travelled distance and service duration of DRT system are equal to 179 km and 290 hr, which are 55 percent and 80 percent lower than PT's travelled distance and service duration, respectively. As demand increases, DRT shows comparable and slightly worse than PT's performance in terms of travelled distance and total duration. While PT's travelled distance is 640 km for both morning and afternoon scenarios, DRT's travelled distance are 600 and 709 km for morning and afternoon scenarios. In addition, DRT's service time is higher than PT for both morning and afternoon scenarios, where DRT's duration time is 6 and 18 percent Higher than PT duration time, respectively.

Plot d compares the DRT and PT's performances in terms of operational cost. This experiment shows that DRT is a notably cost-effective replacement for PT in low demand scenarios. In the Evening scenario, the operational cost of DRT is almost 40 percent lower than the PT's operational cost. The results indicate that running DRT for transporting passengers in evening scenario requires almost 740 AU$, while it is equal to 1,180 AU$ for PT. However, demand growth has more influence on the operational cost of DRT. This comparison demonstrates that PT becomes a more cost-efficient system in high demand scenarios, such as the afternoon scenario. In afternoon scenario, running PT requires 1,440 AU$, while it is equal to 1,710 AU$ for DRT. According to the analysis of DRT's performance in terms of distance and duration between morning and afternoon scenarios, there are only minimal differences observed. Therefore, it can be inferred that the most crucial factor contributing to the increase in operational costs of DRT during the afternoon scenario is the number of required vehicles or drivers.

Plot e pertains to environmental impact. In this experiment, fuel consumption is considered as the indicator of environmental impact. The results demonstrate that DRT is a more environmentally friendly system than PT across all scenarios. DRT's fuel consumption is 85 percent and 70 percent lower than PT's fuel consumption in low (evening) and high demand (morning and afternoon) scenarios, respectively.

Regarding passengers' convenience, in all scenarios DRT provides a better or equal quality of service in all scenarios (Plot f). The average travel time of passengers is improved by 10 percent and 15 percent in morning and afternoon scenarios, while it remains almost the same for the low demand scenario. According to this analysis, passengers on average spend 10.2 minutes traveling by each of the transport systems. However, during morning and afternoon scenarios, the average travel time increases to 11.1 and 11.5 minutes for DRT, and 12.2 and 13.4 minutes for PT, respectively.

Figure 3: Performance comparison of DRT and PT. Plot a: number of vehicles - Plot b: distance travelled - Plot c: total duration time (total service time of systems) - Plot d: operational cost - Plot e: fuel consumption (environmental impact) - Plot f: passengers' average travel time (passengers' convenience).



5. Conclusion

The objective of this study is to examine the potential impact of substituting PT with DRT as a local transport service. The study evaluates the performance of DRT in low and high demand scenarios, and compares it with the performance of existing PT. This analysis considers three perspectives: operational cost, environmental impact, and passengers' inconvenience. The results show that in scenarios of low demand, DRT outperforms PT in terms of operational cost and environmental impact, while providing an almost equivalent travel experience for passengers. However, as demand increases, the operational cost of DRT is significantly affected. Therefore, the results suggest that DRT displays a promising level of performance and potential for success in substituting for PT in low-demand scenarios.

The study's results imply that the use of a DRT system can offer advantages in low-demand areas, with the model being optimised based on distance travelled. To gain more insight about the potential impacts of DRT with different prioritising in objective of the problem, future research can explore a multi-objective function. Additionally, this study considered several assumptions in the simulation process to ensure consistent conditions for both systems. However, to address more realistic conditions, future studies may explore the impact of DRT implementation on demand alteration, changes in the origin and destination locations of requests, changes in preferred arrival/departure times of passengers, impact of DRT on waiting time of passengers, and investigate on potential network effects of DRT in combining passengers from different routes to provide more efficient system in their simulation process.

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