Proceedings of 23^rd International Scientific Conference. Transport Means 2019.

Vehicle Routing of Special Urban Transport Service

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Abstract

Special Urban Transport Service (SUTS) is used by people in wheelchairs, those who use crutches, temporarily or permanently disabled including people with reduced mobility or elderly persons. These passengers need specific conditions for their transportation. That causes higher operation costs of SUTS due to a lot of factors: special modified vehicles, special way and time of reservation process (through a dispatcher), individual mode of transport (door-to-door), time-limited operation or reduced ticket price for passengers. One important aspect that affects operating efficiency of SUTS is coefficient of vehicle occupancy and related route scheduling. The paper is focused on optimisation of vehicle routes and its impact on total operation costs of SUTS. Method of exhaustive search for vehicle routing optimisation is described in this paper as well as the model for evaluation of total operation costs. Economic and technological data of SUTS from the year 2017 are used as input data for optimisation. Outputs of optimisation are compared to the situation in SUTS Pardubice (2017).
KEY WORDS: *optimisation, people with reduced mobility, special urban transport service, trip clustering*

1. Introduction

Two kinds of extreme types of public transport scheduling (organisation) include regular service and demand-responsive service. Regular service has a fixed timetable and fixed routes. Routes are scheduled on the basis of transport demand analysis in the given area to transport maximum number of passengers. Demand-responsive service may be realised on any route and with flexible timetable. This service is arranged upon request including individual approach to the customer. This type of scheduling does not aim at satisfying all requirements of customers regarding time and destination. Disadvantage of the demand-responsive service lies in reduced predictability of transportation range and lower capacity of vehicles.

Compromise solution between regularly scheduled service and irregular demand-responsive service is achieved when it is operated on fixed routes with flexible timetable. This system has been used on some bus lines of regular public transport service: buses run to villages with low transport demand only upon request (booking call). This system can be useful also for people with reduced mobility when using nonbackbone bus lines of urban public transport means with stops near Health Centres, Welfare facilities or Organizations for People with Disabilities.

To satisfy requirements of disabled people or other passengers (e.g. older people with crutches), the concept which combines regularly scheduled and demand responsive transport (fixed routes with flexible timetable) can help. Transport is carried out as regularly scheduled with possible deviations from the route [1]. Timetable specifies only the route of the bus line but times of departures from less frequented stops are deliberately omitted. Only departure times from transfer points or other important stops are defined there. Passengers travelling from stops between them have to wait for the service in the interval between departure from the previous stop and arrival at the following one. Travel time between stops is set in a more tolerant way to observe departure times from all such stops even if buses serve them rarely. Therefore possible isochrones of route deviations are specified when scheduling these routes. If the stop is equipped with a digital information panel, it is possible to inform passengers about the deviation from schedule. Disadvantage of this concept lies in longer travel time for passengers travelling only from stop to stop and greater deviations from the schedule compared to regularly scheduled urban public transport. This can also have an impact on transfer time between SUTS and public urban or long-distance passenger transport [2].

Densely populated cities attempt to use urban public transport in maximum extent also for people with reduced mobility. Demand-responsive service (door-to-door service) can be provided in big cities and agglomerations. Transport problems for PRM do not have to be brought only by quality of transport. People with reduced mobility often prefer individual transport to public regardless higher costs. There are not only physical but also psychological barriers. As the survey carried out in Poland and the Czech Republic [3] showed, these include also shyness (disabled people can be uneasy around others) or inappropriate behavior of drivers and / or others passengers. These issues are dealt by social sector helping PRM with social integration and teaching the society right attitude to them.

2. Trip Clustering

Costs of demand-responsive services with flexible routes and timetable can be optimised e.g. by clustering [4]. The municipality of Pardubice have one specially modified car Fiat Ducato with capacity 5 – 9 seats available [5].

Optimisation process aims at increasing annual coefficient of vehicle occupancy using exact methods (e.g. exhaustive search) or heuristics (evolutionary algorithms, genetic algorithms, vehicle-routing problems, e.g. Clark-Wright method). Cargo transport optimisation tasks occur in literature more frequently [6], [7]. The extent of this service provided by Pardubice municipality (1car) enables using exact method of route optimising. All feasible solutions of the task are found first. Because of high computational demands, it is necessary to identify limiting conditions (maximum number of passengers, trip origins and destinations, i.e. graph vertices). To serve one customer, it is necessary to pass through two graph vertices, whose order is not interchangeable (first it is necessary to collect the customer at the pick-up address and take them to the destination address). Next step implies evaluation of all feasible solutions based on the set criteria using multi-criteria analysis (WSA method). In this case the following criteria were selected to evaluate variants of feasible routes:

- total travel time/costs of transport (min.);
- travel time/costs deviations per passenger trip (min.);
- coefficient of vehicle utilization (max.).

The results bring percentage evaluation of individual feasible solutions based on selected values of criteria. The route with the highest score of WSA is considered optimal. Disadvantage of this kind of solution lies in high computational demands when searching for all feasible solutions and limited range of vertices to pass through. To solve optimisation of SUTS routes in Pardubice, we selected maximum of 8 vertices (when clustering routes of maximum 4 customers, we get 40320 route permutations, out of which 2521 are feasible). This range is sufficient for optimisation of routes for only one time window (feasible time range for the route is max 2 hours). Daily vehicle routing and scheduling consists of calculation of optimal routes for every time window. Calculation of optimal routes between time windows is not carried out in this case.

3. Impact on Technological and Economic Indicators

Optimization results were compared to selected days of registered routes in 2017. Table 1 presents values of the actual distance travelled (traffic performance in km) in comparison with optimised route of a selected day. First two cases (days) bring positive impact – vehicle kilometres travelled reduction. The last case (the last line in the Table 1) shows worse results for optimised route compared to the actual route. That was caused by low number of passengers on selected day when almost every customer occurred in a different time window. Therefore, the software was not able to cluster more passengers because it only clustered trips in one time window.

Table 1

Comparison of selected routes

	Number of passengers	Number of km (actual situation)	Number of km after optimisation (MS Excel)	Number of km after optimisation (ODL studio)
1 March 2017	18	150	125.3	118.2
2 March 2017	20	140	131.5	130.4
3 March 2017	12	110	115.5	111.2

The last column in Table 1 shows information about the route optimised by ODL studio software (*Open door logistic studio*) applying single-objective optimisation (minimisation) using total vehicle route costs.

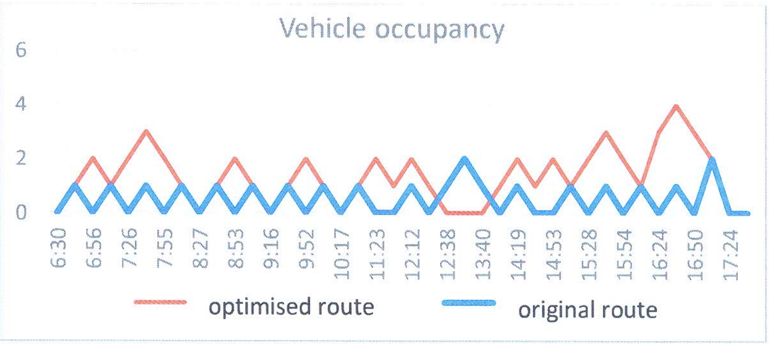

Fig. 1 Vehicle occupancy on a selected day

Fig. 1 shows vehicle occupancy on original and optimized route by means of *ODL studio* software compared to trips from 1 March 2017. This process results in grouping of up to 4 passengers into feasible time window 16:24 – 17:24 h. Travel time can be too long for some passengers, which might be viewed negatively. Such long travel times can be eliminated in the *ODL studio* software only when the routes are manually adjusted by the user.

Fig. 2 displays various scenarios for annual number of transported passengers (pass-km). Provided that there is a direct correlation between traffic performance (veh-km) and transport performance (pass-km), it is possible to fit straight lines to the chart showing average annual occupancy of the vehicle. Maximum capacity of the SUTS vehicle in Pardubice is 5 wheelchair users. Blue dashed line shows maximum annual vehicle occupancy (occupancy coefficient = 1). This vehicle occupancy value is theoretical and it cannot be achieved with demand-responsive way of transportation. Red line represents average vehicle occupancy in 2017 (10%). Traffic performance 35 000 veh-km corresponds to 17 500 pass-km (transport performance). This situation is marked by the blue spot. If the average vehicle occupancy increases by 10% while maintaining the same traffic performance (veh-km), the transport performance (pass-km) increases by 50%. We can make a realistic assumption when introducing dispatch management - increased vehicle occupancy to 15%, while cutting down the number of travelled km (traffic performance) by 10% (yellow spot).

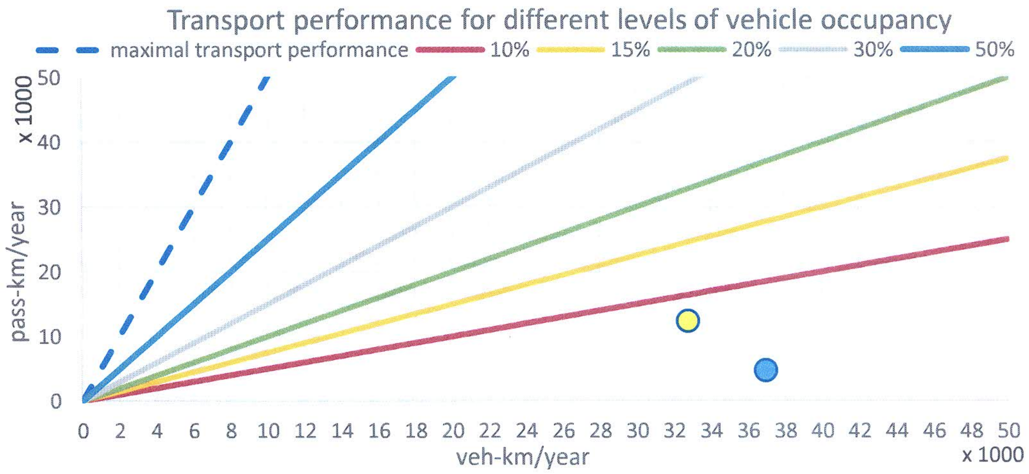

Fig. 2 Number of transported passengers (transport performance) and vehicle occupancy

4. Tariff Changes

Fig. 3 displays how traffic performance (veh-km) depends on overall economic balance (difference between costs and revenues from passenger tickets without municipality subsidies). Blue line shows total vehicle operating costs in dependence on kilometres travelled per year (traffic performance). In 2017 total operating costs of SUTS Pardubice reached 989 568 CZK (ca. 38 430 €). Dashed lines show total vehicle operating costs including revenues from passenger tickets.

Fig. 3 Financial loss (STUS 2017)

SUTS ticket price in Pardubice is 15 CZK (0.58 €) for one trip in Zone I (city zone) regardless the number of kilometers travelled by one customer. The blue spot displays vehicle operating costs of 921 807 CZK (35 798 €) where the average annual vehicle occupancy is 10 % and traffic performance 35 000 veh-km. Every time the vehicle occupancy increases by 10% (dashed lines), the costs reduce by 67 350 CZK (2 616 €), which is the value corresponding to overall annual revenue from fares.

According to this model, STUS total operating loss was 221 807 CZK (ca. 8 610 €) in 2017 when subsidized by municipality in the amount of 700 000 CZK (ca. 27 200 €, which is marked by red solid line in Figs. 3 and 4). To make a profit, it would be necessary for the operator to increase vehicle occupancy to 30 % and cut down traffic performance (veh-km) to 11 500 (yellow spot in Fig. 3) while maintaining the ticket price and amount of subsidies. Transport performance of the year 2017 (17 500 transported passengers) remains the same with these parameters of annual indexes.

Fig. 4 displays proposed fare increase from original 15 CZK (ca. 0.25 €) to 30 CZK (ca. 1.17 €). Proposed fare increase stems from comparison of fares in other cities in the Czech Republic [8]. Under the same circumstances (30 CZK as the ticket price, traffic performance of 35 000 veh-km, average vehicle occupancy of 10%, annual subsidy of 700 000 CZK), there would be loss in the amount of 155 904 CZK (6 063 €). To make a profit, 20% vehicle occupancy and cut down traffic performance (to ca. 17 500 veh-km/year) would be sufficient while increasing the price to 30 CZK and keeping the subsidies in the amount of 700 000 CZK. It is clear from the graph that in this situation the operator could make profit of 1 750 € maintaining annual transport performance 17 500 pass-km.

Fig. 4 Financial loss of STUS after fare increase

5. Conclusions and Discussion

Pardubice municipality believe that STUS significantly contributes to improvement of life quality for people with disabilities. Therefore they spend a considerable amount of money annually subsidising this service. Possibilities for optimisation of operating STUS and their impact on passengers and operators were analysed in the context of the student grant project. The proposed solution for routing is based on the concept of flexible routes and flexible timetables. For this model, clustering is presented as an option of optimisation together with economic effects of higher vehicle occupancy coefficient when maintaining or increasing fares. To keep annual transport performance (pass/km) and make a profit, it would be necessary to increase vehicle occupancy to 30 % and simultaneously cut down traffic performance (veh-km) by ca. 2/3 when keeping fares and subsidies on the same level. The annual transport performance (17 500 pass-km) reached in 2017 would remain the same. On the contrary, if fares increase, 20 %vehicle occupancy would suffice when reducing travelled km by ca. 50 %.

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