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HOW LEAD TIME BEFORE SERVICING INFLUENCES THE COMPETITIVENESS OF AN AUTOMATED ON-DEMAND SHUTTLE: A CASE STUDY

Summary. A simulation study was employed to investigate the question of how an automated shuttle fleet can be sensibly parameterized in on-demand transport. The two main influencing parameters studied were lead time, which indicates the delay before starting the journey to the first demanding customer, and the number of shuttles to reach dedicated service levels. The operation should be able to replace a conventional bus route. In addition to passenger transport, the automated shuttles are also used to organize parcel delivery services. An innovative vehicle concept consisting of the drive unit and the exchangeable payload was used for this purpose. This paper examines the passenger transport use case, for which up to three shuttles will be available. The level of service that can be achieved with different operating logics was simulated. In terms of demand, a traffic count by the bus operator was used, although the shuttle service as a demonstrator will presumably generate different and additional demand. Based on the analyzed scenarios, the times for which a shuttle should wait before serving the first incoming demand can be estimated in order to balance bundling effects and total waiting times for passengers and to characterize the overall service quality.

1. INTRODUCTION

In local public transport, new types of services will be added to existing ones in the future. The familiar forms include [1] scheduled public services, shuttle services, ride sharing, ride pooling, and taxi services. So-called on-demand services are new to local public transport (e.g., the MOIA service in Hamburg) [2]. Such services are also referred to as demand responsive transportation services [3], although the exact form of operation has not yet been specified. These are transport services that transport passengers on prior order without a fixed route between specific boarding and alighting points within a defined area and fixed operating times. In Germany, these transport services are regulated in [4]. The IMoGer project [5] will establish a demonstrator for future mobility in the "Schwarzer Berg" district of Braunschweig, a town in Germany with a quarter of a million inhabitants (see Fig. 1).

The innovation trends currently under development include automation and digitalization. The concrete implementation of these two trends is currently being advanced as part of the IMoGer project. A shuttle service will be established for the passenger transport use case, which will be demonstrated alongside a freight transport concept. The ability of the system to demonstrate an on-demand service is a key aspect of the project. Users should be able to book journeys and be served spontaneously, with the shuttles adapting the route of the conventional bus line running there. There are no plans to vary the route, at least in the test area.

Therefore, a demonstration operation will be implemented based on the U-Shift (see Fig. 2) fleet in Braunschweig [6]. This operation will act as a showcase for customers, public transport authorities, and transport companies to make the concrete implementation tangible and scalable for their own applications. However, it remains unclear how this operation must be designed in order to be competitive

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with current forms of transport. This study, therefore, examines the basic parameters for passenger operation and compares them with the status quo. The study focuses on passenger transport, but the project’s scope also includes a logistics use case based on the special design of the fleet.

Even if the use case in Braunschweig is only a demonstration intended to make the technical possibilities tangible for users worldwide, the question remains regarding what advantages such a system offers over conventional (bus) systems. For transferability, it is therefore necessary to determine the effort that must be made with new mobility solutions in order to achieve at least the level of service of the previous system. Based on this baseline, it can then be analyzed to what extent improvements can be made compared to the status quo and at what price this would be achieved. In this paper, we focus on the traffic impact of the new system, particularly from the customer's perspective. The question of how long it will take to be served at the stop if one's own behavior is no longer based on timetables will arise for every on-demand shuttle system and will determine its success.

The autonomous, driverless, electric vehicle concept “U-Shift” enables a new type of modularity through the separation of the driving module and transport capsule and, thus, also a new intermodality, new products, and business models. The driving module can be used in combination with various types of capsules to transport both people and goods. Examples of applications include autonomous, electro-mobile night deliveries, autonomous intra-logistics, and barrier-free passenger transport. The autonomous drive module integrates all the components and systems required for driving. In addition to the electric drive, battery, and automation components, the drive board has an integrated lifting system that allows the quick and easy replacement of different types of capsules. According to [7], the replaceable payload capsules are changed "on-the-road" (i.e., during operation) to enable new transport and mobility services. The capsules are only equipped with the most necessary technical equipment and can therefore be produced cost-effectively. Automation is much more closely linked to the infrastructure than current cooperative automated driving (CAD) approaches. U-Shift utilizes the next level of automation known as managed automated driving (MAD). Key elements of this type of automation are protection via infrastructure-side sensors, the optimized use of the road infrastructure, and the shuttle service simulated in this study in the "Schwarzer Berg" district of the city of Brunswick.

The examined district is accessed via a circular road, sections of which are named "Am Schwarzen Berge" and "Sielkamp." At the eastern edge, this road connects to "Hamburger Straße." The combined tram and bus stop "Stadion" is located close to the intersection. The area is characterized by an urban mix of multi-storey residential units in the northern settlement area, a sub-center with local amenities, a school, a kindergarten, a retirement home, and small-scale development with terraced, semi-detached and detached houses in the southern area. The entire area is connected to traffic via a junction with "Hamburger Straße" near the Braunschweig stadium. All other roads in the settlement area end in green spaces and are limited by the River Oker to the west and the railway line to Wendessen to the north.

As of June 2025, public transport in the service area was provided by Bus Route 454 during the day. This line runs every half hour from around 6:00 a.m. to 8:00 p.m., with slightly different departure times and, in some cases, departure points in the later evening hours. The last journey of the day is sometimes offered as a call line taxi (ALT). Outside of this time, there are occasional journeys on Route 414 in the service area. The demonstration operation with the U-Shift shuttles only takes place during the day. Therefore, for comparative analyses, the focus was on the peak traffic period between 6:00 a.m. and 8:00 p.m. However, the demonstration operation will probably take place in significantly shorter time windows in order to meet the demand for interested parties who would like to ride the shuttle services as test subjects.

Bus Route 454, which operates in this area, travels the ring exclusively in a counterclockwise direction. The infrastructure with bus stops is also only located on the outside of the ring road. This special feature will also be adopted for the demonstration of operation with the U-Shift shuttles. The standard plan is to offer shuttle journeys between line departures. The focus is on experiencing an automated shuttle. On selected days, however, the test operation will also aim to make better use of the possibilities offered by digitalization and demonstrate on-demand transport instead of scheduled services. In the test area, a demand-responsive service will likely take place, meaning that the basic route will remain the same and all stops will be served in the same order. This will enable a better quality of service to be realized than with a fixed timetable. However, it is not clear how a suitable operating strategy would have to be parameterized in order to offer a substantial advantage over regular services in practice. During the evaluation phase of the shuttles, the current bus service will maintain its normal operations to satisfy customer demand and give a second choice to interested customers. In [8], customer feedback addressed many practical issues, such as getting a booking or disappointing service quality.

Fig. 1. Service area and current Bus Route 454. Credit: Stadt Braunschweig I Abteilung Geoinformation I Digitaler Basiszwilling

Fig. 2. The U-Shift as a minibus (front), as a goods transporter (rear), together with the single passenger capsule (center). Credit: DLR (CC BY-NC-ND 3.0)

2. METHODOLOGY

This study is motivated by the lack of clarity about the operational parameters in on-demand trial operation for passengers, especially concerning the DLR's U-Shift shuttles. A simulative parameter study was conducted under the assumption of some more or less fixed dependencies. A microscopic simulation model of the test area was created and used for the traffic effects.

Due to the decisions made in the IMoGer project framework, this study is based on existing conditions. Essentially, these include the usability of up to three passenger capsules in the planned design with seven seats, together with the associated drive boards. The route corresponds to that of Line 454, which currently runs as a one-way loop line. The traveling speed of the U-Shift shuttle is expected to be lower than that of the regular service, which is currently limited to 30 km/h on most of the route, mainly due to the speed limit. For safety reasons, the shuttle's maximum speed is expected to remain well below this, as this is a test run of an automated shuttle without an active driver. A maximum speed of 18 km/h was set for the simulations, and this was the case for another study with autonomous shuttles investigated by [9]. This does not actually lead to a significant extension of the tour, as it is very short in absolute terms and only lasts around 6–8 minutes. Passenger changeover times are of much greater importance.

A microscopic simulation model based on the commercial simulation software "Anylogic Professional" was created for this study. The road network in the test area, including the existing stops, was modeled. Other road traffic was also modeled in addition to the shuttle and bus traffic under consideration so that stochastic effects could be included in the simulation of the traffic. However, due to traffic’s overall subordinate volumes and generously dimensioned road cross-sections, this addition had only a minor disruptive effect on operations.

Anylogic makes it possible to create microscopic and agent-based traffic simulations. The road network to be used in the current test operation was generated using the simulation. In addition to the ring road, it also considered the connection to the Stadion stop, where there is a (non-modeled) transition to Lines 1 and 10 in Braunschweig. All existing side streets were also modeled in order to enable a more realistic traffic scenario with additional road traffic. For this purpose, sources and sinks of motorized individual traffic were created, which represent the real (but, overall, quite small) number of travel relationships. The main task of the simulation was to generate the passengers at the bus stops and have them wait for service. Passengers who were picked up by the shuttle traveled to an individual destination along the route and got off there. The distribution of origins and destinations of passengers used in Demand Scenarios A and B are shown in the Table 1 below. The simulation also took over the control logic of the shuttles used, in particular with regard to the lead time and the departure signal of the shuttles waiting at the start stop. The waiting times at the en-route stops were randomly diced from the triangular distribution of waiting times for each operation. The entire simulation used internal random variables to model stochastic variability. The simulation in each demand scenario was therefore limited to one run, and a change in lead time by (a further) 10 s was implemented for the next simulation run. In a more in-depth analysis, a higher repetition rate of 100 was deliberately used in order to fulfil the requirements of a Monte Carlo simulation. An even more precise analysis using further simulation runs could provide more statistically reliable figures, but the assumptions about future operation remain subject to uncertainties. As the results already show a harmoniously changing picture from step to step, the analysis with up to 100 stochastically cubed repetitions fulfils the requirements of the study.

All simulated departures start and end at the "Stadion" stop. A capacity of 70 passengers was assumed for the existing regular service (Bus Route 454). The passenger figures available from surveys in May 2024 show that the operator, Braunschweiger Verkehrs GmbH (BSVG), regularly uses vehicles with capacities of 69 and 74 passengers in the study area. At no time in the selective surveys were there more than 39 passengers in the vehicle, which means that almost all passengers were able to use a seat.

For simulations with the DLR's "U-Shift" shuttle, a capacity of seven passengers was assumed. The configuration included seven seats and a multi-purpose space that could be used for wheelchair users or pushchairs, for example. Standing room was not offered. Although this limited the capacity to the existing number of seats, the de facto availability of seats known from conventional bus operations was adopted as a quality criterion. The shuttle’s size was relatively small in comparison to other tested configurations, but its key feature was the ability to split into a drive board and the passenger capsule, which means the drive board could be used with another payload if the passenger capsule was not in use. In [10] major tests of on-demand services were collected, and shuttle sizes ranged from five to 26 seats per vehicle.

The stopping times of the vehicles at the en-route stops were approximated with a triangular distribution (minimum value = 10 s, most probable value = 15 s, maximum value = 25 s). The mean values of the recorded real stopping times varied between 13 s and 19 s. The arrivals of passengers willing to travel were randomly generated in the simulation based on the arrival rate for each hour, regardless of whether the service was scheduled or on-demand. The real arrival distributions of passengers in the known scheduled service did not show a random distribution. Instead, most passengers arrived at the stops shortly before the scheduled departure. However, this behavior represents passengers who are already adapted to the supply and does not reflect a free demand response. In this respect, we assumed that there is a random distribution of demand for transport, which is influenced by the announcement of the timetable in such a way that waiting times are at least partly waited for at the point of departure (e.g., at home) and only to a lesser extent at the stop itself. In this respect, identical demand arrival distributions were used for scheduled services and on-demand transport, thus creating a link to the moment when the customer is ready to use the service.

For the on-demand operation mode with U-Shift shuttles, an operational waiting time was introduced, which was waited for after receipt of the first service request before the journey was initiated. In addition, there was always an assumed general departure delay of 10 s which is used for immediate journey preparation and for closing the doors. The operational waiting time is among the parameters analyzed in the parameter study for dimensioning the operation. It defines an additional departure delay, aiming to fulfil further, spontaneously occurring service requests during the waiting time or the journey and, thus, achieve bundling effects. If the operational waiting time is longer, the waiting time until service is provided will be longer, at least for the demand triggering the journey. At the same time, the utilization of the vehicle increases due to the desired bundling effect. Whether this increases or decreases the waiting time for other passengers depends on the specific situation. With lower bundling effects, the waiting time should generally increase with higher departure delays, as the operational delay only occurs again with the next departure and thus becomes effective for those passengers who were not registered in time for the previous service journey.

In real-world trials, different values have been used in testing, but five minutes seems to be the expectation for a good service [11]. The additional waiting time is called “lead time” and it was used in the present study to better distinguish from waiting times from passengers’ perspectives. [12] stated that the maximum waiting time for passengers should not exceed 10 minutes, whereas it is of relevance whether waiting starts at the earliest pickup time or at booking off the pickup location. In the given testbed scenarios, demanding passengers arrive at the station and request transportation immediately. In real trial tests, the arrival of passengers was tracked by Bluetooth Low Energy transmitters and a cell phone app, according to [13, 14]. When arriving in the signal’s receiving area, the customer’s cell phone sent a message to a backend. For the simulation study, the same arrival event acts as a trigger for the mentioned service claim.

The other dynamic value considered in the parameter study was the number of vehicles deployed. In trial operation, a maximum of three U-Shift drive boards were expected to be available for a maximum of three passenger units, which together can represent a maximum of three passenger transport vehicles that can be used in parallel. Therefore, all scenarios for the above-mentioned variation of the operational waiting time were simulated with one, two, and three available shuttles. All vehicles used for on-demand transport always ran along the fixed route and served the existing demand as long as it did not exceed the available seating capacity. If passengers could not be picked up, this triggered the activation of the next shuttle when it arrived at the starting stop. If there were more than one vehicle, the next available shuttle was sent on its journey, even if the vehicle that was already full was still underway. Similarly, the next shuttle was sent on its journey if there was a demand for service and the shuttle already in circulation had passed this stop. If several vehicles were in operation at the same time, the rule in the simulation was that the shuttles were not to overtake each other.

On the demand side, two different scenarios were modeled. On the one hand, a generic demand model was used that assumed a general fluctuation in demand over the course of the day. On average, around 220 passengers were transported per day, half of whom boarded at the start stop ("Stadion"), while the other half boarded at all other stops on the circular route. Such a scenario could be relevant for the trial operation, in which passengers are likely to travel to a stop specifically to use the shuttle and would not travel there without the trial operation. This scenario is labeled as “Demand Scenario A.”

On the other hand, a scenario was compiled from real count data collected by the local public transport provider BSVG (“Demand Scenario B”). These data, provided to us from May 2024, were automatically recorded using appropriately equipped buses. These buses circulated throughout the network, which is why not all journeys on a given day were documented. Instead, average values were calculated for each of the records and used as simulation input. As the count data are available for each stop on the route under consideration (Route 454), each stop was given its own demand map. Although the count data show boarding, alighting, and total passengers for each stop, no clear relationships emerged between these measurement data (i.e., it was not possible to trace who boarded and alighted where at the passenger level). In the simulation, we instead used constant probabilities for all scenarios as to which stop the respective passengers would like to travel to. The scenario based on the extracted count data contained approximately 160 passengers for the operating day (from 6:00 a.m. to 8:00 p.m.).

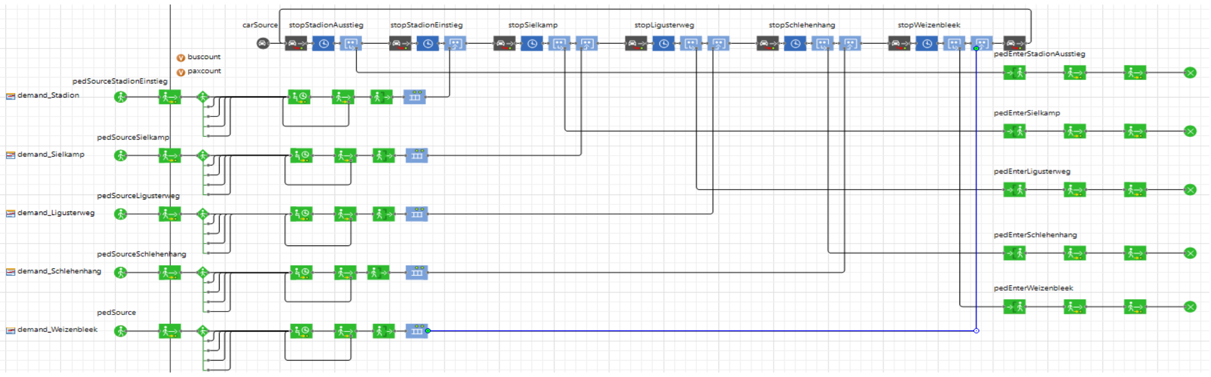

Fig. 3. Simulation flow chart for entering (left side, green boxes) and disembarking (right side, green boxes) the shuttle on its counterclockwise path through the test area (upper side, blue boxes)

The demand data used for Scenario B are based on real count data collected on boarding and alighting processes along the conventionally operated Route 454, from which it was possible to estimate the proportion of destination stops requested from each stop. However, precise passenger-related tracking did not take place, which is why the origin-destination relationships cannot be reproduced exactly but can only be reproduced in terms of quantity. In the simulation, probabilities were derived from this for each stop at which a person making a request wanted to reach one of the following stops on the route (Table 1). Due to the inhomogeneity of the population density in the test area, around 40% of all destinations were accounted for by the “Schlehenhang” stop when boarding at the "Stadion" start stop. This stop, alongside the stop at the stadium, is the stop with the highest demand.

Table 1

Probability with which passengers at the origin stop requested service to the destination stop

p (o:d)	origin stop				
Destination stop	Stadion	Sielkamp	Ligusterweg	Schlehenhang	Weizenbleek
Sielkamp	0.2	0	0	0	0
Ligusterweg	0.2	0.05	0	0	0
Schlehenhang	0.4	0.05	0.05	0	0
Weizenbleek	0.1	0.1	0.05	0.05	0
Stadion	0.1	0.8	0.9	0.95	1

3. RESULTS

In the scenario with higher traffic demand (“A”), a comparison of the average waiting times for service shows a clearly recognizable area in which an on-demand service would have advantages over service at half-hourly intervals. For operation with exactly one U-Shift demand responsive transportation shuttle (“DRT shuttle” in the charts), and a lead time of no more than 11 minutes led to better results for the average waiting time. Assuming a lead time of five minutes (300 s), for example, this resulted in an expected waiting time of 10 minutes at the stop (see Fig. 4). If two U-Shift shuttles were used, the expected waiting times were significantly reduced, on average by 226 s across all lead time values (from 733 s to 507 s). This almost always resulted in an advantage over the existing scheduled service for all lead time values analyzed up to a maximum of 15 minutes.

However, adding a third vehicle did not lead to a significant increase in service quality, as the gain in waiting times was very small (mean value of all waiting times = 492 s). If we look at the utilization of the vehicles deployed, we can also see that three vehicles ran at almost the same capacity as two. This is a clear indication that a third vehicle was unnecessary, at least given the assumptions made in this study and the assumed passenger numbers. If only one vehicle were to be used, this would result in significantly higher utilization rates (Fig. 5). For example, a lead time of approximately five minutes resulted in a utilization rate of slightly more than two passengers per trip for two and three shuttles, but more than 3.5 passengers per trip for just one shuttle. As a benchmark, the scheduled service with half-hourly intervals is also shown as a point in the diagram. With the large buses that are usually used, an average capacity utilization of 7.2 passengers per trip was achieved, significantly more than in on-demand operation. If a single U-Shift vehicle was used instead of the bus in the half-hourly regular service, a capacity utilization of 7.7 passengers per trip would be achieved. However, the downside would be that many passengers would not be taken on the first service to the stop because the capacity of just seven seats would already be utilized. This hardly ever happens on scheduled city bus services, as they provide more than enough capacity, at least for average days. Another interesting aspect is on-demand transport with the U-Shift shuttles. If only one is available for operation, "denied boarding" occurs more frequently because the shuttle is already full and the passengers left behind can only be served on one of the following journeys (Fig. 6). In the variation of the lead time from 0...900 s in 10-s increments (=91 simulation runs), a total of 409 such cases occurred in the simulation. With two and three shuttles, this occurred much less frequently, and it only occurred for longer lead times. Even more passengers could not travel as desired in the scenario with three shuttles (31 cases) than in the scenario with two shuttles (27 cases) because of the specific simulation and the randomized service arrivals, which led to a slightly higher number of service requests in an apparently less even distribution on average.

The availability of the shuttles in on-demand transport is also reflected in the number of tours traveled. Scheduled services with a large city bus set the benchmark, with 28 journeys. With on-demand transport and three shuttles while immediately responding to any requests as they arose, an extremely high number of kilometers driven was achieved in just under 200 journeys. However, the availability of three shuttles was also relativized, as the lead time increased and the number of trips made with two and three shuttles became increasingly similar. If only one shuttle was available, between 89 and 34 journeys were realized, depending on the lead time (Fig. 7).

The results were qualitatively similar in the scenarios based on average values of passenger demand from count data from the transport company BSVG (“Demand Scenario B”), but they are also significantly less pronounced at the extremes due to the lower passenger numbers. In all variants, significantly fewer passengers were not transported directly because the vehicle was fully occupied. A maximum of 10 passengers per day were affected, and only for certain, absolutely high lead times (Fig. 10). Whether such a demand-related overload occurs depended not only on the set parameters but also on the randomness of the generated demand. Due to the overall lower demand of around 160 travelers per day, the number of trips traveled was also significantly lower compared to the scenario discussed first, with around 220 passengers per day in this case. Overall, this scenario, which was based on real data, also shows a tendency for two shuttles to offer transport advantages for users compared to one shuttle, but it also leads to expected higher costs for service provision. This is reflected in the lower capacity utilization (Fig. 9). Using three shuttles only increased costs but did not improve service quality and, therefore, were clearly oversized.

The layout of the study stipulated that each scenario could be simulated only once. To this end, each scenario was derived from the previous scenario by means of an incremental step, thus creating a certain diversity of scenarios. However, a valid impression of the range of results could be obtained only if scenarios were simulated a sufficient number of times and stochastic elements ensured random results. This procedure led to a Monte Carlo simulation. For this reason, three scenarios were simulated 100 times each in this study. Due to the generic model parameters, which could not be validated on an existing system, a fixed value of repetitions was chosen instead of a more meaningful metric for the convergence of the results. Scenarios with a lead time of 300 s were selected. On the one hand, this meant a high level of service for passengers, but on the other hand, it meant that considerable bundling effects were already offered. The availability of one, two, and three shuttles was analyzed. It was again assumed that passengers only communicated their journey request when they arrived at the stop. In real life, users will surely order online and even before leaving the origin, but this simplification was set to present comparable results in simulations. As a result, passengers waited 8.5 minutes for service when one shuttle was available and approximately 6 minutes when two or three vehicles were in operation (Fig. 8). The standard deviation was around 22 s for one vehicle and around 12 s for two or three vehicles, which indicates a significantly reduced spread (see Table 2).

Table 2

Simulation results for one to three available shuttles and a lead time of five minutes
(each scenario randomly repeated 100 times)

Number of shuttles available		Number of passengers [1]	Average waiting time for service [s]	Average number of passengers per tour [1]
1	Var	167.16	479.05	0.04
	Std	12.93	21.89	0.20
	Mean	160.32	510.74	2.85
2	Var	232.67	155.88	0.02
	Std	15.25	12.49	0.13
	Mean	161.00	367.43	2.08
3	Var	177.82	135.17	0.02
	Std	13.33	11.63	0.12
	Mean	161.59	358.57	2.05

4. DISCUSSION

The aim of the task was to find a sensible framework for the trial operation of the U-Shift vehicle fleet for the passenger transport use case in the IMoGer project. In the absence of a known demand for ridesharing in this test field—and with the intention of operating the whole thing as a scalable showcase for mobility solutions of the future—two different demand scenarios were quantified using a parameter study.

The lead time (i.e., the response time of the vehicle after receipt of the first journey order in on-demand operation) was simulated in a range between 0 s and 900 s in 10-s increments. In addition, the number of shuttles operated simultaneously varied from one to three. Each scenario was simulated exactly once in this parameter study. The small step size for the lead time resulted in a variety of parameter combinations, which at first glance appeared to be at least meaningful.

The omission of a Monte Carlo simulation (i.e., the multiple repetition of simulation runs with the same parameters but different simulation starting seeds) was acceptable at this point, as the large number of adjacent simulations suggests a sufficiently plausible result.

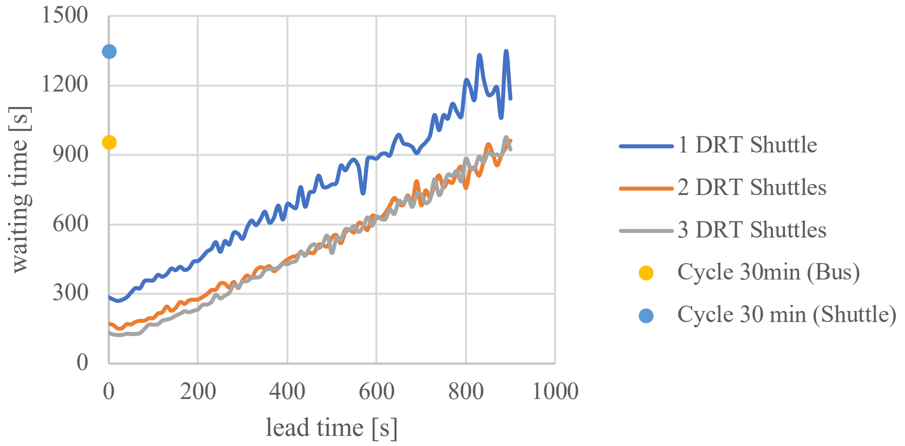

Fig. 4. Average waiting time for service (Demand Scenario A), depending on the shuttle's lead time (additional waiting time before tour start after the first customer claimed for service)

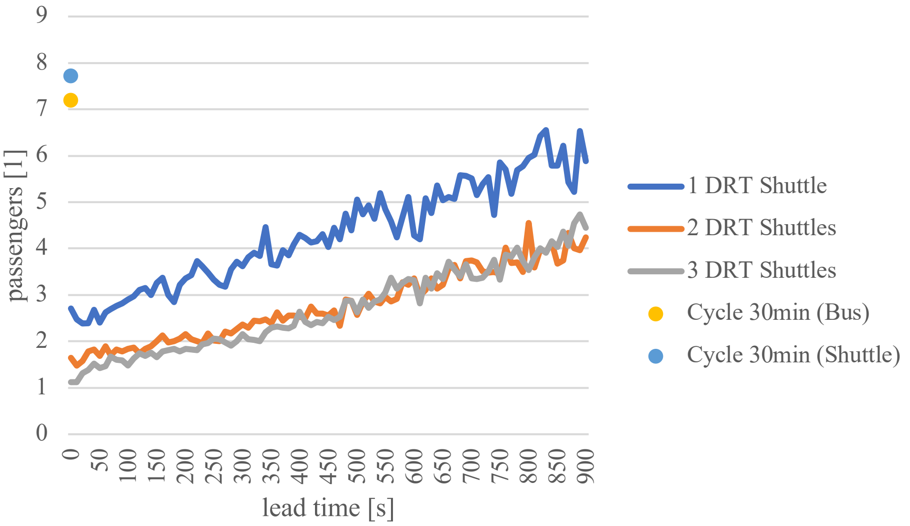

Fig. 5. Passengers per tour (Demand Scenario A)

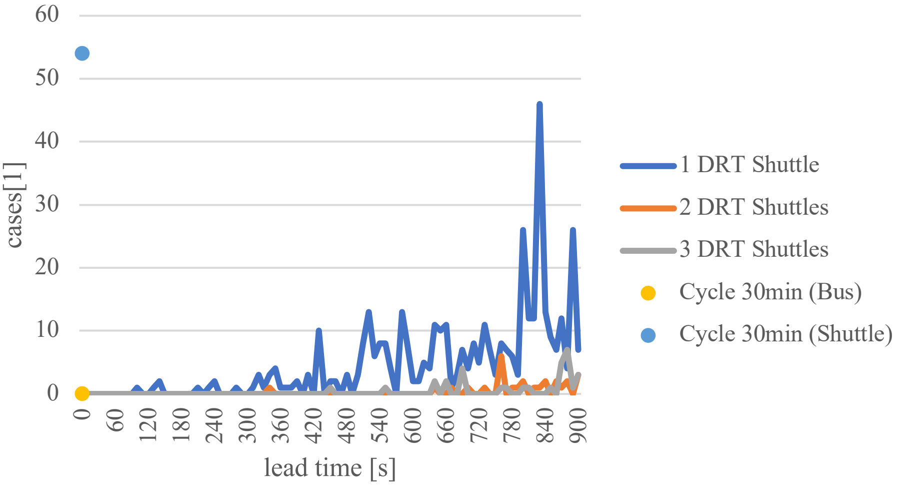

Fig. 6. Denied boarding – number of cases (Demand Scenario A)

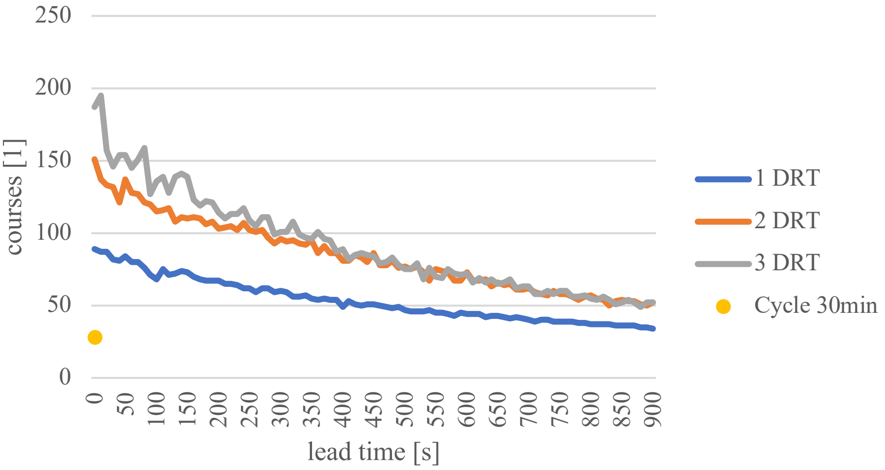

Fig. 7. Number of courses (Demand Scenario A)

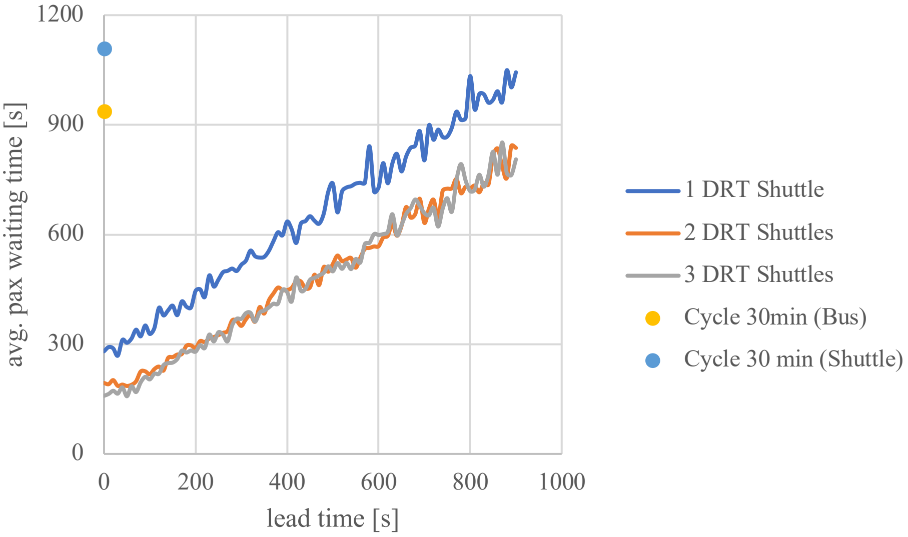

Fig. 8. Average waiting time for service (Demand Scenario B), depending on the shuttle's lead time (additional waiting time before tour start after the first customer claimed service)

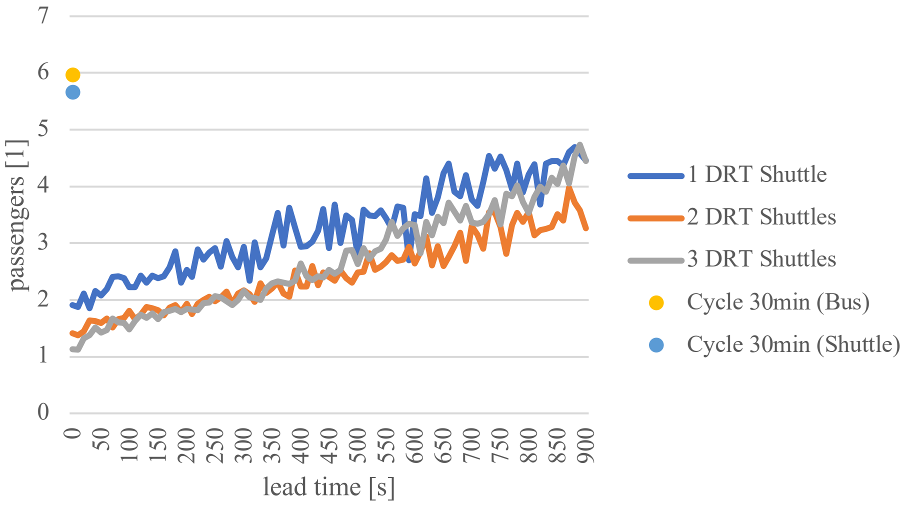

Fig. 9. Passengers per tour (Demand Scenario B)

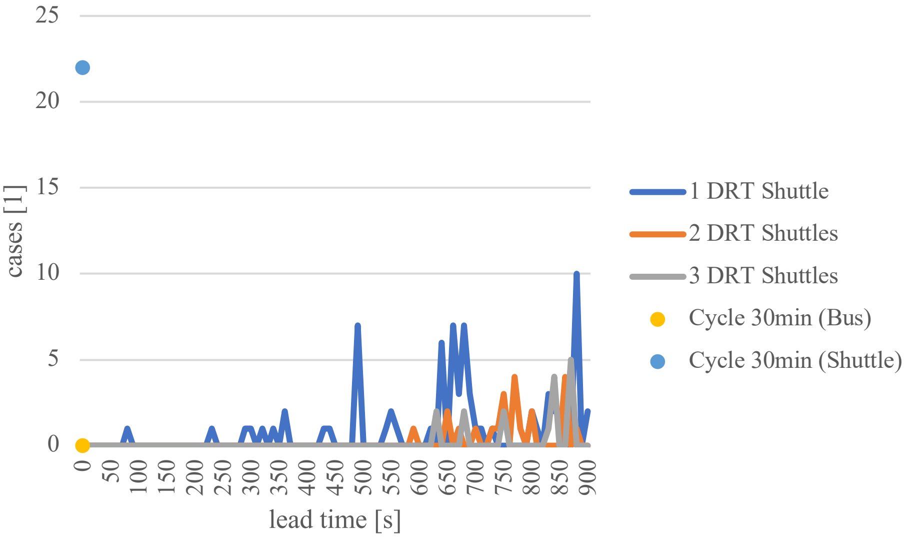

Fig. 10. Denied boarding – number of cases (Demand Scenario B)

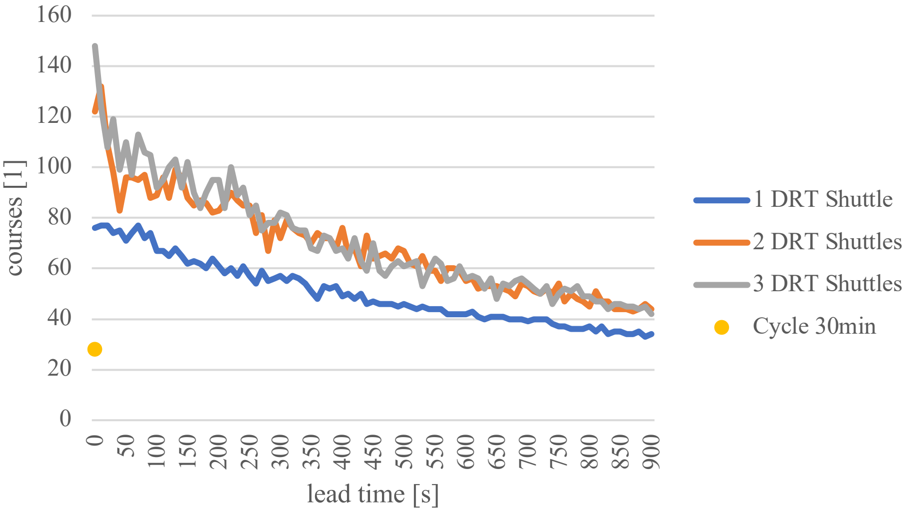

Fig. 11. Number of courses (Demand Scenario B)

It is possible that the specific situations that could occur in a real implementation cannot be precisely predicted with this limited simulation range. Nevertheless, the simulations serve as an initial rough estimate of how the company could be organized. It is also planned to use the trial operations' learnings as an input to adapt the ongoing operation accordingly. Due to the novelty of the U-Shift system, special features will be required that cannot be parameterized precisely in advance but could have an impact on operational characteristics. These include the actual traveling speed of the shuttles in the test area, which has yet to be determined. Due to automation, a driverless operation will be presented, and to ensure safety, the traveling speed must not be too high. In addition, only seated passengers are permitted, and standing places may not be used, at least in test operation as part of the IMoGer project. As the overall ride will be linked to the consent of a test person's agreement due to legal regulations, the operation of the parallel Bus Route 454 will be maintained. It can be assumed that the "test passengers" traveling on the bus will almost without exception represent additionally generated demand. It is also possible that the passenger changeover time will be significantly longer than usual on the bus route due to the special conditions of the ride. If necessary, the scientific staff on site at the stops or the traveling safety driver will have to answer passenger questions before the passenger changeover is completed. This can result in considerable journey time extensions, as the pure journey time is relatively short due to the shortness of the circular route and is largely determined by the stopping times.

Moreover, the two assumed demand scenarios represent only a small portion of the possible demand scenarios. With the scenario based on real passenger numbers, the currently known situation can be considered with regard to the scaling for replacement by an on-demand shuttle of the U-Shift type. A shuttle with a response time of five minutes, for example, would offer clear advantages over the current half-hourly scheduled bus service, but it would also have to disappoint customers from time to time due to its limited capacity. Two shuttles would already cover demand with a very high level of service, leaving practically no demand unmet. The test area and the demand for transport are too small for three shuttles. However, the test area is well-suited to three shuttles, as not all three always have to be active in the circulating service. This allows time for recharging, cleaning, and repairs. In addition, further vehicle deployments are planned for freight transport, which will reduce the availability of the three shuttles.

5. CONCLUSIONS

For the test operation in the IMoGer project with a fleet of up to three U-Shift vehicles, the reaction time (lead time) with which the vehicles start at the starting stop in on-demand mode for operation when the first journey order arrives was investigated. The journey orders were triggered in the simulation when passengers entered the stop and requested a ride via an app, for example. Even if passengers do not appear at the bus stop at random in reality but instead follow the timetable, it can be assumed that the actual transport request would be randomly distributed. The concept of on-demand service allows users to book a journey spontaneously. Compared to scheduled services, there are advantages from the customer's point of view if the aforementioned response time is not so long that it is similar to scheduled services. In the status quo, the fixed interval means that this is around half the interval length. A potentially favorable "sweet spot" is five to 10 minutes for the service to be attractive compared to conventional scheduled services. At higher values, the bundling effects increase, which generally improve efficiency but increasingly mean that journey requests can no longer be taken into account, as the vehicle is already fully occupied. The preliminary simulations show that the average waiting time for service with one vehicle can be maintained in the case of two (and three) vehicles, but the response time can be extended by approximately three or four minutes.

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References

1. Baier, M.J. & Sörensen, L. & Schlüter, J.C. How successful is my DRT system? A review of different parameters to consider when developing flexible public transport systems. *Transport Policy.* 2024. Vol. 159. P. 130-142.
2. MOIA: Elektro-Shuttles Hamburg - hamburg.de. 2025. Available at: https://www.hamburg.de/verkehr/e-mobilitaet/moia-410946.
3. Alonso-González M.J. & Liu, T. et al. The potential of demand-responsive transport as a complement to public transport: an assessment framework and an empirical evaluation. *Transportation Research Record: Journal of the Transportation Research Board*. 2018. Vol. 2672(8). P. 879-889.
4. §44 PBefG: Personenbeförderungsgesetz in der Fassung der Bekanntmachung vom 8. August 1990 (BGBl. I S. 1690), das zuletzt durch Artikel 7 Absatz 4 des Gesetzes vom 11. April 2024 (BGBl. 2024 I Nr. 119) geändert worden ist [In German: German Law on Passenger Transportation §44 PBefG].

5. Automatisierte Testflotte auf Braunschweigs Straßen. 2025. Available at: https://www.bmv.de/SharedDocs/DE/Pressemitteilungen/2025/013-wissing-foerderbescheid-automatisierte-testflotte.html. [In German: Automated test fleet on Braunschweig's streets].
6. Ulrich, C. & Friedrich, H.E. & Weimer, J. et al. Technologies for a modular vehicle concept used in passenger and goods transport. In: *19. Internationales Stuttgarter Symposium* 2019. P. 587-598. Available at: https://link.springer.com/chapter/10.1007/978-3-658-25939-6_49.
7. Österle, I. & Ulrich, C. & Herwartz-Polster, S. et al. Benefits and costs of shared, modular automated vehicles for freight and passenger transport: the case of U-Shift. *Transportation Planning and Technology.* 2022. Vol. 45(3). P. 203-225.
8. Nelson, J.D. & Phonphitakchai, T. An evaluation of the user characteristics of an open access DRT service. *Research in Transportation Economics.* 2012. Vol. 34(1). P. 54-65.
9. David, E. & Kurt, F. & Scheier, B. & Mittag, S. Optimization of DRT concepts using the SUMO simulation software: How can the service quality be improved? *Transportation Research Procedia* 2023. Vol. 72. P. 3972-8.
10. Pettersson, F. An international review of experiences from on-demand public transport services. 2019. Available at: http://www.k2centrum.se/sites/default/files/fields/field_uppladdad_rapport/on-demand_pt.pdf.
11. Archetti, C. & Speranza, M.G. & Weyland, D. A simulation study of an on-demand transportation system. *Int Trans Operational Res.* 2018. Vol. 25(4). P. 1137-1161.
12. Lu C, & Tiwari, S. & Nassir, N. & Nagel, K. Efficient operation of demand-responsive transport (DRT) systems: Active requests rejection. *Procedia Computer Science*. 2024. Vol. 238. P. 81-90.
13. Shafik, M. Emerging Cutting-Edge Applied Research and Development in Intelligent Traffic and Transportation Systems. *Proceedings of the 8th International Conference on Intelligent Traffic and Transportation (ICITT), Incorporating the 8th International Conference on Communication and Network Technology (ICCNT).* Florence, Italy. 16-18 September 2024. Creating a Traveller Digital Twin: Bluetooth Low Energy for Fine-Granular Traveller Localisation.. 1st ed. Amsterdam: IOS Press Incorporated; 2024. (Advances in Transdisciplinary Engineering Seriesv.63).
14. Rudolph, F. & Grunewald, E. & Tremer, D. Dividing Journeys in Milestones – A passenger (agent) trajectory reference. *Transportation Research Procedia*. 2023. Vol. 72. P. 2046-2053.

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