Title: Simulation of passenger demand and operating cost scenarios for the use of autonomous shuttles in rural public transport

Abstract

Problem Statement

Recent data on mobility behaviour in rural areas show the great dependence on cars: For example, in the peripheral districts of Austria and England, around 70% of trips are made by car (Tomschy et al., 2016; DEFRA, 2018). Low population density and gaps in the public transport supply in these areas are major reasons for the dominant use of cars. Urbanisation and an ageing population pose further challenges for rural mobility systems. Demand responsive public transport services and sharing systems with human operated vehicles are reaching their limits, be it with regard to accessibility (e.g. to the Car-Sharing locations) or due to the lack or cost of personnel in the region (Eckhardt et al., 2018). Therefore, autonomous public transport and sharing services are being discussed as a potential solution to create a comprehensive mobility service that enables sufficient mobility without a car even in rural areas (VDV, 2015; ERTRAC, 2019). Such services are piloted in several countries (see e.g. Nordhoff et al, 2018; Rentschler & Manz, 2019) but are currently mainly operating in prescribed operational domains (e.g. university campuses) and are still in early phases of development. In order to advance this technology towards higher levels of automation, the ongoing Austrian flagship project "Digibus® Austria" carries out technological and operational field tests in order to develop the foundations for a reliable and safe operation of autonomous bus shuttles on open roads in mixed traffic in a regional driving environment (Digibus Austria, n.d.). Besides the technological challenges, the user acceptance of these shuttles and whether a viable business case can be made for their operation are further questions for research. This paper presents work in progress on the analysis and simulation of the transport demand impacts and economic viability of potential scenarios for the Digibus® autonomous shuttles for "last-mile" rural transport.

Approach

In order to be able to identify the ideal area of application for autonomous shuttles, we are developing an integrated simulation model for possible Digibus® operating scenarios that simulates the effects of the introduction of autonomous shuttles on transport demand and costs for the operator. For this purpose, a system dynamics model approach is used whose strengths lie in the depiction of strongly interrelated predictive variables and complex system effects over time. An example of such a feedback effect is the negative spiral of increased car use, decreasing utilisation of public transport and increasing car dependency in peripheral regions. System Dynamics models are particularly well-suited to addressing strategic issues in the transport sector, as they may be less detailed than conventional transport models, but can map a larger number of system elements and their interactions (Abbas and Bell, 1994, Shepherd, 2014).

To this end, we firstly develop a qualitative model (Causal-Loop-Diagram) of the relationships and feedback structures influencing potential usage, modal choices and economic impacts of potential use cases for autonomous shuttle buses in rural transport. The impact relationships used for the CLD model are determined from literature and expert knowledge acquired from project partners. In the second step, this model is operationalised in a stock-flow-model for the specific Digibus® case study and calibrated with results from the pilot operation of the bus in 2020.

Progress so far

The qualitative part of the CLD development has been finalised, forming the dynamic hypothesis for the model. The resulting Digibus® system dynamics model is subdivided into four submodels („User Acceptance", "Passenger Potential", „Operating Concept", and "Mode Choice") whose basic structure,

key variables and interdependencies are shown in Figure 1. The acceptance of the Digibus® bus shuttles and the choice of transport mode affect the number of potential passengers. This passenger potential in turn influences the chosen operating concept and, in turn, the choice of transport mode and acceptance of the offer. The resulting full CLD is provided in the supplementary material to this paper.

From the relationships presented in the CLD, four main feedback loops have been identified: Based on a potential increase in the number of passengers there are two reinforcing loops via increasing word of mouth and increased efficiency, as well as two balancing loops through potential overcrowding and additional waiting times and negative user experience (see supplementary material for more detail).

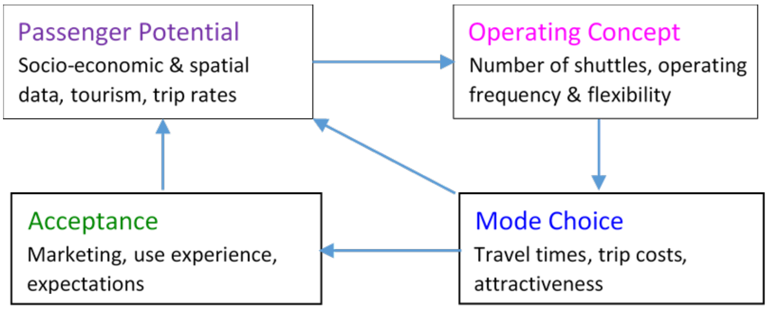

Figure 1: Overview of submodels of the Digibus® model

The effects that dominate and their impacts on passenger demand and economic viability of the shuttle bus will only become apparent from a quantitative simulation. Hence, we are converting the CLD into a stock-flow-model. Figure 2 shows the draft submodel for the balancing loop of overcrowding and increasing waiting times. We use literature and information from project partners for initial model parameters.

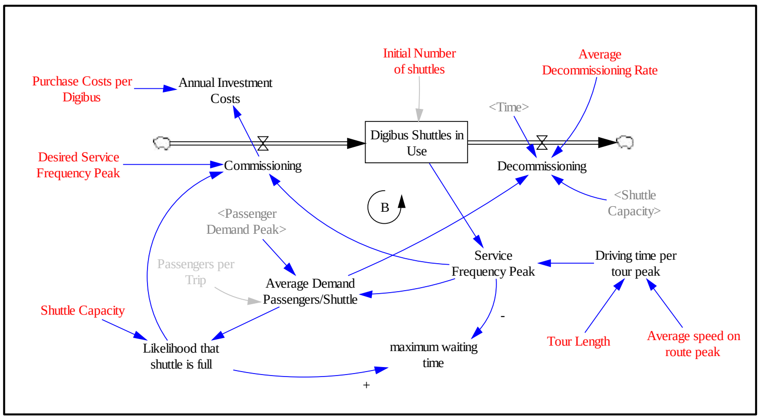

Figure 2: Digibus® waiting times and shuttle capacity submodel

Next steps

It is planned to finalise the stock-flow model, based on data from literature and expert knowledge, by May 2020, including sensitivity and robustness testing. A challenge in the model development is to establish the link between micro-scale simulations of stochastic arrivals and their impacts on average waiting times, and mid to long-term impacts on demand.

In the subsequent step, the model will be calibrated with data from a 3-month real-life demonstration of the Digibus® shuttle in the small town of Koppl, near Salzburg, Austria. For spring and summer 2020 the shuttle bus will provide a feeder service from Koppl village centre to the bus stop for the main regional bus line to Salzburg. This demonstration will provide some data on potential take-up as well as operating costs and reliability of the service. Focus group interviews will complement the operation in order to get more in-depth information on acceptability.

Finally, the calibrated model will be applied in an impact analysis for potential future operating scenarios of such shuttle bus. To this end, a range of service quality parameters (e.g. different operating frequencies for scheduled services or on demand service), variants for inclusion in an integrated mobility-as-a-service offer, and potential varying external conditions will be defined and their impacts on passenger uptake and economic viability of the bus will be tested.

Bibliography

Abbas, K.A., & Bell, M.G.H. (1994). System dynamics applicability to transportation modeling. *Transportation Research Part A: Policy and Practice,* Volume **28**, Issue 5, 1994, Pages 373-390.

DEFRA (Department for Environment Food & Rural Affairs) (2018). *Transport and travel.* [Online] Available from: https://www.gov.uk/government/statistics/rural-transport-travel-and-accessibility-statistics [accessed 8.3.2020]

Digibus Austria (n.d.*) Austrian flagship project for automated driving in public transport*. Project website https://www.digibus.at/en/ [accessed 8.3.2020]

Eckhardt, J., Nykänen, L., Aapaoja, A. and Niemi, P. (2018). MaaS in rural areas - case Finland. *Research in Transportation Business & Management*. **27**, pp.75–83.

ERTRAC (European Road Transport Research Advisory Council) (2019*) Connected Automated Driving Roadmap.* [Online]. https://www.ertrac.org/uploads/documentsearch/id57/ERTRAC-CAD-Roadmap-2019.pdf [accessed 8.3.2020]

Nordhoff, S., de Winter, J., Madigan, R., Merat, N., van Arem, B. and Happee, R. (2018) User acceptance of automated shuttles in Berlin-Schöneberg: A questionnaire study. *Transportation Research Part F: Traffic Psychology and Behaviour*. **58**(August), pp.843–854.

Rentschler, C. and Manz, W. (2019) Transformation der Personenbeförderung - Individualisierte Mobilitätsdienstleistungen und ihre Entwicklungstendenzen. *Straßenverkehrstechnik*. (**5**), pp.315–324.

Shepherd, S. P. (2014) A review of system dynamics models applied in transportation. *Transportmetrica B: Transport Dynamics*, **2**(2), 83–105.

Tomschy R., Herry M., Sammer G., Klementschitz R., Riegler S., Follmer R., Gruschwitz D., Josef F., Gensasz S., Kirnbauer R., S.T. (2016) *Österreich unterwegs 2013/2014.* Ergebnisbericht zur österreichweiten Mobilitätserhebung „Österreich unterwegs 2013/2014“. On behalf of: Bundesministerium für Verkehr, Innovation und Technologie, Autobahnen- und ASFINAG [Online]. https://www.bmk.gv.at/themen/verkehrsplanung/statistik/oesterreich_unterwegs.html [accessed 8.3.2020]

VDV (Verband Deutscher Verkehrsunternehmen) (2015): *Zukunftsszenarien autonomer Fahrzeuge - Chancen und Risiken für Verkehrsunternehmen.* Positionspapier / November 2015. [Online] https://www.vdv.de/position-autonome-fahrzeuge.pdfx [Accessed 8.3.2020]

Supplementary material (CLD and Dynamic Hypotheses)

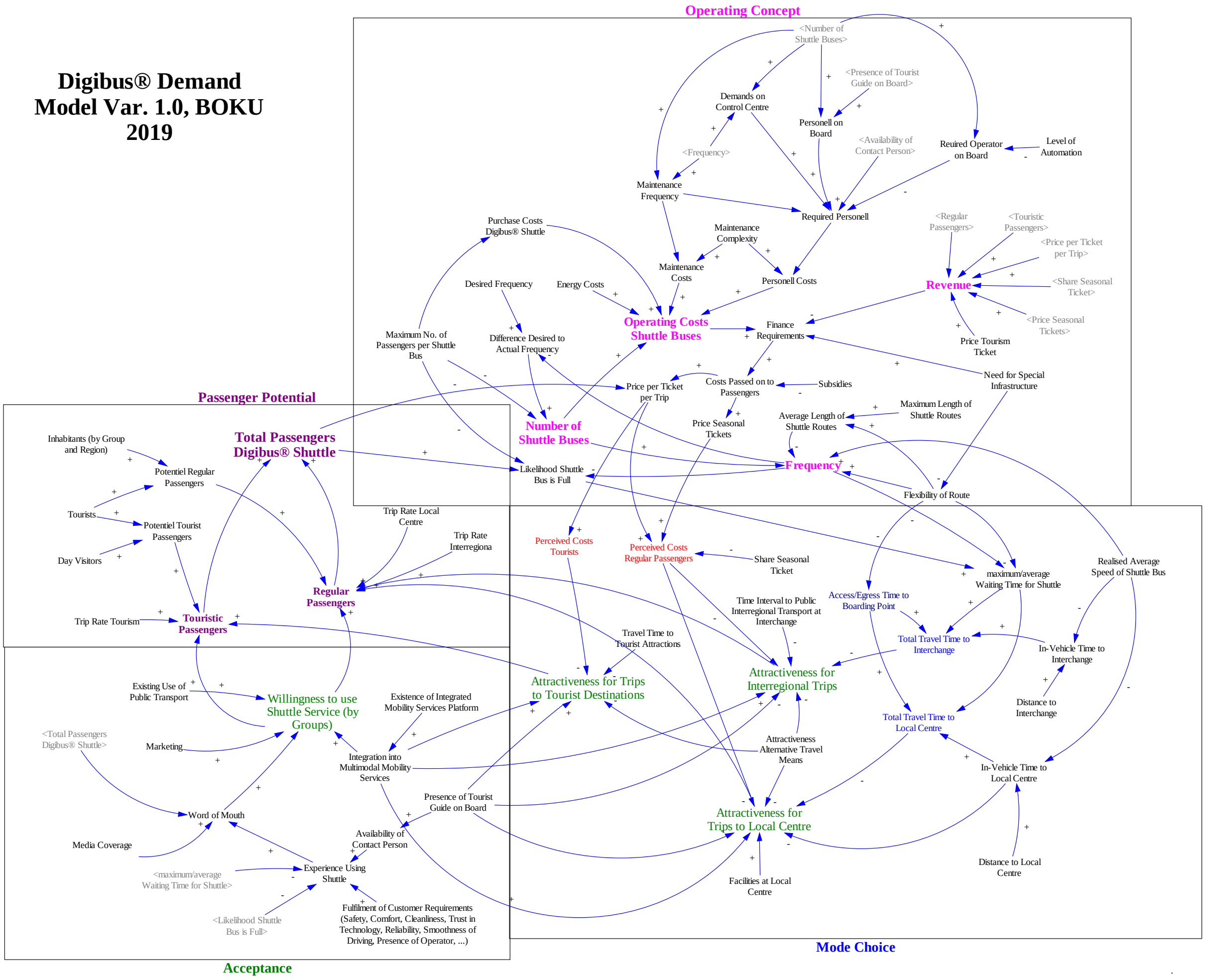

Figure 3: Full CLD of the Digibus® demand model

Nr.	Dynamic Hypotheses	Name of Feedback-Loop	Type of Feedback
1	More Digibus® passengers increase word-of-mouth, which in turn can attract more potential passengers.	Word of mouth	reinforcing
2	With more Digibus® passengers the likelihood of a full shuttle bus is increasing, which leads to a negative ride experience and in turn a potential decrease of potential passengers.	Overcrowding – Word of mouth	balancing
3	With more Digibus® passengers the likelihood of a full shuttle bus is increasing, which leads to an increase in waiting times and reduces the attractiveness of the Digibus® offer and in turn a potential decrease of potential passengers.	Overcrowding – Waiting times	balancing
4	More Digibus® passengers lead to higher revenue, which means that financing requirements and costs passed on to passengers, thus also the price per ticket can be reduced. This increases the attractiveness of the Digibus® offer and in turn the number of potential passengers.	Operating efficiency	reinforcing