Researching the impact of extreme weather events on an On-Demand Transport service - A case study

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Extended Abstract

Introduction

In the course of the KelRide[1] project, an autonomous shuttle service is implemented in the city of Kelheim, Germany. To the knowledge of the authors, the shuttle service is the first ever to operate autonomous vehicles (AVs) in Germany in a public traffic system without fixed routes. In addition to the use of artificial intelligence as a key vehicle feature, the service aims to be highly weather-proof. However, Mobility-on-Demand (MoD) is not a completely new story for inhabitants of Kelheim county. In June 2020 the KEXI[2] service, a Demand Responsive Transport (DRT) system started by the local government, was implemented. The next step for KEXI will be the addition of autonomous shuttles, which will serve parts of the existing KEXI service area without demanding a ride fee. In order to understand the potential impact of weather events such as e.g. heavy rain- and snowfall, fog, high wind speeds or extreme temperatures on the demand for the AV service, the demand data of the existing conventional KEXI service is paired with weather data for the region of Kelheim county. The mobility and weather data is collected on a daily basis. Then, a linear regression analysis is performed to determine possible relations between the daily number of KEXI rides and weather parameters. Subsequently, the findings from the regression analysis are transferred into a simulation study, which aims to perform a demand forecast for the AV service under potential weather restrictions.

Linear Regression Analysis

For the multiple linear regression analysis input data from various sources is needed: Ingolstadt and Kelheim County Weather data from Meteostat[3], detailed weather description data from Weatherstack[4], mobility data is represented by the number of KEXI rides inside Landkreis Kelheim[5] (time period June 2020 - October 2022), stringency (strictness of Covid-19 policies) data is taken from Oxford COVID-19 Government Response Tracker[6] and German holiday data is taken from feiertage-api[7].
As this regression analysis is thought of as a preparation for building a potential transport model using the simulation tool MATSim (Multi Agent Transport Simulation), where typical weekdays (Tuesday - Thursday) are simulated, holidays and non-typical weekdays are filtered out. Considered weather parameters are the average wind speed (*wspd*) in km/h, peak wind gust (*wpgt*) in km/h, temperature difference between daily average temperature and season mean temperature (*tdiff*) in °C, average sea level pressure (*pres*) in hPa, maximum snow depth (*snow*) in mm, daily precipitation total (*prcp*) in mm, average, maximum and minimum air temperature (*tavg, tmax, tmin*) in °C, average wind direction

[1] https://kelride.com/
[2] https://kexi.de/
[3] https://bulk.meteostat.net/v2/
[4] https://weatherstack.com/
[5] This is data received through the KelRide project, therefore it is not public.
[6] https://covidtracker.bsg.ox.ac.uk/
[7] https://feiertage-api.de/

(*wdir*) in degrees and the covid policies stringency (*stringency*), which is represented by the sum of Covid-19 related policies on a daily basis.
In a first analysis step, for each parameter a correlation coefficient is calculated (Pearson coefficients), which expresses the general correlation of each variable with the number of daily KEXI rides. The correlation analysis shows that only the COVID-19 policy *stringency* has a strong influence (high correlation value) on the daily number of KEXI rides (-0.56). Weather parameters do not seem to have a substantial impact, which might be due to the strong effects of the pandemic. Therefore, only weather parameters with a correlation value of bigger than |0.04| are taken into account: *wspd, wpgt, wdir, tdiff, tmax, tavg, tmin* and *pres*.
A first multiple linear regression model indicates that there is a continuously growing trend of daily conventional KEXI rides over time. Additionally, the model, which includes all of the above parameters, can only explain about 49% of the dataset's variance (Adjusted R^2 of 0.492). Hence, a simplified date parameter *date_simplified*, an integer which counts the number of days that have passed since the conventional KEXI service has started, is introduced and included into the regression model.
The resulting linear regression model displays an improved model accuracy of 0.7845. The distribution of the predicted model values as well as the residuals show a typical form. As the model includes multiple independent variables, which are marked as non-significant (p-value > 0.05), it should be possible to exclude those parameters from the regression model without decreasing the model accuracy. The process of linear regression model calculation and subsequent exclusion of non-significant independent variables is repeated until it produces a linear regression model with significant independent variables only: The final linear regression model projects the daily number of KEXI rides as the dependent variable with the variables *tavg* and *date_simplified* as independent variables. With p-values < 2e-16 both independent variables are of very high significance for explaining the dependent variable. The final adjusted R^2 value is 0.7847, which means that 78% of variance in the dependent variable (daily number of KEXI rides) can be explained by the independent variables. Most importantly, the regression model tells us that with an increase of the average temperature by 1°C, the number of daily KEXI rides decreases by 0.708054. This rather low impact is further confirmed by the low correlation coefficient for the average temperature (-0.0480).

Transport Model Simulation

The above sections have shown that weather does not have a direct influence on the overall demand for the conventional KEXI shuttle service. However, extreme weather events might have an influence on the operation of the automated part of the service. Therefore, a simulation study, based on the work of Schlenther et al. (2023), is conducted. The transport model simulation is performed with the open-source software MATSim[8], which is a simulation framework based on activities, extendability and a multi-agent approach (see Horni et al. 2016, p. 4). The service area of the conventional KEXI service consists of the whole city of Kelheim, Germany and one additional zone covering the rail station of Saal (Donau), Germany. The AV service area includes the oldtown of Kelheim, Germany, an industrial park called "Donaupark" and some roads, which connect the two separate areas. For a detailed description of the scenario setup we refer to Schlenther et al. (2023), in particular to case "Fleet 2023". This simulation study aims to predict the demand reaction to adjusted AV speeds which are reported from the manufacturers to decrease in the event of extreme weather. Thus, four different cases with adapted maximum AV speeds are simulated: Max. AV speed of 18 km/h (base case), 12 km/h, 9 km/h and 6 km/h.
The analysis of all simulated cases shows a decrease of AV service quality with decreasing max. AV speeds: The overall AV demand [rides/day] decreases from 50 (base case) to 28 (12 km/h), 18 (9 km/h) and 3 (6 km/h). Similarly, the mean waiting time increases from 178s, to 219s, 349s and 471s. The in-vehicle travel time demonstrates an analogous increase from 281s to 392s, 531s and 610s. The aforementioned findings are intuitive. Additionally, the decreased max. AV speeds seem to drive the AV users into transport modes walk and bike, which seems logical as the AV service area is rather

[8] https://matsim.org/

small and the avg. euclidean distance of AV trips lays roughly around 0.6 - 0.7 km, which is a walk- and bikeable distance. Moreover, the modes walk and bike are the modes, from which AV users mainly changed to the autonomous service in the first place (see Schlenther et al. 2023, p. 11 Fig. 5). The conventional KEXI service stays untouched from the altered max. AV vehicle speeds: Compared to the base case, all key performance indicators (KPI) remain stable.

Conclusion

With the help of a multiple linear regression analysis, the presented study shows that only the average temperature as a representative for weather events does have a marginal impact on the daily demand of the conventional KEXI service (June 2020 - October 2022). The subsequent simulation study performed in MATSim forecasts a decrease of the autonomous service quality when decreasing the max. speed of the autonomous shuttles due to extreme weather.

References

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