Investigating the Impact of Blocked Critical Infrastructure on an On-Demand Service in Kelheim, Germany

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Introduction

In the course of the KelRide[3] project, the addition of an autonomous On-Demand segment to the already existing service[4] is accompanied by multiple simulation studies: (Schlenther et al., 2023) investigated potential combinations of fleet size and service area expansions for the service segment operated by autonomous vehicles (AV). The simulation results show that the greater the service area for the AV is extended, the more demand it generates. Furthermore, the conventional and autonomous service segments seem to complement each other rather than concurring. In another study, (Meinhardt et al., 2023) paired weather data for the region of Kelheim, Germany with real demand data derived from the conventional On-Demand service for transferring possible impact points of extreme weather events onto the AV service. The statistical analysis of the given data discovers a marginal impact of weather variables onto service demand. In a subsequent simulation study, the weather's impact on operational parameters only is therefore researched. Here, weather impact is expressed as a decrease of maximum AV speed and seems to reduce the autonomous service's demand depending on how much the parameter is decreased. As a next step, in the following document, a scenario, where critical infrastructure in the city of Kelheim is blocked, is described and simulated. The results of said scenario are then presented and discussed.

Scenario description

The mentioned study by (Schlenther et al., 2023) already delivers a detailed description of how the general scenario is set up. It includes explanations of the used software MATSim[5] (Multi-Agent Transport Simulation), generation and calibration of the general transport model as well as the calibration of the conventional On-Demand service KEXI (see chapter 3). The addition of the autonomous service segment is covered by chapter 4.1. Therefore, this document concentrates on the scenario modifications, which have been necessary to simulate the blocked critical infrastructure. Case study "Fleet 2023" (see (Schlenther et al., 2023, p. 9f.)) serves as a base case for the following research. In addition to the base case, 4 more cases are simulated, for which one of the following critical street segments are blocked: (1) Case blocked Regensburger Straße, (2) case blocked Kelheimwinzerstraße, (3) case blocked Europabruecke and (4) case blocked Maximiliansbruecke. Figure 1 shows the location of the blocked street segmented the city of Kelheim.

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As seen in Figure 1 the city of Kelheim is situated at the river Donau. Therefore, there are only two bridges connecting the areas south and north of the river. The streets Regensburger Straße on the south of the river and Kelheimwinzerstraße on the north connect the roads, which are crossing the Donau via the mentioned bridges, which makes them critical infrastructure as well.

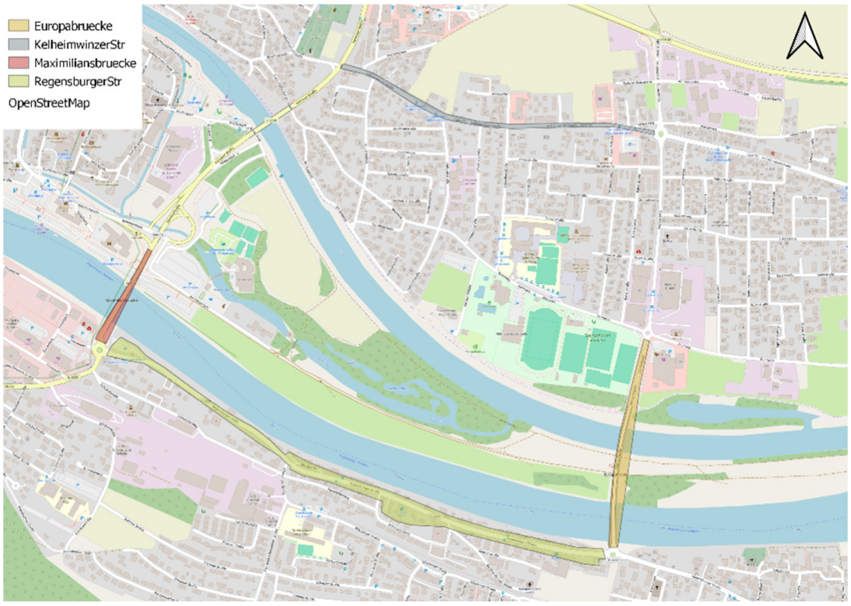

Figure 1: Overview of the different blocked infrastructure segments and their location in Kelheim, Germany.

The actual blocking of the critical street segments is performed by adapting link attributes of the corresponding MATSim-network: The attribute "capacity", which determines how many vehicles can pass the link per hour, is reduced to 10 vehicles/h. In addition, the attribute "freespeed", which defines the maximum speed vehicles can move along the length of the link, is decreased to 0.1 m/s (see Horni, Nagel and Axhausen 2016, p. 14). It is important to mention that both values are not set to 0 because then there might be a high number of agents stucking on the blocked links. With the chosen way of implementing the roadblocks, most of the agents will avoid the usage of the adapted links as they might not be able to enter them for a long time due to low capacity and if so move along the links with marginal speed, which most certainly leads to delays in their following activities. In some cases, one might be able to observe a small number of agents entering the blocked network links as they have activities, which are not accessible from other links. Because the share of agents doing so is well below 1% of the total number of agents, they are neglected in this work. The simulated use cases and their individual specifications are summarized in Table 1.

Regarding the service areas of the conventional KEXI service the cases (3) and (4) do not have any impact on the accessibility of stops. For case (1) stops 114, 104, 95 and 96 and for case (2) stops 36, 41 and 42 are basically not reachable anymore, which should lead to a loss of demand on those stops. With the exception of the mentioned stops, the conventional KEXI service operates in the whole city of Kelheim, as usual. Regarding the autonomous service segment only case (4) impacts the service area. Here, because the now blocked Maximiliansbruecke is the only connection of the two operated zones, the service area has to be split up into 2 separate bubbles (Donaupark and Altstadt). Two of the five AV are manually placed in the Altstadt, whereas the remaining vehicles operate in Donaupark. Figure 2 shows the AV service area for base case and policy cases 1-3. As mentioned, for the fourth policy case the AV service area is split into the 2 bubbles connected by Maximiliansbruecke.

Table 1: Simulated cases and their specifications.

Case study	blocked road segment	No. of served conventional KEXI stops	No. of AV	AV service area
(0) Base Case	-	147	5	Altstadt and Donaupark
(1) Blocked Regensburger Straße	Regensburger Straße from Maximiliansbruecke to Europabruecke	143	5	Altstadt and Donaupark
(2) Blocked Kelheimwinzerstraße	Kelheimwinzerstraße from Hemauer Straße to Starenstraße	144	5	Altstadt and Donaupark
(3) Blocked Europabruecke	Europabruecke	147	5	Altstadt and Donaupark
(4) Blocked Maximiliansbruecke	Maximiliansbruecke	147	2	Altstadt
		3	3	Donaupark

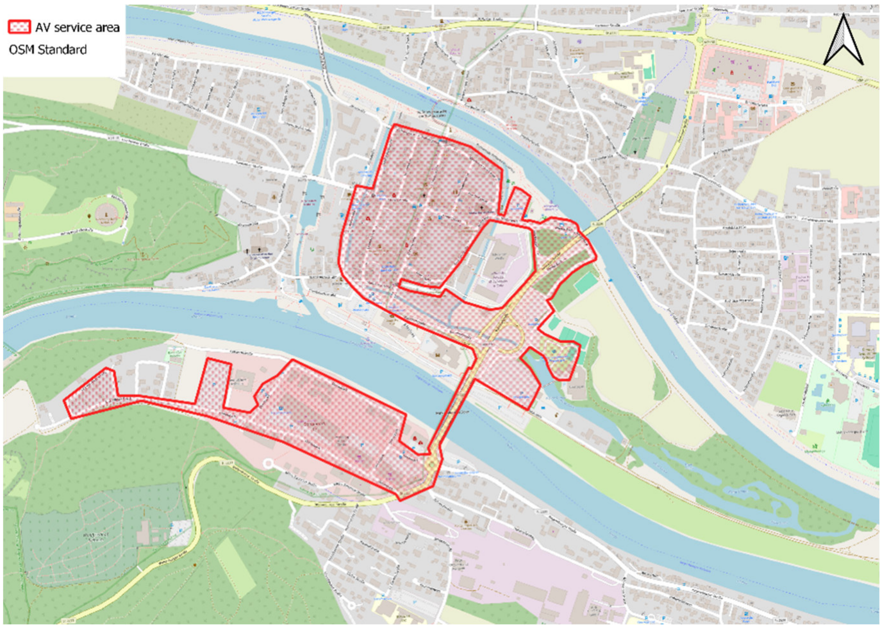

Figure 2: AV service area for base case and policy cases 1-3.

Results

In terms of overall traffic volume, for all simulated policy cases, the traffic demand, which formerly went through the now blocked infrastructure, is mainly picked up by parallelly aligned road segments as well as the corresponding feeder infrastructure: Policy case (1) leads to an increase of traffic volumes in Hohenpfahlweg (main share), Kelheimwinzerstraße and Europabruecke (as a feeder for Kelheimwinzerstraße). The blocked Kelheimwinzerstraße in policy case (2) shifts traffic flows into state road ST2230 as well as Rennweg. Policy case (3), which simulates the blocking of Europabruecke, mainly causes a traffic flow switch to the only two other bridges in the city area (Maximiliansbruecke and Donaubruecke Lohstadt / Kelheim) and the segment of Regensburger Straße which is directed from Donaubruecke Lohstadt / Kelheim citywards. Last, the blocking of Maximimiliansbruecke (policy case (4)) leads to a wide spectrum of affected road segments as not only the two other Kelheim bridges Europabruecke and Donaubruecke Lohstadt / Kelheim pick up the deflected traffic flows but also almost every other bigger city road leading to or from the bridges including Regensburger Straße, Kelheimwinzerstraße and ST2230. For a description of the blocked road segment in each policy case see Table 1.

A closer look onto agents, who in the base case use infrastructure, which then is blocked for the policy cases, goes along with the above findings of overall traffic volume shifts. The closing of Regensburger Straße in Policy Case (1) causes an increase of average travel time by more than four minutes (269s), while the average traveled distance only increases marginally (+ 186m), which indicates that the affected agents are using nearby congested alternative routes. This is confirmed by the above overall traffic volume analysis, which suggests that the parallelly aligned Hohenpfahlweg picks up a major share of the traffic volume originally traveling through Regensburger Straße. For Policy Case (2) (closing of Kelheimwinzerstraße) we observe a similar pattern. Here, the increase of average travel time is rather moderate (+ 145s), but the average traveled distance also increases marginally (+ 251m). Paired with the knowledge that the traffic volume of Kelheimwinzerstraße is shifted to stateroad ST2230, which has the same street layout as Kelheimwinzerstraße and therefore should be able to pick up the additional volume rather easily as well as to Rennweg, where (due to it being a residential road) the additional traffic volume causes congestions, the increases of mean travel time and distance in this case are intuitive. For the closing of the two bridges in policy cases (3) and (4) the average traveled distance increases quite remarkably (+ 1.0km / + 1.3km). Whereas for both policy cases the average traveled distance features a similar increase, the average travel time reacts rather differently: While the closing of Europabruecke (policy case (3)) triggers a marginal increase of 39s, the closing of Maximiliansbruecke (policy case (4)) causes an increase of almost four minutes (+ 197s). This contrast can be justified by the different location of the two bridges. Europabruecke is closer to Donaubruecke Lohstadt / Kelheim, which is one of the two alternative bridges. This specific bridge features a maximum allowed speed of 100 km/h and is connected to the nearby federal road B16, which also allows vehicles to travel with up to 100 km/h. Therefore, an increase of average travel time is absorbed by the higher maximum allowed speed of the alternative route. The closing of Maximiliansbruecke on the contrary, increases mean traveled distance **and** mean travel time of affected agents by a lot as the next possibility to cross the river is Europabruecke, which has the same maximum allowed speed as Maximiliansbruecke (50 km/h). Additionally, the above traffic volume analysis displays an increase of traffic volumes of almost all city roads leading to or from the bridges. Thus, it can be assumed that the increase of average travel time in this policy case is caused by a combination of longer distance to be traveled and delays due to congested roads.

Regarding the conventional KEXI service the number of conventional KEXI rides remains stable throughout all policy cases (in comparison to the base case (+-8%)), except for policy case (4): The closure of Maximiliansbruecke causes a decrease of daily KEXI rides by 13% from 119 rides/day to 103 rides/day. In terms of trip length, said policy case extends the average euclidean trip distance as well as the direct network distance by 7% (from 2364m to 2532m / from 3335m to 3583m). The slight changes of the mentioned KPI (key performance indicators) suggest that for some agents the closure of Maximiliansbruecke and therefore a triggered reroute decreases the attractivity of transport mode DRT such that it is not the most attractive alternative anymore. Second, for some agents DRT remains the most attractive

transport mode. Thus, a physically longer route is accepted (as seen in increase of euclidean trip distance and direct network distance). For the previously stated reasons, Maximiliansbruecke seems to be more critical for the KEXI service than the other infrastructure segments considered.
An analysis of average and median waiting time indicates that for the conventional DRT service also Kelheimwinzerstraße is of high importance. While all other KPI remain in a range of +-5% of the base case, the average waiting time (+9%), median waiting time (+17%) as well as average in vehicle travel time (+18%) increase more heavily for this policy case. Combined with the fact that average trip distances do not seem to be highly affected by this road block, and the findings of the above analysis on overall traffic volumes we can assume that for DRT routes through Kelheimwinzerstraße there are multiple alternative routes, which do not cause an increase of trip length, but due to the overall increase of traffic volumes in the alternative road segments (DRT) vehicles are slowed down. All of the above-mentioned values are average values over five simulation runs with different random seeds (analogous to (Schlenther et al., 2023)).
In three of the four policy cases, the impact of infrastructure closure on the automated service segment is rather marginal. Compared to the base case, the KPI for closures of Regensburger Straße, Kelheimwinzerstraße and Europabruecke barely display deviations of more than 10%. The number of daily AV rides remains stable throughout all three policy cases, as does the mean waiting time, in-vehicle travel time and average trip length. As the bigger deviations are only observed in single parameters, such that there is no pattern to be recognized, they can be traced back to the higher traffic volumes in some parts of the city as described above. On the contrary to policy cases (1) to (3), we observe an extreme demand reaction to the closure of Maximiliansbruecke in policy case (4): Due to the bridge being blocked and therefore the splitting of the AV service area into two separate bubbles (as described above) the demand for AV drops to 0. It is not surprising that there is some kind of demand reaction to this rather big intervention on AV operation, but a decrease to 0 daily rides is. In the base case, about 60% of the trips are undertaken from Donaupark to the oldtown or vice versa. As those trips are not possible anymore (by AV at least) it is intuitive that there is a dropoff in overall daily AV rides, but the rides within the now separated service areas should not be affected by the bridge closure. Table 2 displays the KPI for each simulated case.

Table 2: KPI for the autonomous DRT service over all simulated cases.

Average	number_of_requests	waiting_time_mean	trips_euclidean_distance_mean	trips_direct_network_distance_mean	n_vehicle_travel_time_mean
Case 0 (base case)	55	182	612	1032	276
Case 1 (blocked Regensburger Str)	52	209	605	1017	282
Case 2 (blocked Kelheimwinzerstr)	53	181	612	1048	277
Case 3 (blocked Europabruecke)	47	180	627	1059	281
Case 4 (blocked Maximiliansbruecke)	0	12	82	90	22

Conclusion

The presented study investigates potential impacts of the closure of critical infrastructure in a transport model for the region of Kelheim, Germany. The simulation results show that the general traffic flows of the blocked infrastructure segments are mainly picked up by parallelly aligned road segments. This can be seen by comparing the traffic flows of base case and the policy cases as well as varying increases of travel times and distances for agents, which formerly used the then blocked infrastructure segments. Regarding the conventional DRT service only 2 of the 4 blocked roads seem to be essential. The blocking of Maximiliansbruecke causes a decrease of daily total rides by 13%. The blocking of Kelheimwinzerstraße does not lead to a significant decrease of total number of rides, but an increase of average waiting time, median waiting time and average in-vehicle time (due to the overall higher traffic volumes in alternative (parallel) road segments) indicates that Kelheimwinzerstraße also is of high importance for the conventional DRT service. In regard to the autonomous DRT segment 3 of 4 infrastructure closures only have marginal effects on the KPI. Only in case 4 (blocked Maximiliansbruecke) an extreme demand reaction is observed. Due to the closure of the bridge, which connects the 2 service area bubbles and the subsequent division of the autonomous service area in 2 separate bubbles the demand for this case drops to 0. As in the base case around 60% of the trips by the autonomous AV are between the 2 service area bubbles, it is somewhat unclear what causes this huge demand dropoff because the other 40% (inner bubble trips) should stay untouched by the blocking of the bridge. This should be investigated further in future analysis. Moreover, this study should be repeated in the future due to several reasons: As the KelRide project is still ongoing, the service area for the autonomous segment will be extended in the future. Additionally, the model is under continuous development leading to advances in mode choice behavior, DRT rebalancing algorithms and a bigger data pool of demand data. The mentioned developments possibly could end up leading to different simulation results.

References

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