Understanding of group travel and weekend travel behavior for on-demand mobility services
UNDERSTANDING OF GROUP TRAVEL AND WEEKEND TRAVEL BEHAVIOR FOR ON-DEMAND MOBILITY SERVICES

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ABSTRACT
Many on-demand mobility simulation models focus on modelling the average weekday, even though TNC data have shown distinct differences in trip patterns between the average weekday, Saturday and Sunday. This means that these simulation models do not necessarily capture essential weekend characteristics, especially the high tendency for group travel.

This study investigates the relationship between weekend travel and the operational efficiency of on-demand mobility service, focusing on shared autonomous vehicles (SAVs) with a dynamic ridesharing system. It also proposes a methodology for creating group travelers from travel surveys with limited information on group travels. Weekend trip patterns are compared with weekday patterns to extrapolate how this might affect SAV policies.

The findings reveal that when simulating on-demand mobility services, there are some slight differences between an average weekday and the weekend, with Saturday being more distinctive. Furthermore, we show that failing to consider group travelers in ridesharing simulations affects the results on pooling, whereby the effects can be underestimated with an error of up to 38% for our case study.

Keywords: On-demand mobility, SAVs, ridesharing, weekend models, group travel, MATSim
INTRODUCTION
Agent-based models, which are gaining popularity in the field of transportation planning, have proven to be a powerful method for modeling complex problems related to travel behavior at the microscopic scale. With these models, policies and operational decisions that could directly impact travelers can be modeled and tested to manage travel demand. While the importance of agent-based modeling is evident in its increasing adoption in many regions of the world, the focus to date has been on modeling an average workday. However, when only weekdays are considered, the effects of transportation policy or of externalities of travel behavior are not properly captured (1, 2). This is particularly relevant for scenarios and policies that rely on modeling leisure activities and designing the operation of emerging shared-use and demand-responsive mobility services. Studies have shown that demand for these flexible modes, such as carsharing, ride-hailing and ridesharing, is highest on weekends, especially Saturdays, with weekend trips evenly distributed throughout the day, but concentrated in the afternoon on weekdays (1, 3, 4). These differences between weekday and weekend activity patterns could affect the operational performance of future mobility solutions.

Modeling weekends for on-demand mobility becomes even more important when considering the future of transportation and the need for passenger pooling. Autonomous vehicles (AVs) have become an important research topic because they are believed to have the potential to reduce transportation externalities and become the backbone of future transportation systems. Although there are conflicting results on how much positive impact AVs would bring, there is a common push for shared autonomous vehicles (SAVs), especially pooled, as a way to maximize the benefits of automation, especially since the AV technology is capable of facilitating large-scale shared systems. If the future of transportation requires shared mobility solutions, the best starting point is to look at existing on-demand mobility services and how shared trips operate on different days of the week.

Consequently, the weekend trip patterns of flexible modes become important as this is the time when most shared trips are made, potentially affecting existing on-demand mobility systems. However, there are very few studies in this direction with mixed results, and depending on the study, ridesharing may be high on weekends or weekdays (5, 6). For example, studies that analyzed data from Chicago transport network companies (TNCs) found that ridesharing was lower on weekends. At first glance, this is counterintuitive. The Swiss 2015 Microcensus on Mobility and Transport (7) showed that most weekend trips have a higher percentage of shared trips - car passenger trips (about 19%) compared to weekdays (9%). Clearly, groups of friends or households tend to travel together for leisure activities and therefore carpool or share rides. Thus, one could surmise that groups of friends using ride-hailing trips in Chicago are being represented as single passengers and pooling potential is underrepresented.

As more simulation models emerge for various on-demand services and SAVs, weekday travel demand is still used and group travel is usually not considered. This is due to poor data availability and cost. In the past, travel surveys typically ignored weekend days and focused on weekdays. This is mainly because of the emphasis placed on analyzing travel behavior on weekends where the highest traffic demand occurs. In addition, it is more expensive to also include weekends in travel surveys as it increases the response burden. With the shift in research towards the understanding of flexible modes, changing leisure patterns, and the spread of disease, the interest in quantifying and understanding weekend travel behavior has grown, and data is also becoming more cheaply available.

Thus, this study highlights some key aspects of modeling the weekend in the context of
on-demand services. The study examines the relationship between weekend travel and the operational efficiency of on-demand mobility services, focusing on shared autonomous vehicles with a dynamic ridesharing system. A comparison is made with weekday trips to extrapolate the characteristic patterns of weekend trips and how this might affect policies for SAV operations. A methodology is proposed for creating group travelers using travel surveys with limited information on group travel. The generated shared trips, representing people travelling in groups, are subsequently considered in the simulation. This is done to holistically characterize the impact of pooling. While the focus is on shared autonomous vehicles, this also applies to other on-demand mobility services.

This paper is structured as follows. Section 2 provides a background with the pertinent literature. Section 3 describes the methodology and section 4 describes the scenarios tested in this study. In section 5 results are presented with discussions on the findings. Finally in section 6 we conclude while highlighting areas for future work.

BACKGROUND

There are several studies that examine weekend travels, and they provide an analysis of the differences in travel behavior between weekends and weekdays (8–13). These studies argue that special attention needs to be paid to weekend travel in order to develop a comprehensive travel demand model for evaluating transportation policies aimed at reducing congestion, improving air quality, and enhancing well-being. For example, Bhat and Misra (9) noted as early as the 1990s that policies that focus on weekday traffic can exacerbate weekend traffic congestion. In this section relevant findings from various studies on weekend travel behavior are highlighted to emphasize the gaps in weekend modelling in simulation of on-demand mobility services, the focus of this study.

The differences in weekend trip patterns are reflected in the activity types, trip length, mode choice, and even duration of trips. Leisure trips account for a higher percentage of weekend trips, and vehicle occupancy is higher because there is more time to participate in household and group activities (13–16). For example, Hunt et al. (14) found that weekend mode choice was related to travel party size, while Yagi et al. (17) found in Indonesia that the mode share of fully joint household trips differed between weekdays and weekends. Due to the nature of weekend travel, it may be more convenient and cheaper for individuals to travel together by car. As a result, vehicle occupancy levels are higher because of the increased use of private vehicles for these joint trips. These differences also occur between the two weekend days. For example, while the general consensus is that weekend trips are generally longer than weekday trips, some studies show that Saturday trips are longer than Sunday trips (10), while others find the opposite (13). This could depend on the region, and therefore, it may be necessary to model Saturday and Sunday differently.

In terms of shared autonomous vehicles, one can look at the studies of current on-demand mobility services. TNC data serve as a rich data source for various empirical studies on ride-hailing and ridesharing. In the Chicago, New York, Boston, Chengdu, Berlin, and Hamburg regions, these data are available, and studies based on these data show the differences and similarities between weekday and weekend trip patterns for various travel characteristics. Similar to the above studies, studies on ride-hailing for example, emphasize the need to model the demand for the weekday and weekend separately. This is due to the strong relationship found between ride-hailing use and leisure activities (2, 4, 18). It stands to reason, therefore, that ride-hailing use is more prevalent on weekends than on weekdays, when people engage in more leisure activities. This can be observed in different regions of the world. However, the results do not always agree on some points. In
pooling, which is of main interest in this study, differences were found between regions. Dean and
Kockelman (5), Du et al. (19), Wang and Noland (20) found that pooling was more prevalent during
the week in Chicago (4.5% higher). This could be because party trips may not be accounted for in
the ride-hailing trips. Based on TNC data from the pooling-only service MOIA for two German
cities, it was found that more trips are pooled on Saturdays than on any other day of the week
(21). Another mixed finding is that of Gehrke et al. (6), who found that ridesharing in the Boston
area was more prevalent on weekends or in the middle of the day during the week. This suggests
that a better analysis of weekend ridesharing is needed, especially when examining the potential of
SAVs for pooling. In addition, the distinction between Saturday and Sunday applies to on-demand
mobility services. In Berlin, Bischoff et al. (22) observed a peak in demand on Saturdays for taxi
dispatch using GPS trajectories, while demand was lower on Sundays. This is similar to other
cities such as Madrid, where usage increases on late Friday evenings and on Saturdays (4).

Agent-based modeling and simulation, which model real-world systems, are an appropriate
tool to understand these on-demand mobility services. This is because flexible transportation ser-
vice serve passenger demand with both spatial and temporal flexibility that can only be captured
through a microscopic representation of individual travelers and individual vehicles. Simulation
models help to understand the impact of such flexible and dynamic behavior. Several simulation
studies for SAVs, ridehailing, carsharing, or taxi exist, but few have addressed the weekend as-
pect. These few are either toy examples (23), focus on electric vehicles and their energy demand
(24, 25), or a limited exploration of the weekend (21, 22, 26), whereby for example, when the
weekend is considered, a weekend day is chosen, usually Saturday, as this is the day with the high-
est demand. In general, these studies do not really fully explore the differences between weekend
and weekday, and as far as the authors are aware, there is no study that examines and compares the
impact of weekends and weekdays, especially considering the potential for shared rides.

**METHOD**

To fulfill the study objectives, an agent based scenario representative of the weekend was devel-
oped. From this scenario, group trips were generated and then prepared for the simulation frame-
work used. The simulation framework, MATSim (27), was extended to include the capability for
group travel. This section describes these in detail.

**Simulation Framework**

The multi-agent transport simulation framework MATSim has been used for this study. MATSim
provides the ability to realistically model large scale transport systems. It requires scenario data
necessary to emulate the transportation system: the network of links and nodes and a travel de-
mand in the form of a synthetic population of agents with their travel plans and other transport
elements such as facility location, and transit schedules. Agents in MATSim are iteratively routed
and simulated through the network, using their chosen modes of transportation to get from one
place to another while engaging in various activities. As the agents interact with each other in
the network, congestion occurs, affecting their decisions in the next iteration. Agents optimize
their plans in each iteration until the system converges to a steady state. This enables MATSim to
simulate emerging behaviors that drive travelers’ decision making. In this study, only the network
routing functionality of MATSim is used, which serves as the basis for future agent-based research.
This is mainly because this work focuses solely on comparing ridesharing between weekdays and
weekends without the need to capture the entire travel behavior of the transportation system.
TABLE 1 Modal shares

<table>
<thead>
<tr>
<th>Mode</th>
<th>Saturday MZ (%)</th>
<th>Saturday Sim (%)</th>
<th>Sunday MZ (%)</th>
<th>Sunday Sim (%)</th>
<th>Avgday MZ (%)</th>
<th>Avgday Sim (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>car</td>
<td>28.74</td>
<td>28.85</td>
<td>30.45</td>
<td>29.50</td>
<td>29.19</td>
<td>29.27</td>
</tr>
<tr>
<td>car passenger</td>
<td>17.73</td>
<td>17.67</td>
<td>18.9</td>
<td>21.0</td>
<td>9.14</td>
<td>8.46</td>
</tr>
</tbody>
</table>

To represent an on-demand mobility service, the MATSim demand-responsive transit extension (DRT) extension is used (28). The DRT extension was developed to enable MATSim to simulate a dynamic ride-sharing service where vehicles can pick up and drop off agents at their request. It has a dispatching algorithm that uses a load-balancing heuristic for its operational strategy (29). The dispatcher is presented with a list of available vehicles. It traverses the list and assigns each request to the closest vehicle after ensuring that constraints on wait time or detour times for passengers are not violated. Only individual passenger trips are considered for each request and as such, group travel is not captured in the existing system. In reality, a single request might involve a group of travelers and this will require more than one seat, which must be considered when assigning an appropriate vehicle for such a request. Therefore, an additional constraint was added to the cost function of the dispatching algorithm to check the number of passengers in the vehicles to ensure that there are enough seats for the reserved number of seats in a request. The DRT system, therefore, represents a fleet managing system for shared autonomous vehicles (SAVs) that allow for pooling and group travel.

SCENARIO DEFINITION

Several MATSim simulation studies have been conducted for the city of Zurich using the available Switzerland Baseline scenario (30), which consists of a synthetic agent population that reproduces the sociodemographic characteristics and travel behavior of Switzerland. This baseline scenario, based on the Swiss 2015 Microcensus on Mobility and Transport, that reports the daily travel behavior of 60,000 respondents living in Switzerland, models an average workday. The microcensus however contains additional information that characterizes weekend travel behavior. Over 22% of the trips recorded are weekend trips, which provides an opportunity to capture weekend travel behavior, making the data suitable for this study. Following an approach similar to that used to develop the baseline for Switzerland, an extension was developed for a weekend scenario for Saturday and Sunday. Thereafter, a Zurich region was cut out for an average weekday, a Saturday and a Sunday, as the study area of interest. This region consist of the 12 districts of the city of Zurich and a 5 km buffer around the city. The modal shares from the cut out models were compared to the microcensus weighted shares for the same region. See Table 1, where “MZ” and “Sim” refers to the Microcensus and the simulated model shares respectively.

The cut out Zurich scenarios were then converted to a trip-based model, retaining only car and car passenger trips. This means that each of the trips that make up a person’s plan becomes an individual agent. Next, all trips that start or end outside of the Zurich region are removed, since the SAV service is defined to operate only within the region. In summary, the 8 million agents of the synthetic population of Switzerland are reduced to 456,148, 539,629, 371,382 trips with a car to car passenger ratio of 1.51, 1.57, and 1.61, for an average weekday, Saturday, and Sunday respectively.
Representing group travel

Data that capture joint travel are not readily available. The 2015 Microcensus on Mobility and Transport, for example, surveys only one person per household. And even if such a person has taken a trip in which he or she was in a group, this information is not clearly captured. What is recorded are cases where a person is a passenger in a car with a substantial share of car passenger trips recorded with Saturday and Sunday with a share of 19.38% and 21.72% respectively compared to the weekday’s share of 9.52%. Thus, making it possible to create group travel scenarios for this study. Table 1 also shows similar shares for the cut out region.

A heuristic approach was developed to assign these rides from passengers to car drivers based on the following assumptions:

- Joint trips are made in small groups of two people
- They may be within the same household or among friends
- One member of the group drives a car while the other is a car passenger
- Trips are made together when the departure time, point of origin, and destination are approximately the same

The matching problem here follows a minimum weight matching in bipartite graph problem. Given two subsets N and M representing car passengers and car drivers respectively, the problem instance is described by an \( n \times m \) matrix \( C \), where each \( C[i, j] \) represents the cost of matching node \( i \) of the first subset, car passengers, and node \( j \) of the second subset of car drivers. The goal is to find a complete matching of the drivers and passengers at a minimal cost. The cost, in Equation 1 is defined as the sum of the weighted difference in departure time, and weighted unshared distances (derived from the sum of the distance between the origin of the driver and the origin of the passenger, and the distance between the destination of the driver and the destination of the passenger).

\[
c_{ij} = \sum (\alpha \times t_{ij} + (1 - \alpha) \times d_{ij}) \tag{1}
\]

where \( t_{ij} \) is difference in departure time between passenger \( i \) and driver \( j \), and \( d_{ij} \) is the unshared distances between passenger \( i \) and driver \( j \). \( \alpha \) is a weight applied to the departure time differences and the unshared distance. An \( \alpha \) value of 0.2 has been chosen placing more weight on the distance. This value gives the smallest error and best matching results whereby the unshared distance on average is 1.55km and a median of 1.2km and average difference in departure time of 16 minutes with a median of 8 minutes.

To minimize the difference in departure time, and unshared distances the linear problem is thus formulated as:

\[
\text{Minimize} \quad \min \sum_{i=1}^{n} \sum_{j=1}^{m} (c_{ij} \times x_{ij}) \tag{2}
\]

where \( x_{ij} = 1 \), if passenger \( i \) is matched with driver \( j \) otherwise 0

Subject to:

Each passenger is assigned one driver

\[
\forall i \in \{1, \ldots, n\} \sum_{j=1}^{m} (x_{ij} = 1) \tag{3}
\]
Each driver is assigned at most one passenger

$$\forall j \in 1, \ldots, m \sum_{i=1}^{n} (x_{ij} \leq 1)$$

Scenario configurations
The SAV service in this study operates door-to-door for 24 hours with vehicles that can accommodate 4 passengers. The maximum waiting time was set to 10 minutes, based on empirical case studies for on-demand services in Switzerland (31). Although the DRT extension provides a possibility to set rejection constraints for a maximum wait time and maximum detour time (the time an in-vehicle passenger is willing to lose while the vehicle picks up another passenger), this is not considered. Rather, a constraint is set for rejection when there is no available vehicle with more than one seat available that can pick up agents traveling in groups. A range of fleet sizes is tested in different scenarios with the SAVs initially placed based on the population density of the network. When the vehicle is empty, the vehicles remain at their last drop-off location until they need to serve another request. The simulation goes through four iterations to reach an equilibrium state in terms of the number of SAV trips served, average travel times, and waiting times. This is because the system uses a dynamic vehicle routing problem for its dispatching algorithm, where the free speeds of the network are used to calculate the travel times in the first iteration and updated later until the times are stable.

MATSim version 15.0-SNAPSHOT (https://github.com/matsim-org/matsim-libs) was used with the corresponding DRT version. A 100% population is simulated, although this requires more computational resources due to the dispatching algorithm used by the SAV service, the negative effects of using a sample population can be avoided (32). The simulations were performed using the ETH High Performance Computing Cluster (Euler) with maximum resource request of 8 cores and 192 GB memory.

Scenarios
Several scenarios were tested comparing an average weekday with a Saturday and a Sunday.

- Days: the SAV simulation of the average weekday is set as the baseline scenario, which is then compared to the Saturday and Sunday weekend scenarios.
- Group travel: for each of the simulated days, a group scenario or a normal scenario was defined, differing in whether group trips were made or not. For example, for the baseline scenario, a "AvgdayGroup" and a "AvgdayNorm" were defined, where in the AvgdayNorm, car drivers and car passengers use SAV for their trips independently, although the passengers have the same trip characteristics as the car drivers to whom they were assigned. In the AvgdayGroup, passenger trips are removed because their trips have been merged with the corresponding car drivers. This was done in a similar manner for the other two days.
- SAV Fleet Size: a range of fleet sizes between 4000 and 10,000 are simulated for all scenarios. Fleet sizes are varied because this is one of the most important operational measures for planners to consider when offering such services, as it affects the impact on overall service levels and customer experience. The range of fleet sizes was selected based on results of related studies (31, 33), with assumptions made about the number of vehicles that could serve the proportion of car trips in the study region.
For this study, a total of 42 scenarios were simulated, consisting of the 3 days of interest (average weekday, Saturday, and Sunday), a case where requests are with groups of travelers or single, and a set of 7 fleet sizes.

**RESULTS**

The results below describe the operational performance across the different scenarios looking specifically at the vehicle occupancy, vehicle empty distance, wait times and detour time.

The result shows the differences in the estimation of the operational efficiency of a ridesharing system when different week days are considered. From Figure 1 one can see that Saturday (shown as lines with box marker) stands out especially for smaller fleet sizes. For example, in Figure 1c, the relative difference in the average wait time is about 400%. This shows that modelling an average day will not be reliable at predicting operational efficiency on Saturdays. It is reasonable that the Saturday operation exhibits different behavior as its demand of about eight hundred and eighty thousand trips is 46% and 16.4% higher than the demand on Sunday and the average day. However, this higher demand is representative of the current state of ridehailing and ridesharing services in reality, as have been shown in studies that analysed TNC data (2, 4, 5). To note is the average vehicle occupancy for SaturdayNorm for the fleet size of 4000 1a, which stands out as an outlier and shows that the fleet size is not sufficient for the demand. This is possibly due to the fact that the SAV system is not allowed to reject passengers’ requests for single trips unless there is no vehicle in the system able to serve its request within the operation time (based on our design). Consequently, for the requests in the “group” scenario, one can observe very high unrealistic average wait time, detour times, and even high share of empty distance (see Figure 1b-d), as vehicles try to meet up the high demand. Still, this artefact in the simulation is revealed because Saturday is modelled separately.

Furthermore, it is not only the modelled day that has an impact on the operational efficiencies of the system. From Figure 1, one can immediately see some differences between the "group" scenarios (blue lines) and "norm" scenarios (red lines). Differences can be mostly seen when looking at vehicle occupancy whereby, on average the vehicles in the "group" scenarios perform better in pooling passengers than in the "norm" scenarios, even though, the car passengers in the "norm" scenarios share the same trip characteristics with their assigned car drivers in the "group" scenarios. The relative difference between the average occupancy of the "norm" scenarios and the "group" scenarios in this study is up to 38%. This highlights the need for ridesharing simulation studies to consider group travel, as when not done, one of its key benefits is largely underestimated.

Another important metric for fleet performance, especially from the view point of operator’s profitability, is the share of empty distance. Figure 1b highlights this share by showing the ratio of the occupied distance to the total travel distance. On average one can see that from a vehicle fleet size of 5000 vehicles, the empty distance of the fleet is below 10%. From fleet size of 6000 vehicles, the vehicles are occupied 95% of all its traveled distance across all scenarios. This finding corroborates the point that ridesharing brings benefit to the use of SAVs as there would be less empty distance covered as the SAV system efficiently pools trips with similar origin and destination.

From the customer’s perspective, wait times and detour times are of major importance. In Figures 1c and 1d, these are represented by the average wait times and the detour factor respectively. The detour factor is the ratio of total travel time of a passenger to their expected travel time if they were riding alone. With fewer vehicles, as one would expect from a scenario where
FIGURE 1 Operational performance. (blue lines represent group travelers and red lines represent the norm - single travelers)
passengers are not rejected, detour factors are quite high and then reduce as the fleet size increases. This happens especially for the "norm" scenarios where each passenger whether in a group or not is considered differently. What is surprising is that already from a fleet size of 5000 there is no gain from increasing the fleet, compared to the "norm" scenario where the plateau is reached at fleet size of 8000. This difference can be credited to the efficient pooling of the vehicles with a system that considers group travelers. This further emphasizes the potential for reporting errors when no attempt is made to account for group travel in ridesharing simulations.

**CONCLUSION**

This study simulates the use of SAVs for weekend and weekday travel in the city of Zurich, extended by a 5km radius. Synthetic population generated from the Switzerland baseline model for an average day, Saturday and Sunday, has been used with a focus on the car driver and car passenger trips. Group travel is considered in this study by combining drivers and passengers into travel parties to investigate its impact on pooling for ridesharing services.

The results show that it is necessary to explicitly model weekend on-demand mobility service operations in Zurich, as not doing so can impact the estimation of the operational performance of ridesharing systems. This is because of the distinctive difference in demand between Saturday and other days. While some studies have used Saturday as the primary simulation day (22, 26, 34), this is not the standard practice. This kind of study where the differences and potential errors are clearly shown helps to create awareness to do much more. Also, group travel for leisure activities, mainly performed on the weekend, has a large impact on ridesharing, as the results have shown that one can underestimate the pooling potential of such systems when these group trips are not considered.

This study is a first step to open discussion and research on the inclusion of weekend travel behavior in ridesharing and SAV modeling and provides several opportunities for future work. It is also a valuable study for on-demand mobility researchers in regions where data on group travels are limited in travel surveys, as it proposes a methodology for representing group travelers in their simulations. Still, there are limitations, and the following discusses them to ensure a path for more realistic results in future work.

**Car-only demand scenario:** Only car drivers and car passenger trips have been considered in this study. This means that other potential SAV users are not adequately represented. In addition, the simulations assume free-speed travel times with only the SAVs on the roads. Therefore, the results must be interpreted within this scope. Ideally, a mode choice model should be applied to ensure that demand is reactive to the newly introduced transport mode. This is where MATSim’s ability to simulate agent decision-making can be fully exploited as it can then be used to more closely approximate actual real world demand for the fleet of SAVs, as agents consider wait times, travel times, rejections, price, and other factors when choosing a mode.

**Group trips are limited to a party of two:** The matching algorithm presented here only matches a car driver with a single car passenger. Future work includes extending it to larger groups of travelers dependent on data availability.

**SAV vehicles:** The vehicles in this study are assumed not to require maintenance, recharging, or refueling and to transport agents without needing drop off, pick up, or parking space.
REFERENCES


