On the Generality of On-Demand Mobility Services' Operational Processes.

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Amid the rapid penetration of inherently dynamic mobility services into transportation systems, the case for explicitly modelling service provision processes is strong. Albeit not yet mature or streamlined, the literature on modelling on-demand mobility services indicates consensus on the importance of modelling operational policies and service performance [1]-[5]. While research efforts are scattered across a range of specific mobility service case studies, the operational activities involved can be fairly similar. Generalizing operational activities offers great potential to streamline service provision processes and significantly reduce modelling efforts.

Several authors have noted that establishing clear distinctions among mobility services is a daunting task due to their volatile nature [6], [7], which becomes more complicated due to the influence of disruptive technologies such as Autonomous/Electric Vehicles (AV/EV) and shared systems. Examples abound; to name a few:

- In the context of AVs, differences among operations of taxi, carsharing, and ridehailing services become negligible. Simply, all are reduced to cars transporting customers; with drivers out of the equation, the main differences reside in the role of parking.
- A great resemblance exists between a shared ridehailing service (e.g. UberPool) and a Demand Responsive Transit (DRT) service (e.g. on-demand microtransit). Although DRT implies a higher degree of complexity in its processes overall, both services involve customers sharing small vehicles (usually up to 5 passengers). Moreover, both services could either involve independent human drivers or AVs.
- Carsharing and bikesharing services (either one-way or free-floating variants) are almost identical from an operational perspective. Both services require customers to drive the vehicle themselves and both can involve stations/parking spots.
- E-bikesharing services and e-scooter services involve exactly the same operational problems (charging and fleet rebalancing, for instance).

Under these circumstances, developing service provision models becomes a "moving target" task, and thus, requires generic models that are resilient enough to accommodate variations. Moreover, considering that semantic boundaries among services are blurry, along with the striking similarity of certain mobility services, a step further can be taken to generalize service provision processes. This undertaking is reported in detail in the main author's doctoral thesis [5], involving extensive literature review efforts and the subsequent establishment of a conceptual modelling framework. In short, generic daily operational activities of service providers include matching, rebalancing, dynamic pricing; whenever independent human drivers are involved, driver activity is also identified as a fundamental component. This paper reports comparisons among service provision processes of key on-demand mobility services, focusing on how these can fit within a unified generic service provision process.

Considering that several on-demand mobility services show great similarity, it can be argued that ridehailing, carsharing, bikesharing, and DRT provide an adequate representation of the most important short-term operational activities. The development of a generic service provision process encompassing such activities and other processes is reported at length in [5], which is designed for a time-step-driven model and is developed under an agent-based modelling paradigm. The most generic case in terms of operational activities involved is arguably ridehailing (RH), hence, this service is taken as a benchmark for comparison. Table 1 reports a slightly modified version of the generic process proposed in [5] and demonstrates how it can represent the four services mentioned above (as well as their variants).

Table 1: Generic Service Provision Process Mapped Against Key On-Demand Mobility Services.

For each time interval (RH):		**SB-BS**	**OW-CS**	**FF-BS**	**FF-CS**	**DRT**
1	Accumulate trip requests and available vehicles over interval	✓	✓	✓	✓	✓
2	Calculate a supply/demand ratio. If dynamic pricing, update fares according to pricing mechanism. Also, input for rebalancing.	✓	✓	✓	✓	✓
3	Compute distances/travel times (retrieve if preprocessed) among trip request origins and locations of available vehicles.	Users assess this themselves.	Users assess this themselves.	Users assess this themselves.	Users assess this themselves.	Might involve routing also, depending on service variant
4	Deploy matching mechanism to allocate vehicles to trip requests/ Users´ choice of station-vehicle.	FCFS regime or in-advance app booking.	Mostly in-advance app booking.	FCFS regime or in-advance app booking.	FCFS regime or in-advance app booking.	More complex matching process to handle sharing
5	Update future location and time of allocated vehicles.	Issue: dock availability.	✓	✓	✓	✓
6	Assess expected spatial distribution of the fleet at a given point in time in the future and deploy rebalancing mechanism.	✓	✓	✓	✓	✓
7	Update future location and time of allocated vehicles.	Issue: dock availability.	✓	✓	✓	✓
8	Resolve/manage unserved trip requests. Either users switch modes or wait (shifted forward to the next iteration).	Users less likely to wait.	✓	Users less likely to wait.	✓	✓
9	Advance a time step and repeat process.	✓	✓	✓	✓	✓

***Acronyms: FCFS:** First-Come-First-Serve; **RH**: Ridehailing; **SB-BS**: Station-based bikesharing; **OW-CS**: One-way carsharing; **FF-BS**: Free-floating bikesharing; **FF-CS**: Free-floating carsharing; **DRT**: Dynamic Responsive Transit

While ridehailing or one-way carsharing are implementation-ready use cases of the generic service provision process described in Table 1, some important challenges remain for some on-demand mobility services. The first challenge is concerned with uncertainty in vehicle availability, relevant for services that do not perform matching centrally but rather depend on users choosing vehicles to ride/drive on a FCFS basis. Namely, at a given instant in time, users choose a given service based on whether a vehicle is available at their desired location/station;

however, upon arrival, all remaining available vehicles might already be taken. This creates a choice problem, which can be solved assuming users: wait for a vehicle to become available at the current station/location; walk to nearby locations/stations in search of vehicles; or switch their transportation modal choice. User waiting is the easiest scenario to model but is also arguably unrealistic for some services (e.g. bikesharing). Searching for nearby stations is the most common in real life, but it introduces complexity in modelling because it likely requires a certain degree of real-time monitoring of the system. Switching mode choices is plausible in real life, albeit at the cost of modelling complexity due to mode choice reassessment – these choices are usually computed as a prior step in conventional (sequentially designed) travel demand models.

The second challenge consists of parking availability. It arises in cases where users arrive to drop vehicles off at stations/docks/locations, only to find them full. In this case, the alternative solutions described above for the first challenge are reduced to two, since re-choosing mode is not possible (vehicles must be returned). Further, waiting for an available parking spot implies additional costs to users, who are more likely to search for free parking spots in nearby stations.

The third challenge arises in unbalanced supply/demand scenarios, wherein vehicle/user agents remain "unmatched" (i.e. idling/waiting, respectively) after a service provision time interval. For vehicle agents operated by independent human drivers (e.g. Uber), drivers´ decisions should be handled a driver activity model integrated to (but independent from) the service provision model. The case of users, however, is more complicated because their modal choices are already modelled at the demand component of a conventional travel demand model system, implying that choices to wait, or abort a chosen mode, must be reassessed "outside" of the demand component.

This paper demonstrates that on-demand mobility services involve similar operational activities, and a generic service provision process can indeed be designed to allow instantiating a range of services. Hence, challenges related with modelling constantly evolving mobility services can be tackled to a great extent through the establishment of such a flexible, generic process that logically connects "encapsulated" operational features (matching, rebalancing, pricing, and driver activity – if applicable). Further, the generic service provision process outlined in this paper can provide travel demand model systems with the required functionality to instantiate on-demand mobility service provider agents within an overall *service provision component*.

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