Model of information system for combined ride-sourcing service

Dávid Földes, Csaba Csiszár

Abstract— **Efficiency enhancement for urban mobility is one of the key elements in smart city conceptions. Nowadays, there is significant underutilization of vehicle capacities in the case of individual vehicles, taxis, and vehicles, especially for food or small package delivery services. The motivation of our research is to reveal opportunities for so-called dynamic, combined ride-sourcing service. Passengers and certain goods sharing the same destination can be transported in shared vehicles. Since such novel service concepts are based on new forms of information management, the research question is: how the information systems and the operations are to be modeled in order to create the service. In such a service, demands and capacities are coordinated by dynamic prices based on real-time data. The logical correspondences of pricing are also revealed. During model development, we considered autonomous vehicles as well, because their emergence requires fundamentally new operational approaches. Accordingly, the developed information management method can be adopted for services based on autonomous vehicles. The results provide a basis for innovation and development of these services.**

Index Terms— **system structure, operational model, dynamic price, package delivery, ride-sourcing, taxi**

I. Introduction

THE recent evolution of society's lifestyle has caused an alteration in mobility habits. The consumer society implies mobility and delivery demands. Customers increasingly prefer personalized services, and therefore, development of smart mobility systems with easily accessible services is necessary [1]. Several so-called transitional road-transportation modes provide similar convenient services as individual car, like taxis and ride-sourcing. On the one hand, the volume of both passenger transportation and package delivery are rising, and on the other hand, free vehicle capacities remain available. For example, in many cases multiple disparate passenger transport/delivery companies flock to the same destination at the same time.

The basic challenge is to efficiently coordinate these demands and capacities through proper information management. In the case of sharing economy, the capacity utilization for high-value assets is enhanced in several ways [2]. Types of sharing in transportation include vehicles (e.g. car-sharing) or seats (e.g. ride-sharing, shared ride-sourcing).

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Combined ride-sourcing is defined as follows: extended ride-sourcing, wherein the vehicles are shared between passengers, passengers and packages, or packages. Our aim was to determine the information management functions and operational processes of this new service in order to model this system. The research questions were: what the fundamental constituents of the combined ride-sourcing system are, and how it is operated, considering conventional vehicles with drivers. The autonomous vehicle (AV) is only mentioned as it is a key future opportunity for this service.

We compared similar existing mobility forms to reveal the best practices. During information system modeling, we revealed the participants' tasks in each function. We used a top-down approach. Accordingly, we elaborated the demand-management function in detail as an example. The results can be expeditiously used for development of the system. Since the efficiency of operation depends highly on prices, we have identified the elements and the variables of dynamic prices. The information management method can be adopted for driverless services, with only slight modifications.

The remainder of the paper is structured as follows. In Section II, the situation analysis is provided by comparison of the existing services. The current state of the art is summarized in Section III. The main features of the combined ride-sourcing service are determined and summarized in Section IV. In Section V, the information system model for the combined ride-sourcing service is presented. The functions and operational methods are elaborated in Section VI. The ordering function is presented in detail in Section VII. The description about dynamic prices is described in Section VIII. This paper is completed by the concluding remarks, which include further research directions.

II. Situation analysis

In a combined ride-sourcing service, the advantages of ridesharing, ride-sourcing, taxi, and package delivery services are merged. In order to clearly define the new combined ride-sourcing service, we compared various similar services in Table I. (Detailed description of the combined ride-sourcing service is available in Section IV.)

Ridesharing (e.g. BlaBlaCar) is a non-profit, barely regulated transport service, mostly for longer distances. The goal of the service is to increase vehicle seat capacity utilization during travel; namely, the free seat capacity of a vehicle is shared by unknown people. Travellers can join the ride if their destination coincides with the driver's destination. In general, ridesharing is offered as a paid service, but the transportation is not a traditional business-like service. The driver and the passenger share the cost of ride. The demand-capacity coordination is not automatic; therefore, the passenger and driver directly discuss the details of the travel.

Taxi is a profit-oriented, strictly regulated transport service for shorter urban distances with official prices and unified brands, differentiated by color, type of vehicle, payment options, etc. The role of human dispatchers is still relevant as they assign the demands to vehicle capacities and control the processes. Several types of demand management are available, such as hailing, via phone, or even by mobile applications.

Ride-sourcing (e.g. uber, lyft) is a special type of ridesharing in cities, where the driver's purpose is not to reach the passenger's destination; the purpose is to transport the passenger to a destination, in exchange for money. A passenger in need of transport is searching (sourcing) for a ride, or a driver is searching for a customer. Namely, ride-sourcing is a business-like service. It is like a taxi but with softer regulations. Nevertheless, the name of this mobility service is still not unified (e.g. ride-sourcing [3], for-profit ridesharing [4]). The service is provided by an individual driver with their own vehicle and is typically based on a smartphone application. The company provides the application interface that connects passengers with drivers. Demands and capacities are coordinated automatically. Prices depend on the current demands and available vehicle capacities. The price is paid virtually via the mobile application. Passengers can share seats of the vehicle. These so-called 'shared ride-sourcing' services result in lower travel prices (e.g. uberPOOL).

Based on ride-sourcing principles, services providing food delivery have also been spreading (e.g. uberEATS). We called these services 'delivery-sourcing', which are also based on a mobile application. The ordered food is delivered by an individual driver with their own vehicle.

III. State of the Art

Motivations and characteristics of ride-sourcing drivers were analyzed in [4]. It was found that unfixed working hours and less strict regulations are the most relevant motivation factors. Zha et al. [5] examined market scenarios and found that prices do not necessarily decrease in a competitive market as the demands are split among the providers.

Rayle et al. [3] examined the differences between taxi and ride-sourcing services in a survey. They found that the services are disparate in user characteristics, wait times, and trip characteristics. Mainly a young, well-educated and smartphone-equipped population uses ride-sourcing services. Santi et al. [6] revealed that cumulative taxi trip lengths can be cut by 40% or more if passengers share the vehicles. Shared taxi services result in reductions in service cost and gas emissions. Because of split prices, passengers more easily accept the shared services. Analyzing data of taxi movements showed that the system capacity in time is not used with full efficiency which implies profit loss [7]. Taxi companies may also provide shared services, such as taxi ridesharing or collective taxis. A simulation of taxi services showed that distances of vehicle movements, volume of traffic, gasoline consumption, and expenses of a user could be significantly reduced, while the profit of a driver would be increased [8].

Taxi service providers also develop mobile applications. These so-called taxi-hailing (e-hailing) applications have similar features to those in ride-sourcing applications. Wang et al. [9] revealed the impacts of pricing strategies applied on e-hailing platforms. They found that demands may either increase or decrease depending on customer satisfaction with the service, when the price of e-hailing is higher than the price of 'conventional' hailing. The average waiting time for a vehicle is shorter, and the attractiveness of a taxi service is higher in the case of using an e-hailing application [10].

Coordination of demands and capacities requires fleet tracking [11] and mathematical models [8]. Results of a matching simulation indicated that the use of sophisticated optimization methods instead of simple greedy matching rules substantially improves the performance of ride-sharing systems [12]. A general mathematical matching model for real-time ride-sharing showed that the occupancy of the vehicle depends on the fleet size, capacity, and the maximum waiting/delay time [13].

TABLE I
Comparison of Ridesharing, Ride-sourcing, Taxi Service and Combined Ride-sourcing

	ridesharing	**taxi**	**ride-sourcing**	**combined ride-sourcing**
goal	free seat capacity utilization	profit making	profit making	profit making
regulation	barely present	strict	soft	soft
ordering	via application	hailing/via phone, application	via application	via application
dispatching	software + manually	human dispatcher + software	automatic	automatic
select a vehicle	vehicle characteristic	vehicle/company characteristic	vehicle characteristic, position	vehicle characteristic, position
find the vehicle	plate number	company logo, plate number	plate number	plate number
identification	with words (name)	with words (name)	with words (name)	**via application (fingerprint)**
distance	>10 km (for commuters too)	<10 km	<10 km	<10 km
personalization	low	low	adequate	high
temporal availability	low	high	adequate	adequate
waiting time	announced travel time	depends on current capacity	depends on free capacity	depends on current capacity
spatial accessibility	low	good	average (good in downtown)	average
vehicle sharing	yes	no	shared ride-sourcing	**yes**
package delivery	no	no	no	**yes**
prices	cost sharing	fix, official prices	dynamic, demand responsive	**dynamic, demand responsive**
payment	cash, transfer, (application)	cash, credit card, application	application	**via application, automatic**

Home delivery is increasing as new consumer technologies are adopted (e.g. purchasing products via the internet) [14]. The authors showed that fragmentation in the retail channel increases vehicle movements; however, it may motivate the provider to adopt a more sophisticated coordination system.

Alteration of the so-called transitional mobility modes, as a consequence of emerging AVs, was revealed by [15]. A new, telematics-based, shared, demand-responsive transportation mode (TS-DRT) based on small or medium-size autonomous vehicles (so called ‘pod’) was defined, which merges several currently available modes. This new mode is to be extended towards a combined ride-sourcing service. The essence of such services is the usage of real-time data. Generally, real-time information is one of the most required features in the case of transport related mobile applications [16].

We conclude from the literature review that increased personalization of transportation and delivery services enhances demand for such services. Additionally, a more efficient urban mobility system is feasible due to shared services. These services require advanced information technology for demand-capacity coordination and information provision.

IV. Definition of Combined Ride-Sourcing

A combined ride-sourcing service is a merged and extended version of ride-sourcing and delivery-sourcing services. The transport processes are generated by either travel or small package delivery demands (Fig. 1.). The adjective ‘combined’ means that the passengers and the goods are transported at the same time, to ‘share’ the vehicle’s free capacity. The transportation service is based on private vehicles. The customers may:

- order a vehicle for traveling,
- order a vehicle for sending his or her small package to another customer (direct delivery),
- purchase a product, which is delivered to him or her (indirect delivery).

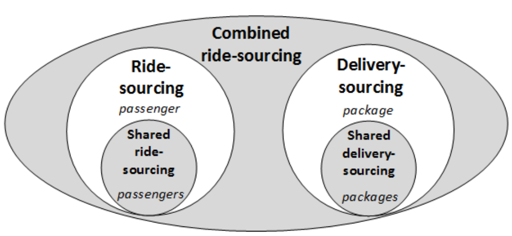

Fig. 1. Types of sourcing services

In the case of indirect delivery service, the customer purchases the products (e.g. food, pharmacy) from an external sender, who sells the products. The dynamic ride-sourcing vehicle carries the product from the sender to the customer. There are two business models for indirect delivery service:

Separated purchase: products are purchased on the sender’s own interface. Then, the sender uses the combined ride-sourcing service for delivery.

Integrated purchase: products are purchased directly via the application of the combined ride-sourcing service. The external senders receive the demands via the application. The products are delivered after preparation. In this case, product purchasing and delivery are managed jointly. The senders make a contract with the combined ride-sourcing provider.

The integrated purchase is more comfortable for the customers. The service applies a dynamic price depending on current demands, capacities, and willingness to share the vehicle. In order to always ensure the required capacity, the drivers are motivated by higher wage per travel.

V. Information System Model

The system constituents and their connections are represented in Fig. 2. The main elements are:

C. **c**ustomers (passengers, buyers, senders),
M. **m**anagement center: organizes and operates the service,
D. **d**rivers,
E. **e**xternal senders: product providers, sending packages to the customers,
T. **t**raffic management center: operates and controls the urban road traffic.

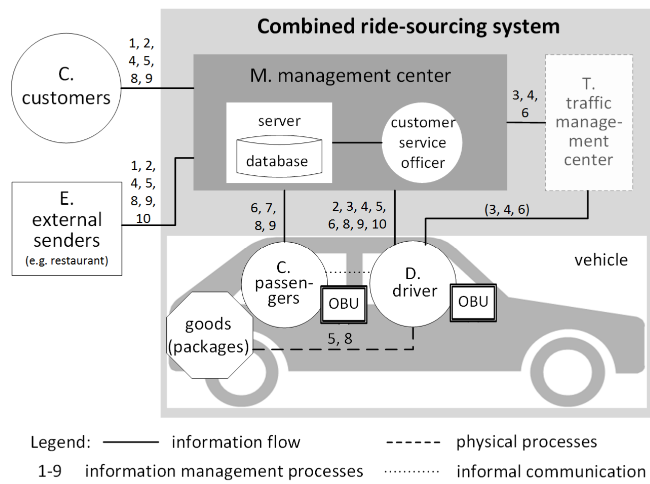

Fig. 2. Information system model

The information management processes are indicated by numbers on the arrows; the numbers are described in Section VI. The service is based the application running on smart devices. The goal is to replace the human voice-based communication by data communication. For example, on the user side, the smart devices are used for ordering and payment; whereas on the driver side, devices are used for task description (dispatching) and supplementary information purposes. The external senders receive the order and then signal the completion of package preparation by using a device. During ordering, the options (expectations) for a given travel or delivery (e.g. destination, sharing options) are set via the smart device.

The demand-capacity coordination is performed by the management center automatically. As the vehicles (or drivers’ smart devices) send location data, the vehicle movements are tracked in real-time. Each demand should be announced in advance. Hailing a vehicle is not possible because of capacity optimization aspect. Perishable deliveries are given priority during the assignment. The human dispatcher is eliminated; however, personal interactions as customer service are needed in special cases (e.g. information provision for technically underdeveloped passengers, management of emergency situations). Apart from the management center, the other elements are not connected directly to each other in most cases. The traffic management center, which is a partially integrated constituent, may provide current traffic information.

The vehicles are installed with smart online devices. Information about tasks and routes is transmitted automatically to the driver via the application. When the drivers are replaced by AVs, the management center and the vehicles communicate with each other. Interactive, touch-screened On-Board Units (OBU) are also installed in the backrest of the seats for the passengers. On one hand, these provide infotainment (information + entertainment). On the other hand, they enhance the security, by being equipped with camera and microphone. The microphone is also used for voice-based communication with the application.

The special (perishable, fragile) goods are transported in special storage equipment (e.g. heat-retaining bag). The drivers handle the packages (identification, loading, carrying, unloading, etc.). The AVs will be equipped with secure boxes, in which the sender transports the packages.

VI. Operational Model

We have described and modeled the functions and the entire operation (Fig. 3.). The functions were assigned to the elements (C, D, E, M). One function may include several information management processes according to the number of concerned elements. Since the traffic management center (T) is only partially integrated into the combined ride-sourcing system, its functions were not investigated in detail. The information management processes are illustrated in the white boxes in Fig. 3. The boxes can be identified in the description by the first capital letter of the elements and the number of the function. For instance, M2 refers to the tasks of the Management center (M) in the case of demand-capacity coordination (2) function.

1. Ordering. Types of ordering are travel, delivery or purchasing a product. Pre-registration, profile generation (general settings, payment details) are mandatory. In most cases, prompt demands are served. However, ordering in advance makes the capacity planning more efficient. Therefore, ordering in advance is motivated by pricing. The customer may set the options (e.g. personalization settings) for the given travel or delivery (C1). The external sender firstly prepares the product and then announces the delivery demand (e.g. pick-up time) to the center (E1).

2. Demand-capacity coordination. Considered aspects

- number, free seat capacity, current location and direction of the vehicles,
- setting options (e.g. sharing mode allowance),
- characteristics of the delivery (e.g. perishable),
- current traffic situations.

The data for coordination are queried mostly from the database of the combined ride-sourcing service; however, some current traffic data arrive from the traffic management center. After the coordination, the routes are planned automatically (M2). The center sends information about the plan (e.g. vehicle description, vehicle arrival time, calculated price, arrival time) to the customer (C2). The external senders receive information about the planned pick-up time (E2).

3. Dispatching. The driver receives information about the task (e.g. location of pick up and drop off points). The driver may accept the task via OBU (D3).

4. Approaching pick-up point. The management center supervises the processes and prepares operative plans according to the current traffic information (M4). The vehicle (OBU) sends position data and navigates the driver (D4). The customers are able to cancel the purpose for a penalty fee (C4). The customers and the senders may track and trace the given vehicle on the map. In addition, supplementary information (e.g. arrival time) is also available (C4, E4).

5. Vehicle arrival – identification. At the pick-up point, the driver notifies the arrival via the application (D5). The user is required to provide identification via individual smartphone (by sending a short-range signal) (C5). In the case of delivery tasks, the driver picks up the package(s). The correct matching and successful pickup is confirmed by both the sender and the driver (via application). In the case of AV usage, doors for passengers and boxes for packages are opened via the application, using a short-range signal sent to the locker.

6. Information management during travel. When a passenger confirms entry to a vehicle, the OBU becomes an extended interface for his own smart device. In this manner, the passenger can receive personalized, location-based advertisements or advice and offers about Points of Interests (POI) (e.g. restaurants) as well as access their social profile and email accounts (C6). The driver automatically receives traffic information and route modification advice. (D6).

7. Vehicle sharing. If a sharing mode is accepted, notifications about the fellow passengers and packages may pop up on the OBU (details of personal and/or package data, the estimated detour time and the cheaper price). Admittance may be given after looking at the fellow passenger’s profile (e.g. picture) and with consideration of the modified route (extra time, new travel price). During the travel, the passenger can also request route modification for an extra fee (C7), which implies the re-coordination of demands and capacities.

8. Arrival – price calculation. The customer is informed about the arrival. The price is calculated automatically (M8).

9. Payment. Either mobile payment after each travel or monthly withdrawal from the bank account is applied (C9). In the case of a product purchase, the price of the product is transferred to the external sender (E9).

10. Task completion. The driver notifies the system upon task completion. If another passenger or package remains in the vehicle, the driver continues the travel/delivery. After completion of all tasks, the driver may request for a break, accept a new task or the vehicle can be driven for recharging (especially in the case of electric vehicles or AVs) (D10).

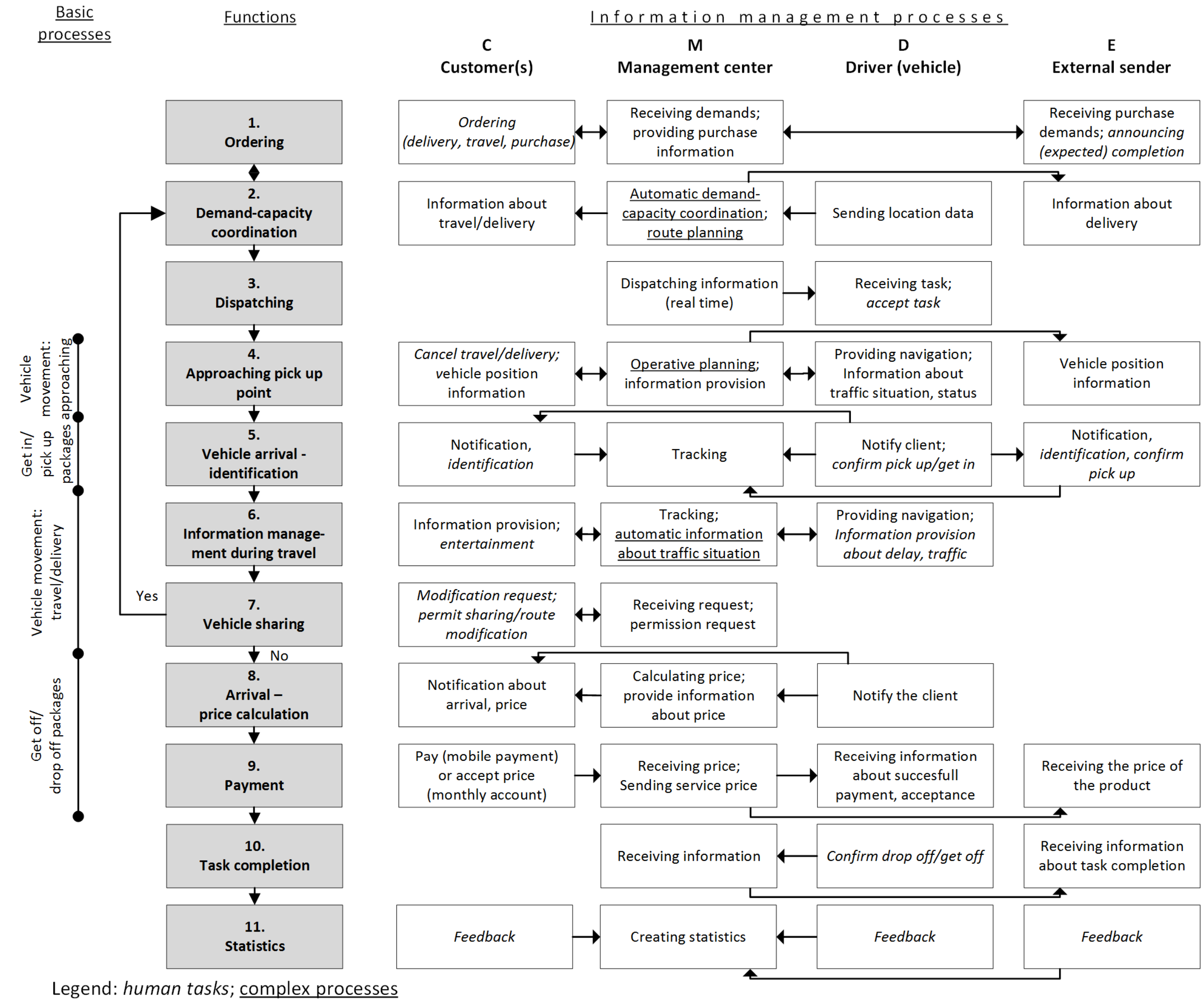

Fig. 3. Operational model

11. Statistics. Statistics are created and used for demand forecast and capacity distribution by the management center (M11). Every human participant can give feedback. Scores are obtained and summarized in the user profiles.

VII. Ordering Function

The operational model is used for detailed planning. In order to present the practical applicability of the model, the first function is elaborated in detail.

During the ordering, the customer (or the external sender) may set the travel or delivery options. Table II. summarizes the travel/delivery-setting options. Italic letters indicate the non-mandatory options; whereas gray background denotes options set by the external sender. The passengers decide the sharing of the vehicle with another passenger (or packages) during the trip. They set the maximum detour time, and the sharing option (s): no sharing, unconditional, conditional, or conditional with selection. In the case of conditional sharing, only the persons, whose characteristics matches the set characteristics *(a, b)* are listed. Further selection makes possible the detailed assessment of fellow passengers. The preferred comfort of the vehicle can be low, medium, or high (e.g. limousine). In the case of delivery, the categories of goods (*g*) are to be selected: perishable (e.g. food), fragile, or simple; small box or envelope (max 5 kg, small caliber).

TABLE II
Setting Options

purpose	option	sign	values
travel	origin, destination		
	departure/arrival time		
	maximum detour time	t	
	preferred sharing type	*s*	no/unconditional/conditional/ conditional with selection
	fellow passenger's age	*a*	
	fellow passenger's gender	*b*	*male/female*
	preferred comfort	*v*	*low/medium/high*
	wheelchair accessibility	*w*	*yes/no*
delivery	origin, destination		
	departure/arrival time		
	category	g	perishable/fragile/simple box
purchase	destination		
	arrival time		
	expected pick-up time		
	category	g	perishable/fragile/simple box

Legend*: non-mandatory*, set by the external sender

In the case of purchasing products, the customer selects the product(s), the expected delivery time and destination. The application displays the best offer (e.g. lowest price for product and delivery). The demand is received by the external sender, who sets the origin point, the expected pick-up time and the category of the package (*g*).

VIII. Description of Dynamic Pricing

The dynamic price depends on the time of the calculation: in advance, just before, or after travel/delivery. The considered price variables (Table III) are: basic service fee (p_0), waiting time for the passenger (t_1), travel/delivery time (t_2), waiting time because of sharing (t_3), additional time because of sharing (t_4), covered distance (d_5), covered distance because of detour (d_6), product price (in the case of purchasing a product) (p_7), available vehicle capacity (m_c), and sharing option (m_s).

When demands exceed the available vehicle capacity, the travel/delivery price is higher. The sharing option reduces the travel/delivery price when selected, in order to motivate sharing. The price reduction is greatest in the case of unconditional sharing, because in such cases, the management center can combine the demands more efficiently.

TABLE III
PRICE VARIABLES

variable			source of variable according to time of the calculation		
			in advance	before	after
time	t_1	waiting for the passenger			
	t_2	travel/delivery	historic	historic forecasted	completed travel
	t_3	waiting because of sharing			
	t_4	additional because of sharing			
dis-tance	d_5	travel/delivery	planned	real-time calculated	completed travel
	d_6	detour			
opera-tional	m_c	available vehicle capacity	historic	real-time	completed travel
	m_s	sharing option		forecasted	

IX. Conclusion

Such a complex ride-sourcing service has still not yet been created. Therefore, our study has high relevance for innovation and development. The main contributions are the definition, the information system, and operation model of the combined ride-sourcing service. Key findings include:

- mobility systems are turning into information systems because each constituent manages information,
- more personalized and automated mobility services are needed in order to reduce the human constituents' information management activities,
- information management procedures of AVs can be designed on the basis of Fig. 3. (column D).

Software development related to this service can be initiated according to our system model, as a proposed framework. Solving the pick-up and delivery problems, with time-window and capacity constraints, are potential research tasks. Our further research focuses on the elaboration of functions, especially price calculation methods. We are going to use simulations to compare the combined ride-sourcing service to regular sourcing services.

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