Model for Crowdsourced Parcel Delivery Embedded into Mobility as a Service Based on Autonomous Electric Vehicles

Yinying He * and Csaba Csiszár

Department of Transport Technology and Economics (KUKG), Faculty of Transportation Engineering and Vehicle Engineering (KJK), Budapest University of Technology and Economics (BME), 1111 Budapest, Hungary; csiszar.csaba@kjk.bme.hu

* Correspondence: he.yinying@edu.bme.hu; Tel.: +36-7055-314-42

Abstract: Faced promising development of autonomous vehicles, the concept Mobility as a Service embraces AVs. The autonomous delivery has also been arising and tested for last-mile solution. Accordingly, passenger transportation and delivery service are to be jointly coordinated in the future MaaS. The research niche is summarized as how to embed crowdsourced parcel delivery into MaaS based on AVs. Electricity powered vehicles are to be applied considering energy consumption and air emission. Research questions are identified as what this novel service is and how it works, especially focusing on task coordination and the related information management. The system engineering process-oriented approaches, matching theory, and numerical method have been applied. The service concept has been elaborated, which contains information system architecture model and functional model. The matching condition of this service is summarized. As the embedded delivery can partially share the demand of traditional delivery service, the calculation scenarios of energy savings and emission decrease per parcel delivery are presented. The results facilitate service planning and development.

Keywords: mobility as a service; autonomous (electric) vehicles; crowdsourced parcel delivery; embedded service; information management

1. Introduction

The mobility as a service (MaaS) is implemented and researched as 'an integrated service of services' focusing mainly on passenger transportation nowadays. The freight transportation or urban logistics is proposed to be considered as well [1,2]. Especially, the small parcel delivery is booming to aid the e-commerce. However, such a combination in MaaS has not been implemented yet. Faced by several difficulties such as efficient task coordination among passengers, very limited research on topics such as combined services is available, even though, the concept to combine logistics into public transportation has been proposed, e.g., to use a shared network [3,4], or to use a shared vehicle.

The word 'embedded' means that parcel delivery service can be operated individually too; however, the assignment of simultaneously matched, same route passenger transit, and parcel delivery is an optimized solution to support energy resource allocation, as battery electric vehicles (BEVs) are preferred when considering energy consumption and sustainability [5]. In this combination case, the passenger has priority; thus, it is called as embedded service. The demand of logistics is increasing rapidly due to the e-commerce. More and more vehicles run on the road to serve increased demand. Sufficient management of related logistic processes benefit energy management.

Small sized driverless cars or robots for parcel delivery have been already tested and operated in several cities around the world: the self-parcel delivery robot Starship in England (https://www.starship.xyz/ (accessed on 20 December 2020)), TeleRetail in Switzerland (https://teleretail.com/ (accessed on 20 December 2020)), the Nuro in USA

(https://nuro.ai/ (accessed on 20 December 2020)), and JingDong in China (https://corporate.jd.com/ourBusiness (accessed on 20 December 2020)). However, the vehicle speed and delivery frequency are relatively low. These small vehicles run on sidewalks with limited speed, the vehicle capacity to carry parcels is also limited because of vehicle size. The demand toward small parcel autonomous delivery is growing, especially in recent pandemic situation with the need of contactless delivery.

Autonomous vehicles (AV) technology is developed continuously. The six levels (0–5) of vehicle automation introduced by National Highway Traffic Safety Administration are widely accepted according to device supported driving (https://www.nhtsa.gov (accessed on 20 December 2020)). Vehicles in level 4 have been tested on road. Vehicles of level 5 with full automation and electric propulsion where no driver is needed is considered in our work. Research of AVs either focus on autonomous private cars [6] or public transportation based on AVs. Incorporation of AVs into the MaaS is to solve gaps between operators and drivers: 'to manage vehicles instead of drivers', which is a kind of advantage to increase the management efficiency.

Traditional delivery is performed by professional couriers. Resource is assigned with broader meaning benefiting from information handling; one practical example is the sharing economy: personal tools or unused space could be used by unknown crowds. Crowdsourced parcel delivery is proposed to optimize the utilization of resources: travelers who are willing to deliver small parcel on their route are involved, e.g., neighborhood delivery [7,8]. This emerging service type is proposed to supplement the traditional delivery [9,10]. Embedded crowdsourced parcel delivery service into MaaS based on AVs is to enrich service types and optimize the utilization of resources. The main purpose is to decrease energy consumption and to enhance the vehicle capacity utilization both in time and space. In addition, the embedded delivery is applied to share part of traditional delivery demand to crowds contributing to sharing economy.

The objective of this work is to develop the concept of the small parcel delivery service embedded into the MaaS based on AVs. The research questions are identified as following:

1. What is this combined service and how it works?
2. What information system and functions are proposed?
3. What information management processes are elaborated for operation?
4. Why this service benefit to energy management?

The system engineering process-oriented approach, matching theory, and numerical method are applied to answer research questions. Accordingly, the service concept is introduced, the system architecture is modeled, and the functional model is elaborated. The assignment matching condition is proposed. The calculation and comparison of standardized energy consumption scenarios for per parcel delivery are presented. One assumption is the common cloud-based information system and platform, or in another expression: the connected online environment, has to be mature and strong enough in order to support the automated, real-time task coordination of deliverer–parcel–vehicle assignment considering crowdsourcing information in Internet-of-things.

The remainder of the paper is structured as follows. Literature review is summarized in Section 2. In Section 3, the service concept is introduced. The information system architecture is established in Section 4, as well as the main functions regarding travel processes are identified. In Section 5, the functional model is elaborated considering the information related activities. The matching condition of task assignment and energy consumption-based calculation are presented in Section 6. The paper is completed by Section 7 as discussion and conclusion, including further research directions.

2. Literature Review

The relevant literatures have been reviewed in four streams: (i) MaaS implementation, (ii) shared service based on AVs, (iii) crowdsourced parcel delivery in academic research, and (iv) parcel delivery and its automation in practice. The structure of literature has been summarized in Figure 1, in which crowdsourced delivery service is presented as 'Delivery as a Service (DaaS)' embedded into MaaS based on AVs.

The MaaS concept was formally proposed in 2015 to academia in Helsinki [11]. At the very beginning, the literatures on MaaS are limited in the concept identification and business model analysis. In recent years, researchers have paid more attention to its implementation and impact analysis [12]. The characteristics of early willing MaaS adopters are summarized: people who have relatively high income and high-level education, young (age < 55), frequently use mobile applications and travel with public transportation more [1,11]. Several MaaS implementations have been analysed in Madrid [13], Netherland [1], Taiwan [2], Australia [11], etc. Furthermore, the willingness to pay for MaaS is discussed, the monthly package is preferred by users from results of surveys [14]. Mobility cost highly depends on individuals; thus, the personalized mobility package is not available yet. In addition, MaaS is a mobile application-based service, the user group is also distinguished, especially with children and young people: what they expected for the new mobility service, how they will react to the digitalized mobility, and what the factors they considered in their daily mobility choices [15]. The base to incorporate AVs into MaaS is that MaaS market has to be mature. The updated implementation and impacts analyses may enhance the trust of MaaS users.

Adoption of MaaS could decrease car ownership, but it was rarely proved yet. Travel behavior analysis focus on what is the possibilities to change the travel behavior, by which practical way, and how to facilitate to use public transportation more: from theoretical level towards practice [16]. The MaaS system should embrace public transportation. MaaS is proposed not to conflict with private cars, it provides several sustainable mobility choices. MaaS is pointed as one of the solutions for travel behavior change or shift. For example, children and young people are not only considered in household mobility patterns as before, instead they are one significant user group who regard car ownership as less important, especially towards the near future shared mobility services based on AVs [15,17].

The three revolutions in urban transportation are pointed out as electrification, automation, and sharing. The development of electric vehicles (EVs) along with battery technology, have been put in the focus of many countries, such as US, EU, Japan, and China, in order to reduce the dependence on fossil fuel and reduce the emissions in environment [18]. The BEVs and plug-in hybrid EVs (PHEVs) are available to be charged by charging infrastructure. Considering the limitations of battery range and benefits to the environment, BEVs are more appropriate to be used in urban areas [19]. In order to achieve environmentally sustainable transport systems, BEVs and PHEVs could be the solution to accelerate the process, especially with the concept of carbon natural cities [20,21]. Turning to shared mobility services, car sharing is introduced as a short time 'car-rental' service, one-way station based, round trip, and free-floating are typical service types. The electric vehicle fleet is preferred, approaches of task assignment, vehicle charging, parking, and redistribution are widely discussed [17,22,23], especially charging of vehicles and fleet management are addressed. Ride sharing is considered as a non-profit service for middle to long distance travel, e.g., the blablacar service, where the private driver compensates the travel expense such as petrol cost only [24,25]. This service usually requires passengers to schedule service in advance, the available task assignments are matched via the online service platform [26]. The AV based car or ride sharing service is distinguished by the usage purpose of individuals or small groups. Car and ride sharing service are proposed to supplement the public transportation. The occupancy level of vehicles is to be improved in the shared mobility [27]. Users are attracted by the micro-mobility as well, for it is easy access, and is fast moving in congested traffic, e.g., electric scooter/bike sharing [28]. In

the context, the AV based carsharing and ride-sharing are identified as 'vehicle sharing' service and 'small group seat sharing' service, respectively.

'Crowdsourced' is proposed based on the sharing economy, to involve users (travelers, cyclists, and pedestrians) to use the resources together and create maximum value [29]. Crowdsourced parcel delivery problem is classified into three types [30]: with taxi, with multi-modal transport, or with private vehicles. The priority of passenger transit with taxi service remains, with parcel delivery with only short detour is acceptable. The public transportation has fixed schedules and routes, if the capacity could be managed, the possibility to deliver parcels is relatively high, e.g., to deliver parcels from the distribution center to the bus stop. The advantage of private vehicle delivery is the flexibility in theory, parcels can be easily transferred among different private drivers. However, electronic recording methods of such delivery are still missing, the security of the parcel is the concern. 'Neighborhood delivery' models are expanded to encourage citizens from the same neighborhood to collect and deliver parcels to their near final recipients [7,8,31]. Participants involved in specific delivery tasks can receive their reminder message automatically by the common information platform. The deliverer receives 'benefits' (e.g., money, or bonus points), and the delivery cost is lower to recipient as well, which is a mutual benefit to all participants. This kind of solution is more attractive in the highly populated, dense urban areas. Integrating autonomous delivery service into a passenger transportation system is proposed and studied, considering that the autonomous robots or vehicles 'pick up' and deliver goods at public transport station [4].

The last mile delivery problem in city logistics is defined as 'deliver products to the hands of customers' [29,32], and it is recognized as the expensive, inefficient, and high polluting section to transport goods. E-shopping and e-commerce is blooming these years, especially in China. For example, the delivery demand generated on 'Double Eleven Shopping Carnival' of Taobao this one day each year, from RMB 19.1 billion in 2012 to RMB 268.4 billion in 2019 (https://www.alibabagroup.com/ (accessed on 20 December 2020)). In addition, food delivery platform Meituan (https://waimai.meituan.com/) deliver food parcels 6.39 billion in 2018, the maximal daily order exceeds 24 million. The demand of instant small parcel delivery is fiercely increasing. Regarding the crowdsourced parcel delivery in practice, the On My Way service was launched by Amazon to allow Amazon users to pick up their own parcel and deliver other's parcels to others at their convenience. The My Ways service of DHL is opened for all individuals who are willing to share their geographical location and accept delivery request.

Furthermore, the application of automation and robots in logistics is also growing, for example in various sorters, IT-based packaging, in-transit information recording (http://www.sf-tech.com.cn/en/product/automation-and-robotics (accessed on 20 December 2020)), etc., and in automated or unmanned delivery, such as drones [33], indoor delivery robot, outdoor driverless vehicles, and the parcel lockers [34]. Although the operation scale of drones and driverless delivery vehicles is still in process, the tendency of automation and digitalization is promising both in logistics and transportation. The new or combined solutions to optimize the utilization of social resources are needed. The reviewed literature of crowdsourced parcel delivery is summarized regarding the applied methodology in Table 1.
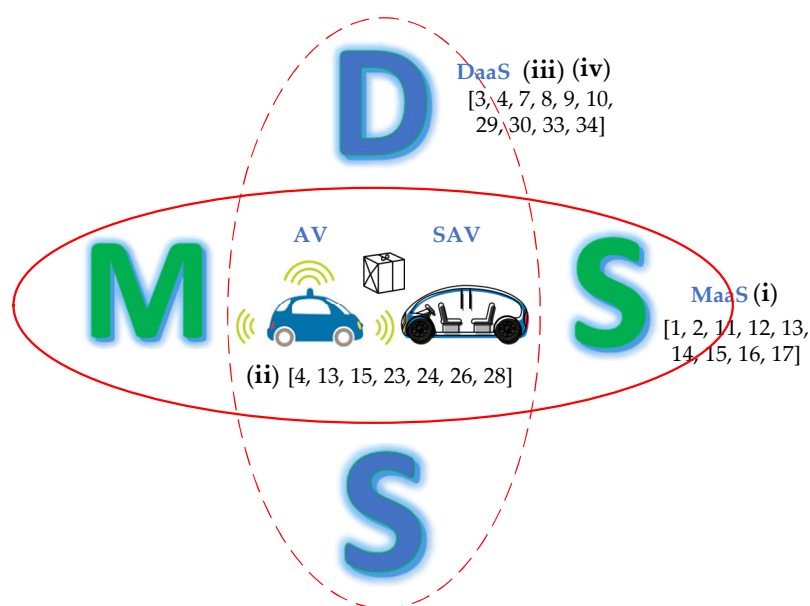
Figure 1. Structure of literature review.**(source:** [1–4,7–17,23,24,26,28–30,33,34]**)**

Table 1. Methodology summary of literatures in crowdsourced parcel delivery.

	Defined Problem	**Methodology**	**Focus**
[3]	Movement of passengers and goods are mixed on the same network.	Mathematical modelling, simulation, (periodic–optimization approach)	Planning and operating a shared PRT–FRT (personal–freight rapid transit) mode in shared networks
[4]	To use the underused assets in people-based systems to transport goods, stochastic optimization problem.	Approximation method, neighborhood search algorithm	The optimization problem has been formulated as a pickup and delivery problem with time windows, with scheduled lines and stochastic passenger demand.
[7]	Neighborhood delivery	Simulation, delivery and population density data, circle packing	The crowd to collect and deliver parcels using neighbors
[8]	Delivery-as-a-service, scheduling of Online-to-Offline parcels	Mixed-integer programming, hybrid neighborhood search strategy (tabu search)	Paired pickup and delivery problem with time window, pickup-first–delivery-second
[9]	A review of available platforms and literatures	Method of classification and comparison	The current practices and literatures are summarized
[10]	A grocery model with delivery time window limitation	Simulation method, case study	To illustrate the potential advantages of proposed concept by comparing results of scenarios
[29]	Truck routes and schedule, simultaneous pickup and delivery problem	A mixed integer non-linear program, a tabu search based algorithm	Cyclists and pedestrians are as crowdsources who are willing to deliver parcels with truck carriers
[30]	A realistic crowdsourced parcel delivery problem	Function approximation, artificial neural network, liner programming	Maximize profitability to manage orders and improve efficiency

Implementation of MaaS service is still ongoing around the world. The 'crowds' and information platform are needed in crowdsourced delivery service. In addition, the involved delivery 'crowds' have to be managed either in taxi model (drivers) or grocery model (customers). By incorporation AVs into MaaS, shared services are to be highly emerged. To manage or coordinate AVs is more efficient, the users of MaaS based on AVs could be the reliable 'crowds' of delivery service. Concluding from the literature review, to introduce a joint service concept has been identified as the research gap. Accordingly,

we elaborate the concept and model the crowdsourced parcel delivery service embedded into MaaS based on AVs.

Most researchers focus on crowdsourced parcel delivery problem by providing mathematical modelling solutions, only very few of them turn to analyze the information system used for operation. However, the common information platform is a base for such integrated service, especially when involving AVs into mobility system. Thus, by applying systematic approaches, we elaborate an information system and its operation to fulfill this niche. In addition, crowdsourced delivery is highlighted from the energy saving point of view as well [10,35], we also discuss the energy consumption per delivery applying the proposed service concept.

3. Service Concept

The first research question 'what is this embedded service' is answered by following concept. Figure 2 is used to identify the limitations in this work, the involved services are summarized regarding travel chains.
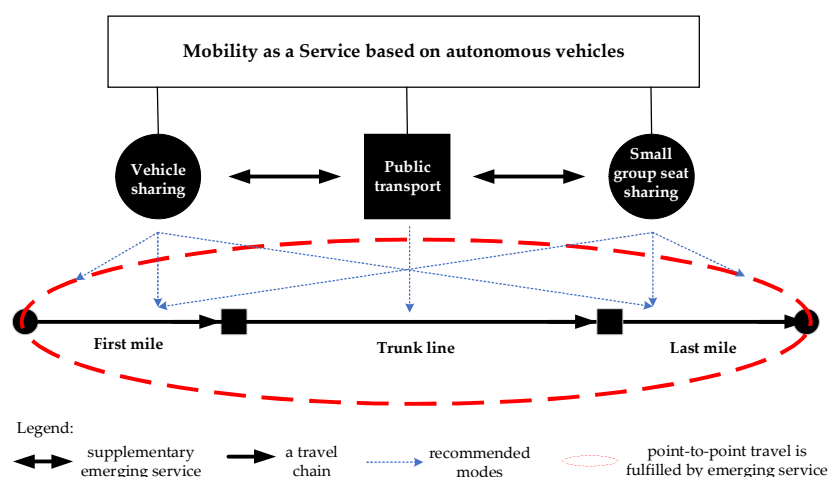
Figure 2. Service types in the MaaS based on AVs**.**

The large volume public transportation service remains for trunk lines operation, aided by automation or autonomy, e.g., automated metro and autonomous bus services. The shared, small, or medium size AV-based emerging services are applied mainly for feeder purpose to fulfil first/last mile demand, which are also applicable in point-to-point service. In this work, the services of shared AVs are introduced as individual vehicle sharing service and small group seat sharing service, accordingly, the service attributes are summarized in Table 2.

Table 2. The attributes of small capacity services.

Aspects	Vehicle Sharing	Small Group Seat Sharing
Vehicle size	small	medium
Capacity limit	individual, maximum 2	2–6
Separated parcel cabin	yes	no
Embedded delivery service	yes	no
Priority	embedded delivery	passenger transit
Only parcel delivery (compensate empty run)	peak-off + redistribution	peak off + redistribution
Affect passenger transit	yes	no
Walking distance to access vehicle	no	yes

Parcel delivery is embedded into individual vehicle sharing service as a priority option, e.g., passenger transit and parcel delivery are simultaneously performed. The delivery demand is not assigned when several passengers are transported, as time reconciliation among passengers is not efficient. Considering small group seat sharing service, either passengers or parcels are transported in passenger cabin.

During peak-off time or vehicle redistribution, both services are available for parcel delivery purpose. When parcel delivery announcement meets the vehicle return route simultaneously, then deliver parcels in passenger cabin. The Figure 3 is used to highlight the parcel delivery in services of vehicle sharing and small group seat sharing.
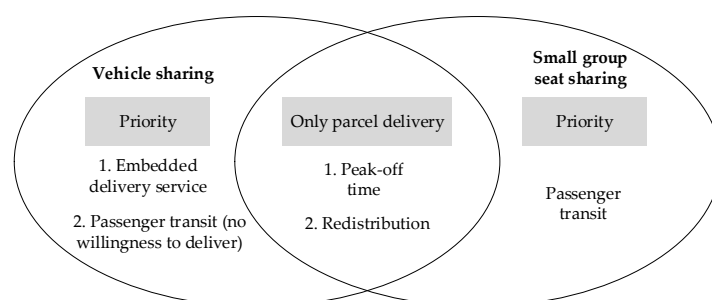
Figure 3. Interpretation of parcel delivery in emerging services.

Parcel delivery is a compensation to increase the time and space utilization of vehicles. The objective is to decrease or avoid empty run of vehicles. The embedded service is assigned with priority if the vehicle sharing user is willing to deliver parcel. Passenger transit demand is fulfilled first both with services of vehicle sharing and small group sharing. The onefold parcel delivery is identified as the intersection of these two services, to increase the opportunity to use vehicle space more in AV related tasks. Considering user types of parcel delivery service [9], Figure 4 is presented to indicate the types of users.
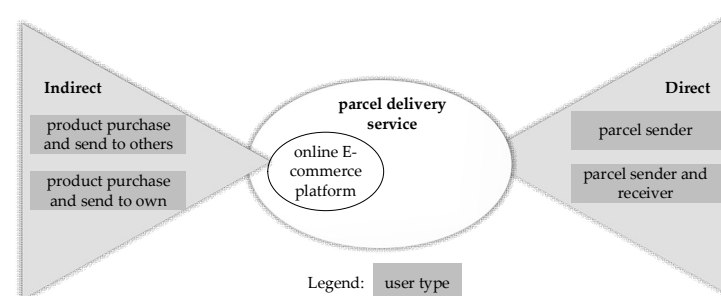
Figure 4. User categorization of parcel delivery service.

As e-commerce is getting more and more popular, in this work, the users who purchase products online and ultimately receive parcels are considered. The parcel delivery request is announced by the third-party e-commerce platform, the user is the indirect parcel delivery service announcer but the direct receiver. For example, the online food order and delivery. Capacity planning of crowdsourced food delivery service is studied regarding service quality [36]. The direct delivery request is announced by the food delivery platform, the direct discount receiver is the platform. However, the person who order and receive food pay for delivery in indirect way.

The crowdsourced delivery is highly depending on the advancement of information system to coordinate task assignments. The first real practice Postmates was established in 2011, and first academic research paper was published in 2016 [9]. This is still a relatively new service to mitigate the problems emerging from the last-mile city logistics [10]. A comprehensive review of crowdsourced delivery is elaborated in [9], both industry practice and academic literatures are summarized. The available crowdsourced delivery

platforms are categorized, types of assignment matching mechanisms and compensation schemes are characterized. In addition, the comparison with ride-sharing and ride-sourcing services are pointed out. Authors also address the topic of hybrid transportation system integrating passenger and freight transportation. Our proposed, so called hybrid service has several properties: real-time matching and pre-scheduling are both acceptable, travel route is determined by vehicle sharing users' priorities. Embedded delivery service based on AVs is to share the vehicle capacity, to decrease delivery cost by saved energy consumption and delivery labor resource.

This embedded delivery is operated by MaaS operator and parcel delivery service operator together, which is defined as an instant delivery service. The 'rush delivery' within 30 min is recommended (https://www.sf-express.com/cn/en/ (accessed on 20 December 2020)). Parcel cabin is equipped with special box when needed or parcel sender puts parcel in special box, for example, the fragile/hot/cold products need extra protection. The small parcels are distinguished into two categories based on the delivery time requirement:

A. **Fresh products contain but not limited at**: (hot) food/drink; material for cooking: vegetables, fruit, seafood, meat, etc.; significant document or letter; gift sending purpose: flowers, etc.; medicine, supermarket/grocery ordering, etc.

B. **General small sized parcel considering vehicle capacity**, delivery requirement is within half or one day. Products in category A are also appropriate if no instant time limitation.

Since the optimal combination is the parcel delivery embedded into individual vehicle sharing service, it is developed in the remaining work. The participants of the service are identified as components:

- U_d: *deliverer*. The users of vehicle sharing service, who accept the parcel delivery task on their travel route.
- U_r: *receiver*. The users of parcel delivery service, who accept the embedded delivery.
- M: *MaaS operator*. AV fleet operator is proposed to execute this role. The major task of M is service management and fleet operation.
- D: *delivery service operator*. Operate the traditional delivery service. The demand of crowdsourced delivery is shared and interoperated with M.
- P: *parking lot operator*.
- C: *charging station operator*.

Taken information management and vehicle movement into consideration, The Figure 5 is introduced to present the phases and processes of this embedded service (before, during, after):
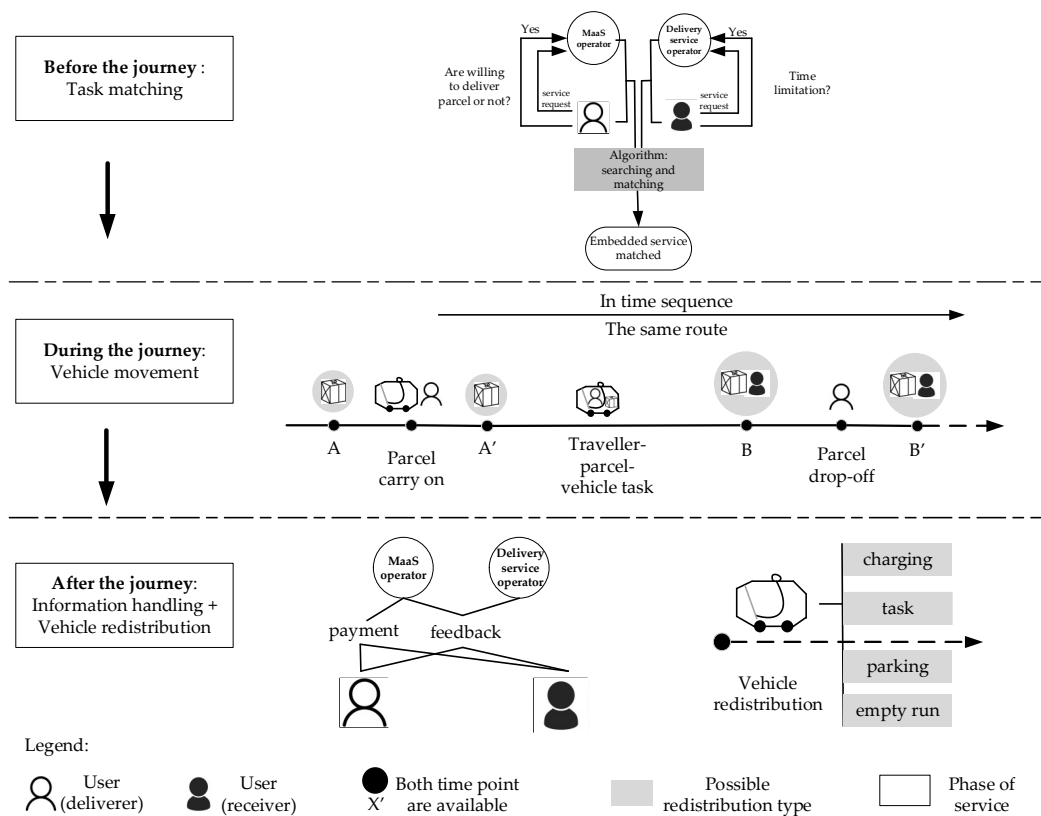
Figure 5. Phases of embedded service.

Phase: before the journey: **crowdsourcing task matching**. Service requests of vehicle sharing and parcel delivery are announced on platform, respectively. Task matching is completed by the background algorithms: searching and matching from two 'pools' of crowdsourcing request. The vehicle sharing user (deliverer U_d) and the parcel delivery service user (receiver U_r) are users of this embedded service. Discount is provided to both when the matched, embedded delivery is completed.

Phase: during the journey: **vehicle movement**. If the vehicle user is willing to deliver parcel, the travel is interrupted and vehicle may stop at the defined point to let the parcel sender put the parcel on, and to stop at another point to let the receiver take parcel off. If the parcel put-on and drop-off points are not located along the route of deliverer, e.g., either before (point A) or after (point B'), then the vehicle sharing service is not affected or just once. The travel of vehicle sharing user should not be delayed by the entire parcel delivery: the process to put on and take off the parcel do not exceed 10 min. The real-time information is accessed by all participants, their tasks are performed on time. The parcel sender receives remainder in advance and waits for vehicle to put parcel on, accordingly the parcel receiver takes off parcel without delay as well. The strict matching and preferred task assignment is to complete delivery within the travel route of U_d.

Phase: after the journey: **feedback and redistribution**. The fare payment is managed by the *M.* Feedback opportunity has high relevancy. The participants can evaluate each other's performance. According to the state of vehicles, vehicle redistribution types are categorized into four cases to decrease empty runs:

- Vehicle with tasks: a. embedded service, b. only passenger transport, c. only parcel delivery,
- Charging, (and parking),
- Parking in short time to wait for very next task assignment,
- Return with empty run.

Authentication between human elements and AVs are ensured by identification technology. Either NFC (near-field communication) or electronic code solution are to be applied. The flowchart (Figure 6) is developed to present the information handling process.
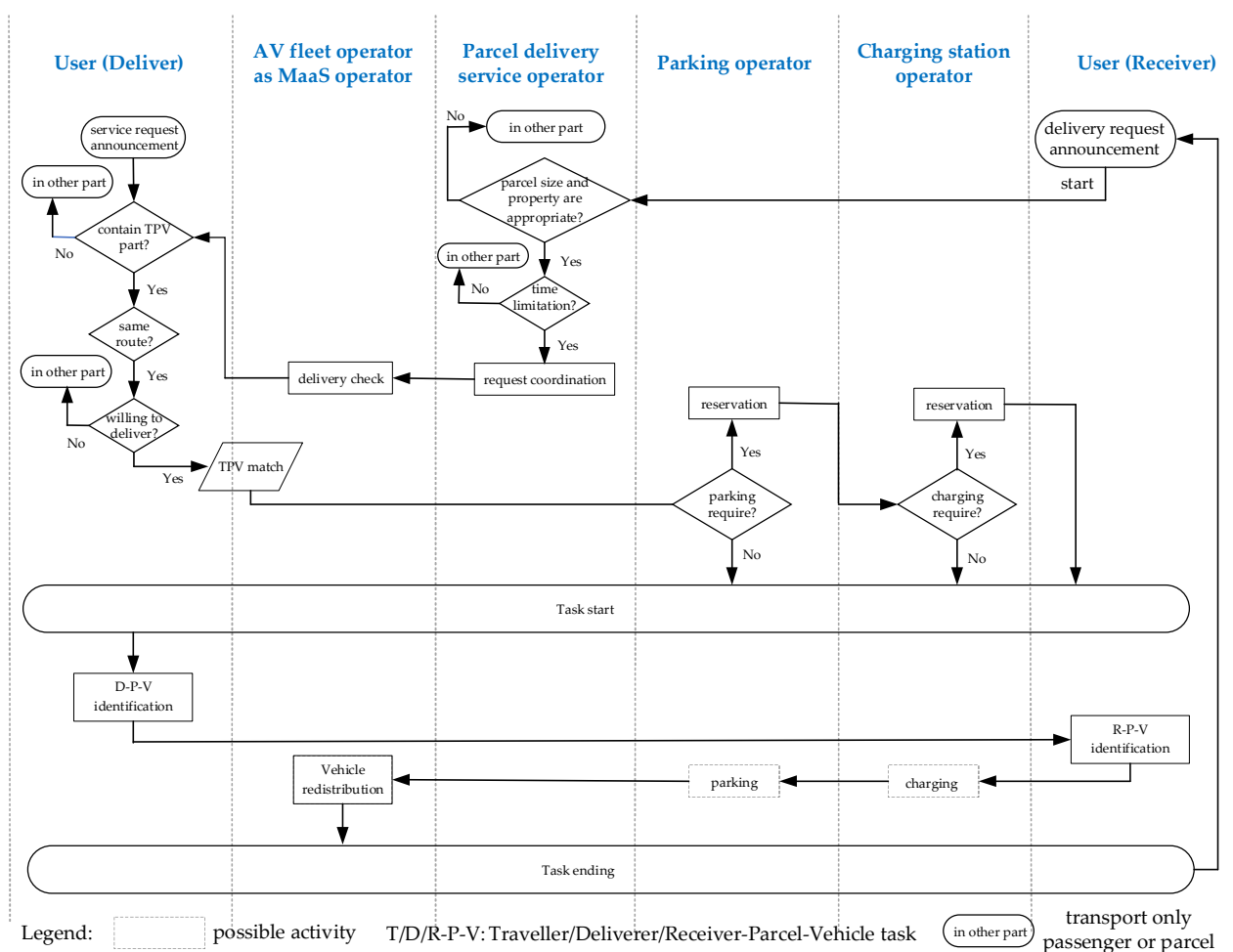
Figure 6. Information handling flow chart.

The information handling process to search, match, and complete an embedded task is presented. Parking and charging service are not mandatory to be used in each assignment, which highly depends on current state of vehicles. Cooperation among operators of MaaS (*M*), parking lot (*P*), and charging point (*C*) are recommended via common information platform. Thus, booking of charging point and parking space are available with real-time information. Either *M* or users may announce parking and charging demand according to state of AVs. The only passenger transport or parcel delivery tasks are coordinated in other processes.

4. Information System Architecture

The second research question 'what information system and functions are proposed' is answered by system architecture in this section. A security logistics system is proposed by applying system-oriented approach, the service processes are well presented by information flow [37]. The information system model of autonomous road freight transportation has been studied, focusing on entire system architecture, as well as processes and functions [38]. Operation of this freight system in metropolitan areas are discussed, automated or autonomous vehicles are investigated as a subsystem. However, last-mile deliv-

ery is a subproblem of city logistics, crowdsourced delivery is applied as one of the supplementary solutions. The AVs are involved in the information system as one system component because of its cognitive ability.

– **AV**: *autonomous vehicle (driverless)*.

The Figure 7 has been elaborated to present the information system architecture of the service.
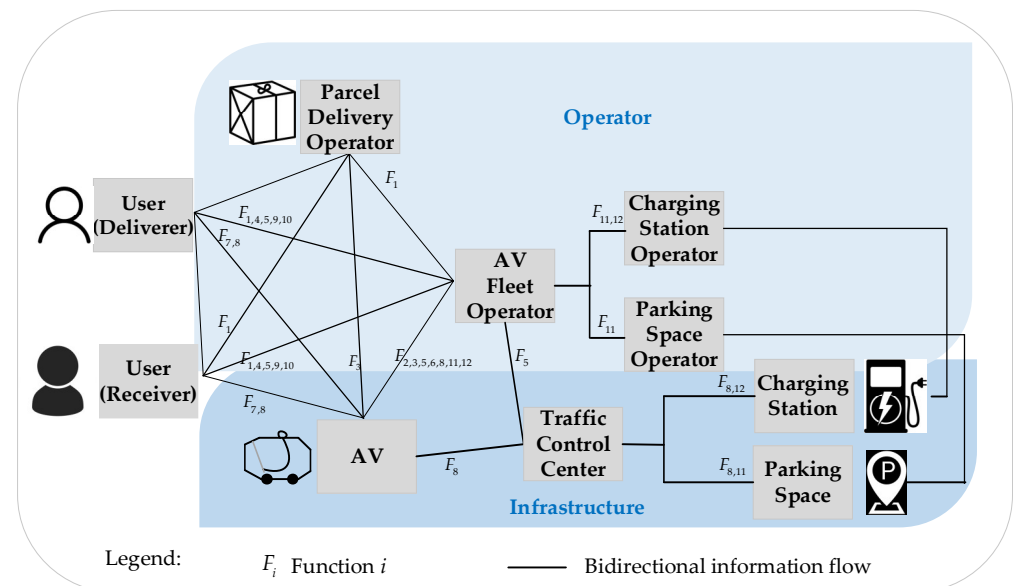
Figure 7. Information system architecture.

The purpose of vehicle-sharing service user (U_d) is to travel either from origin to destination or to fulfil a section in a travel chain. U_d accepts to deliver parcel and the bonus or discount is provided as a mutual benefit. The U_r is delivery service user and ultimate parcel receiver in this context. Typically, U_r are frequent e-commerce users. The traditional delivery service platform is operated by D. The demand of crowdsourced delivery is limited. M is the system operator and the backbone cloud information platform operator. AV is the intelligent transportation tool to transfer passenger and goods. AV is a small or medium sized vehicle. C is the intelligent charging station operator. The smart charging station and parking space are operated by P and C, respectively.

The AVs, charging station, and parking space are categorized into the infrastructure layer, the corresponding operators are listed in the operator layer. Each operator works as a subsystem. As real-time information of connected vehicles are interacted with traffic flow information frequently, traffic control center and AV fleet operator are both assigned to M. AVs, as well as utilization of charging point and parking space, are more relevant for real-time traffic control, the control center is presented specifically. We have summarized the triangle and quadrilateral relations existing among U_d, D, M (fleet operator), AV, and U_r in Table 3.

Table 3. Correspondence of tasks and component in pentagon.

Triangle cooperation in tasks: information process			
U_d–D–M	Offered delivery opportunity	D–M–AV	Delivery vehicle management
M–AV–U_r	Receiver–vehicle match	AV–U_r–U_d	Users–vehicle match
U_r–U_d–D	Service request match	U_d–D–AV	Deliverer–vehicle notification
D–M–U_r	Delivery request response	M–AV–U_d	Deliverer–vehicle match
AV–U_r–D	Receiver–vehicle notification	U_r–U_d–M	Service match and notification
Quadrilateral cooperation in tasks: physical process			

U_d–D–M–AV	Deliverer carries parcel on	D–M–AV–U_r	Receiver picks parcel off
M–AV–U_r–U_d	Pick off confirmation to M	AV–U_r–U_d–D	Pick off confirmation to D
U_r–U_d–D–M	Parcel service ending	U_r–U_d–D–M–AV	Ideal system optimum circulation

The travel and delivery demand are coordinated by the interactive information flow. A highly connected mobility system facilitates the real-time traffic control, as well as response to the supply management. Data recording of tasks increase mutual trust among components. Travellers may be more willing to use public transport service, if automatic management of service and infrastructure response efficiently. For example, if the deliverer–parcel–vehicle embedded assignment is not matched or available, charging and parking are proposed to support vehicle redistribution. The AV in public service is a kind of infrastructure, to avoid empty run and detour is to save energy. The introduced functions in architecture are summarized regarding travel phases in Table 4.

Table 4. Functions.

F_1. Demand Announcement	F_2. Vehicle Checking 1	F_3. Assignment	F_4. Booking
F_5. Routing	F_6. Vehicle checking 2	F_7. Identification	F_8. Monitoring
F_9. Feedback handling	F_{10}. Payment	F_{11}. Redistribution	F_{12}. Maintenance

Phases: before travel, during travel, after travel.

Since cooperation among components are needed, one function may be assigned to several components. The interpretations of functions are unfolded in the following functional model. The functions and their connections are presented in Figure 8 according to time sequence.
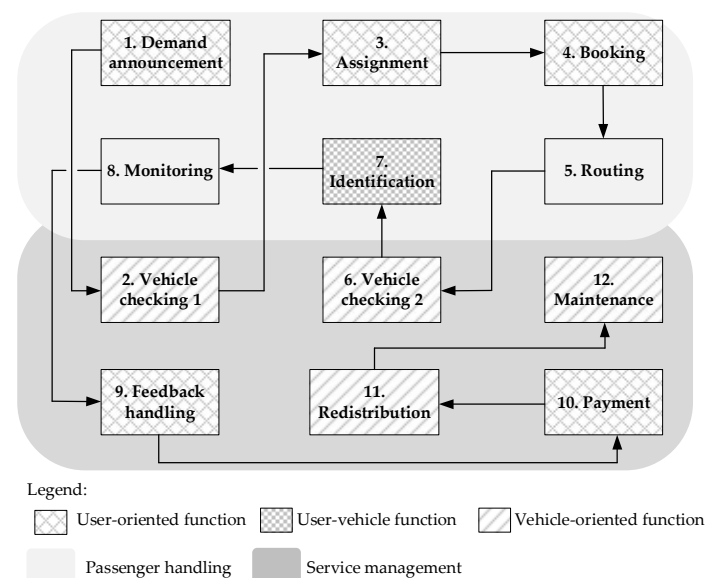
Figure 8. Categorization and connections between functions.

Functions are numbered according to time sequence involved in a travel chain: before/during/after the travel. User-oriented and vehicle-oriented functions are addressed, as demand and capacity are coordinated with these functions. The F_7 identification is categorized as 'user-vehicle function', security to use vehicle and delivery service is supervised by digital identifications. Weakness of crowdsourced delivery could be enhanced by electronic tracking and recording, e.g., records of putting parcel on and taking it off via QR code scanning on the parcel cabin screen.

5. Functional Model

Based on the established system architecture, the third research question 'what information management processes are needed for operation' is answered by the functional model. As the system components, functions, and data are the three main dimensions in functional model, thus firstly data groups are determined in Table 5. According to frequency of update, the data groups of components are categorized into static (s), semi-dynamic (sd), and dynamic (d). The archived data are involved in the static data groups and are rarely updated. Semi-dynamic data are updated hourly or daily according to real needs. The dynamic data are real-time data and keep sync with the cloud platform. The main input and output data of functions have been summarized. As '*D*' is used to represent data group (D), '*O*' is used to indicate the parcel delivery operator.

Table 5. Data groups.

| Data Group	Static Data (s)	Semi-Dynamic Data (sd)	Dynamic Data (d)
User (*U*): **Deliverer** (*U_d*), **Receiver** (*U_r*)	$D^1_{U,s}$ account data $D^2_{U,s}$ customization setting	$D^1_{U,sd}$ service data $D^2_{U,sd}$ preferences $D^3_{U,sd}$ payment $D^4_{U,sd}$ feedback	$D^1_{U,d}$ position <u>(GPS)</u> $D^2_{U,d}$ identification $D^3_{U,d}$ current reservation
Vehicle (*V*)	$D^1_{V,s}$ base data of vehicle $D^2_{V,s}$ battery capacity	$D^1_{V,sd}$ service data $D^2_{V,sd}$ maintenance	$D^1_{V,d}$ state of charge $D^2_{V,d}$ position <u>(GPS)</u> $D^3_{V,d}$ identification
Charging station (*C*)	$D^1_{C,s}$ data of charging point $D^2_{C,s}$ data of charging station	$D^1_{C,sd}$ point reservation $D^2_{C,sd}$ maintenance	$D^1_{C,d}$ current reservation
Parking lot (*P*)	$D^1_{P,s}$ data of parking space $D^2_{P,s}$ data of parking lot	$D^1_{P,sd}$ space reservation $D^2_{P,sd}$ maintenance	$D^1_{P,d}$ current reservation
Network (*N*)	$D^1_{N,s}$ nodes, lines, interchange, etc. $D^2_{N,s}$ vehicles $D^3_{N,s}$ geographic, topology $D^4_{N,s}$ data of route	$D^1_{N,sd}$ route recommendation	$D^1_{N,d}$ GPS of vehicle $D^2_{N,d}$ traffic signal $D^3_{N,d}$ route situation $D^4_{N,d}$ traffic, delay, congestion
MaaS operator (*M*)	$D^1_{M,s}$ fleet data (e.g. number of vehicles, vehicle type, condition) $D^2_{M,s}$ historical records $D^3_{M,s}$ maintenance data	$D^1_{M,sd}$ service coordination $D^2_{M,sd}$ schedule of public transport $D^3_{M,sd}$ reservation $D^4_{M,sd}$ payment split and transfer $D^5_{M,sd}$ service package	$D^1_{M,d}$ current coordination $D^2_{M,d}$ price data $D^3_{M,d}$ redistribution $D^4_{M,d}$ estimated time $D^5_{M,d}$ payment state $D^6_{M,d}$ feedback handling
Parcel delivery operator (*O*)	$D^1_{O,s}$ base data of parcels (e.g. size, goods type, time limitation)	$D^1_{O,sd}$ service data	$D^1_{O,d}$ assignment

$D^2_{O,sd}$	feedback	$D^2_{O,d}$	GPS of parcel
		$D^3_{O,d}$	identification

Service process related data of users, vehicles, parcel delivery operator are recorded, e.g., reservation, boarding/alighting time. Identification data is generated to open the door of vehicles, e.g., QR code. User personal account is established similar to an individual database, data of users are stored and classified, e.g., name, phone, credit card, and email. Static data are to be the input of preference mining. Customization setting requires input about users' preferences manually, e.g., preferred travel mode, maximum walking distance, and waiting time. By contrast, preference recommendation of personalization applies artificial intelligence, users' preferences are set automatically considering collected data of travel behavior and habits, e.g., the recommended route with preferred travel mode.

Base information of vehicles is stored, e.g., brand, capacity, production year, running mileage, battery capacity, range, and type of charging connector. Information about current battery state is relevant for both user and operator.

Maintenance data of vehicle, charging station, parking lot are recorded to optimize the usage of infrastructure. The base information of charging point, e.g., the type of charger, the charging power: super charging or common charging. The information of charging station and parking lot, e.g., number of charging points and parking space, and their location.

In addition, one cubic cell is sliced and presented to interpret the base unit of functional model in Figure 9.
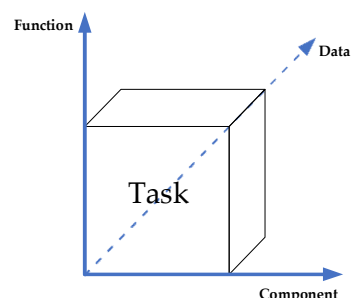
Figure 9. Cubic cell.

The three-dimension cubic cell contains: which function ($F_{1–12}$) is performed by which component (U_d, O, M, C, P, U_r), by which kind of data input (D), in which exact task (each cubic). The simplification is that only main input data groups are listed. Then the three-dimensional functional model of the service is presented in Figure 10.

Function	User (Deliverer)		Parcel Delivery Operator		AV Fleet Manager as MaaS Operator		Charging Station Operator		Parking Lot Operator		User (Receiver)	
1. Demand announcement	Service request	$D^{1,2}_{U_d,s}$ $D^{1,2}_{U_d,sd}$	Parcel information	$D^1_{O,s}$	Vehicle information	$D^{1,3}_{M,s}$	Charging point information	$D^{1,2}_{C,s}$	Parking space information	$D^{1,2}_{P,s}$	Delivery request	$D^{1,2}_{U_r,s}$ $D^{1,2}_{U_r,sd}$
2. Vehicle checking 1	**M**: Optimal searching of vehicle availability regarding position of user (D) and parcel											$D^1_{U_r,sd}$ $D^1_{N,sd}$ $D^1_{O,s}$ $D^1_{V,s}$ $D^2_{M,s}$ $D^1_{O,sd}$ $D^1_{V,sd}$ $D^4_{M,d}$ $D^{3,4}_{N,s}$
3. Assignment	User (D)-vehicle matching (position 1)	$D^1_{U_d,sd}$ $D^1_{V,sd}$	Parcel-vehicle matching (position 2)	$D^1_{U_r,sd}$ $D^1_{V,sd}$	AV assignment confirmation	$D^3_{u_d,d}$ $D^1_{M,d}$	(charging request)	$D^1_{C,sd}$ $D^1_{V,sd}$	(parking request)	$D^1_{P,sd}$ $D^1_{V,sd}$	User (R)-vehicle matching (position 3)	$D^1_{U_r,sd}$ $D^1_{V,sd}$
4. Booking	Identification code receiving (code 1)	$D^{2,3}_{U_d,d}$ $D^1_{U,d}$	Identification code receiving (code 2)	$D^{1,3}_{O,d}$ $D^1_{O,sd}$	Identification code information	$D^3_{V,d}$ $D^1_{M,d}$	(charging point reservation)	$D^1_{C,d}$	(parking space reservation)	$D^1_{P,d}$	Identification code receiving (code 3)	$D^{2,3}_{U,d}$
5. Routing	Route confirmation	$D^1_{U_d,sd}$	Route information	$D^3_{U_d,d}$ $D^1_{O,d}$	Real-time route planning	$D^1_{M,d}$ D_N	(charging point information)	$D^1_{C,d}$	(parking space information)		Route confirmation	$D^3_{U,d}$ $D^1_{O,d}$
6. Vehicle checking 2	Confirmation (charging, parking, etc.)	$D^3_{U_d,d}$	Expected deliver time	$D^4_{M,d}$	Real-time state of vehicle confirmation	$D^{1,2}_{V,d}$	(charging point reservation)	$D^1_{C,d}$	(parking space reservation)	$D^1_{P,d}$	Expected receiving time	$D^4_{M,d}$
7. Identification	Code matching, task start	$D^2_{U_d,d}$ $D^1_{V,d}$	Code matching, parcel deliver start	$D^3_{O,d}$	Supervision	$D^1_{M,d}$ $D^3_{V,d}$	(Code matching, charging)	$D^1_{C,d}$ $D^3_{V,d}$	(Code matching, parking)	$D^1_{P,d}$ $D^3_{V,d}$	Code matching, parcel delivery ending	$D^2_{u,d}$ $D^3_{u,d}$ $D^3_{V,d}$
8. Monitoring	Vehicle position tracking	$D^1_{U_d,d}$	Parcel position tracking	$D^2_{O,d}$	Monitoring all	$D^2_{V,d}$	Maintenance	$D^2_{C,sd}$	Maintenance	$D^2_{P,sd}$	Parcel position tracking	$D^1_{U,d}$
9. Feedback handling	Feedback (1)	$D^4_{U_d,sd}$	Feedback (2)	$D^2_{O,sd}$	Feedback back handling (1, 2, 3)	$D^6_{M,d}$					Feedback (3)	$D^4_{U,sd}$
10. Payment	Electronic payment	$D^3_{U_d,sd}$	Receiving, completion		Confirmation, transfer	$D^5_{M,d}$ $D^{3,4,5}_{M,sd}$	Receiving, completion		Receiving, completion		Electronic payment	$D^3_{U,sd}$
11. Redistribution	**M**: Optimal searching of vehicle availability regarding position of user (D) and parcel											$D^{1,2}_{U_d,s}$ $D^{1,2}_{V,d}$ $D^2_{M,sd}$ $D^2_{U_r,sd}$ $D^1_{C,d}$ $D^{2,3}_{M,d}$ $D^1_{U,d}$ $D^1_{P,d}$ $D^1_{V,s}$ D_N
12. Maintenance					Vehicle checking (charging, repair, etc.)	$D^1_{V,s}$ $D^3_{M,S}$	(charging)	$D^2_{C,sd}$ $D^1_{C,d}$	(parking, wait for next assignment)	$D^2_{P,sd}$ $D^1_{P,d}$		

Legend: component | function | Information management related task | D^i Data group i | ( ) this task depends on real situation | → Electronic cash flow

Figure 10. Functional model. (Remarks: position: 1. passenger get on/off, 2. parcel put on, 3. parcel take off. code: 1. open passenger cabin, 2. open parcel cabin and put on, 3. open parcel cabin and take off.)

U_r announces the delivery request (F1), meanwhile one crowdsourcing U_d is matched to deliver the parcel on the route (F2). AV is assigned and scheduled by M (F3). Then U_d and U_r confirms the booking, respectively (F4). Vehicle sharing may only be part of the travel chain of U_d. Before the vehicle movement starts, the real-time routing and vehicle dynamic condition checking are required and performed, updated information are available on cloud platform and for each component (F5, F6). Then the assigned AV arrives, the vehicle sharing user U_d uses smartphone for authentication and enters the passenger cabin (F7). Outside parcel sender puts the parcel on the vehicle either before U_d enters or after,

identification is performed between parcel sender and parcel cabin (F₇). The same, parcel is taken off by **U**ᵣ either before or after **U**ₐ alighting. AV as a 'rolling computer' is tracked and monitored (F₈). During the vehicle movement, if charging is required, the charging request is detected and sent by **M** or **U**ₐ to **C**, for example, the vehicle detection system receives the battery state information and 'reacts' accordingly. The appropriate charging point is assigned by **C**. Task is completed by digital confirmation with AV, **U**ₐ and **U**ᵣ. Digitalization based mutual authentication is the real-time records of information services [37]. During vehicle redistribution, the aim is to avoid or reduce vehicle empty run (F₁₁, F₁₂).

Two real-time information checking of vehicles are proposed to ensure base service quality: appropriateness checking and availability checking. Vehicle checking 1 (F₂) is to ensure the vehicle availability: whether the selected AV is available to be used in the estimated time and location. Vehicle checking 2 (F₆) is to ensure the appropriateness of selected AV before the movement. The vehicle parameters, such as data of vehicle inner temperature, cleanness, and battery state are checked. Estimated vehicle arrival time and delivery time are provided and updated. Several digital identification processes (F₇) are fulfilled. To improve service quality, feedback opportunities are available for all participants (F₉). **M** is responsible for (F₁₀) electronic payment collection and its distribution. Vehicle redistribution or reallocation (F₁₁) is the core to balance energy efficiency and consumption.

6. Matching Condition and Estimated Energy Saving per Delivery

The rapid task matching is the key to implement such emerging mobility services. The matching theory is applied to present the assignment matching condition regarding special-temporal attributes. In addition, according to EN 16258:2011 [39], estimated energy consumption and comparison regarding per parcel delivery are calculated via built scenarios. In order to keep consistence with signs in equations, the un-bolded '*U*ₐ' and '*U*ᵣ' are applied in this section for explanation purpose.

6.1. Matching Condition

Applying the matching theory [40,41] to the proposed service, the two-sided U_d-U_r matching μ is defined as following: $S_d = \left\{ U_{d1}^{'}, U_{d2}^{'}, \cdots, U_{dk}^{'}, k \in N^* \right\}$, $S_r = \left\{ U_{r1}^{'}, U_{r2}^{'}, \cdots, U_{rl}^{'}, l \in N^* \right\}$, a U_{di}' can only have preferences over the set of $S_r \cup \{U_{di}'\}$, a U_{ri}' can only have preferences over the set of $S_d \cup \{U_{ri}'\}$. The matching results $\mu = \left\{ U_d, U_r \right\}$ from $\mu : S_d \cup S_r \rightarrow S_d \cup S_r$ are satisfied with: $U_d = \mu(U_r) \Leftrightarrow \mu(U_d) = U_r$, and $\mu(U_d) \in S_r \cup \{U_d\}$ and $\mu(U_r) \in S_d \cup \{U_r\}$. The objective function is max. $Z = \mu\{U_d, U_r\}$, Z is the number of matched pairs under the matching condition:

$$C = \left\{ T_{U_d} \supseteq T_{U_r}, R_{U_d} \supseteq R_{U_r}, U_d \subseteq S_d, U_r \subseteq S_r \right\} \Big|_{D_T \leq 30} . \tag{1}$$

Namely, the priority is to match the pairs of U_d and U_r by the matching condition. If embedded task is not available, then only vehicle sharing service for U_d or traditional delivery service for U_r are coordinated. The strict matching condition is interpreted in Figure 11.
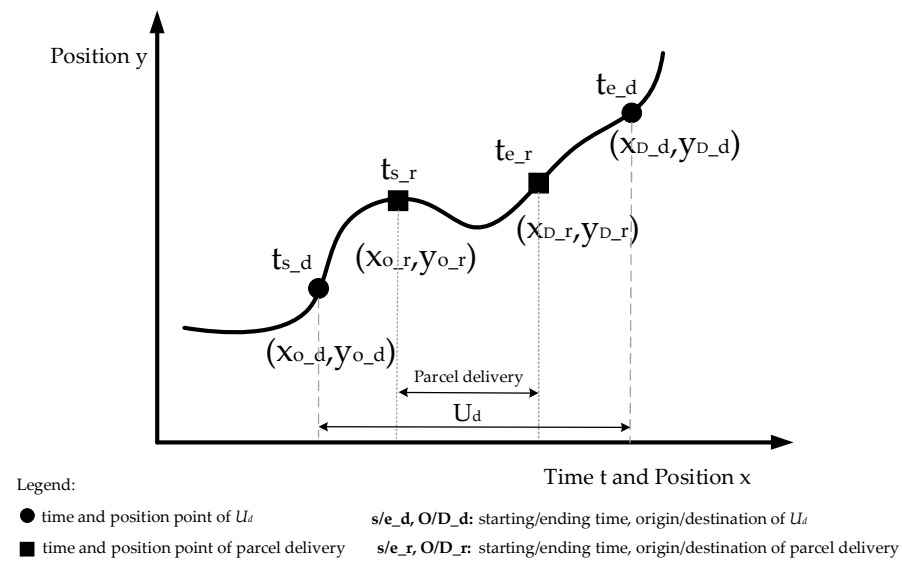
Figure 11. Matching condition of ideal case.

The matching condition regarding the time period $T_{U_d} \supseteq T_{U_r}$ is defined as

$$T_{U_d} = \left(t_{s\_d}, t_{e\_d} \right), T_{Ur} = \left(t_{s\_r}, t_{e\_r} \right) : t_{s\_r} - t_{s\_d} \geq 0, t_{e\_d} - t_{e\_r} \geq 0, t_{e\_d} - t_{s\_r} \geq 0 \quad (2)$$

The time interval of delivery is within the time interval of U_d. The matching condition regarding the same route is $R_{U_d} \supseteq R_{U_r}$. This is an en-route matching, the route of delivery is on the route of U_d. Since the determination of overlapping routes or path similarities is another complex research topic, we are not available to deep the judgment algorithm. Various patents and research papers are existing regarding this topic, applicability is ensured. We present an ideal judgement condition as following: a function $Z = F(x, y)$, i.e., $y = f(x)$ is defined as the route of U_d, part of route is overlapped with delivery:

$$Z_{O\_d} = F\left(x_{O\_d}, y_{O\_d} \right), Z_{D\_d} = F\left(x_{D\_d}, y_{D\_d} \right), Z_{O\_r} = F\left(x_{O\_r}, y_{O\_r} \right), Z_{D\_r} = F\left(x_{D\_r} \right)$$
$$\text{exist, i.e.,:} \quad y_{O\_d} = f\left(x_{O\_d} \right), y_{D\_d} = f\left(x_{D\_d} \right), y_{O\_r} = f\left(x_{O\_r} \right), y_{D\_r} = f\left(x_{D\_r} \right). \quad (3)$$

Other methods to measure similarity or overlapping of routes are acceptable, the algorithm to measure route similarity is the 'black box' in our work, the output result is more relevant for matching algorithm. In addition, in order to solve 'one-to-many' pairs, the 'first-searched-first-matched' rule is applied. The matching optimization is not needed, as overall aim is to obtain as many available matching as possible, not profit-oriented matching. The time interval limitation with matching priority is presented in Figure 12.
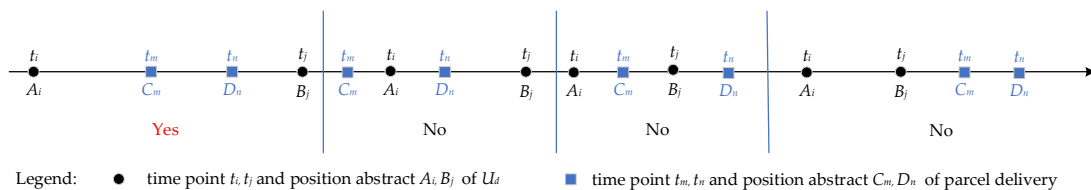

Figure 12. Matched assignment.

Time point is the starting/ending time of task. These four cases all are acceptable, but considering priority of U_d, only the first case: involved interval of time and route is discussed. The pseudocode of assignment matching is presented in Figure 13.

Algorithm 1 Assignment matching.

Input: The set of time point for $U_d : T_d = (t_i, t_j)$, $U_r : T_r = (t_m, t_n)$; The set of location point for $U_d : P_d = (A_i, B_j)$, $U_r : P_r = (C_m, D_n)$; The set of route function of $U_d : F_d$;

Output: Set of matched pairs (U_d, U_r);
 1: Judge whether time interval fulfill require $(t_n - t_m) \leq 30$;
 2: Match of time interval $(t_m - t_i) \geq 0$, $(t_j - t_n) \geq 0$, $(t_j - t_m) \geq 0$. Namely, $(t_m, t_n) \subset (t_i, t_j)$;
 3: Match of route. $F(C_m)$, $F(D_n)$ exist. Route $R(C_m, D_n) \subset R(A_i, B_j)$
 4: Judge wheter $R(C_m, D_n)$ and $R(A_i, B_j)$ is on the same direction.
 5: First searching first matching;
 6: **return** (U_d, U_r);

Figure 13. The pseudocode of assignment matching.

The strict matching is to ensure the service priority of U_d. The route overlapping and direction checking are needed, as route curve is complicated in most circumstances. Detour is not in consideration, route is highly depending on the vehicle sharing service user.

6.2. Energy Consumption Calculation of Scenarios

Electric vehicles and new energy vehicles are proposed to replace fossil fuel powered vehicles, to decrease dependency on fossil fuel resources and to protect environment. Small sized electric vehicles (three wheels) have been applied in parcel delivery. The scenarios have been built to present the estimated calculation results of energy consumption per parcel delivery, regarding electricity, petrol and diesel respectively. Both traditional and embedded cases are considered.

The nomenclature used in this subsection is summarized in Table 6.

Table 6. Nomenclature used in this section.

	Meaning	Unit
F_{ec}	Energy consumption	L or kwh
$f_{fc/100km}$	Fuel consumption per hundred kilometer	L/*100* km or kwh/*100* km
L	Travel distance: length of route	km
T	TTW, tank-to-wheel. Direct consumption and emission from vehicle operation.	
W	WTW, well-to-wheel. Consumption from energy generation and vehicle operation.	
$E_{T/W}$	Standardized energy consumption (tank-to-wheel or well-to-wheel)	MJ
$G_{T/W}$	CO_2 equivalence (tank-to-wheel or well-to-wheel)	kg
$e_{T/W}$	Covert factor of standardized energy consumption	MJ/L or MJ/kwh
$g_{T/W}$	Covert factor of CO_2 equivalence	kg/L or kg/kwh
w_i	Weight of parcel i	kg
W	Weight of vehicle	t or kg
n	Number of parcels delivered per delivery	
cv	Conventional vehicle (petrol or diesel powered)	

Ed	Electric delivery vehicle (small size)
AEV/EV	Electric vehicles or autonomous electric vehicles

Energy consumption of road vehicle is calculated as:

$$F_{ec} = f_{fc/100km} \cdot (L/100) \qquad (4)$$

This is an estimated calculation without considering the current road conditions and detailed vehicle parameters. Average fuel consumption running per hundred kilometers are known by vehicle users. In order to compare estimated energy consumption and caused emission among different fuel per parcel delivery, e.g., petrol, diesel, electricity, and F_{ec} is converted to standardized energy consumption $E_{T/W}$ and CO$_2$ equivalence $G_{T/W}$ by multiply the covert factor

$$E_{T/W} = F_{ec} \cdot e_{T/W} \quad \text{and} \quad G_{T/W} = F_{ec} \cdot g_{T/W} \qquad (5)$$

Values of convert factor are according to EN 16258 standard [39], the applied values in scenario calculations are summarized in Table 7.

Table 7. Value of standardized covert factor (source: EN 16258 [39]).

Fuel Type	Standardized Energy Consumption		CO$_2$ Equivalents	
	e_T	e_W	g_T	g_W
	MJ/L		kg *(CO$_2$e)*/L	
Petrol	32.2	37.7	2.42	2.88
Diesel	35.9	42.7	2.67	3.24
	MJ/kwh		kg *(CO$_2$e)*/kwh	
Electricity (c)	3.6	10.2	0	0.424

In order to compare the estimated energy saving and emission decreasing in one matched assignment, two scenarios are built. Two cases are involved in each scenario. Under the same route assumption, separated parcel delivery vehicle inserted into a vehicle sharing route is set as case 1 traditional delivery, the embedded service is set as case 2. The separated parcel delivery vehicle in case 1 is defined as small size electric vehicle. For example, three-wheel electric vehicles are used to deliver parcels in Chinese cities from 2014 considering the requirement of green logistics (https://auto-time.36kr.com/p/309219806101512 (accessed on 20 December 2020)), which now is in transformation phase to electric car delivery. The applied values of vehicle parameters are summarized in Table 8.

Table 8. Average fuel consumption per 100 km.

Type	Weight	Fuel Consumption	Petrol	Diesel	Electricity
conventional vehicle (cv)	1.5 t	L/100 km	6	4.5	
AEV/EV	1.2 t	kwh/100 km			16
Electric delivery vehicle (Ed)	0.35 t	kwh/100 km			3.3

Weight of vehicles are not used in calculation, but fuel consumption per hundred kilometer is affected by the weight of vehicles and, thus, are presented as well. Average fuel consumption per hundred kilometers is estimated value [42,43], as real data highly depends on individual vehicles. Then two cases involved in scenario are presented in Figure 14, which is regarding to a MaaS travel chain example, as vehicle sharing may only be a 'leg' involved in a travel chain.
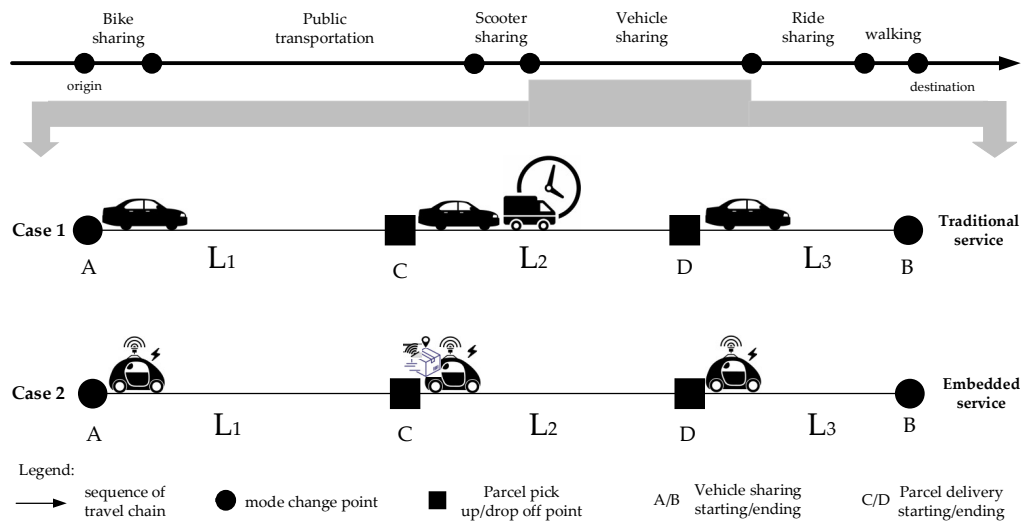
Figure 14. Cases are presented in a MaaS travel chain example.

In order to present the numerical simulation results, the simplified, comparable scenarios are built as: under the same conditions, e.g., the vehicle sharing service is assigned, and what the energy performance of vehicles are in separated assignments and in an embedded one. Embedded delivery is proposed to supplement traditional delivery, both service types could be available in the future.

In Scenario 1, the vehicle is fossil fuel powered in case 1. In Scenario 2, both cases are electricity powered vehicles. Comparison aim between Scenario 1 and Scenario 2 are to present fuel consumption results of petrol, diesel, and electricity powered vehicles in per traditional parcel delivery. In Scenario 2, in order to present the differences in traditional and embedded delivery, both are considered applying fully electricity powered vehicles.

To deliver a single parcel, in traditional case 1, passenger vehicle sharing service is separated from parcel delivery, in travel distance L_2 two vehicles are needed: a conventional vehicle (cv) and a small electric delivery vehicle (Ed). One vehicle is needed in case 2 (AEV). Calculation methods of energy consumption regarding each case are presented as following:

In Case 1: F_{ec} is calculated as $F_1 = F_{car-sharing} + F_{delivery}$

$$F_{car-sharing} = f_{fc/100} \cdot \left(L_1 + L_2 + L_3 \right) / 100 \tag{6}$$

$$F_{delivery} = L_2 / 100 \cdot f_{fc/100} + \frac{\sum_{i=1}^{n} w_i}{W} \cdot L_2 / 100 \cdot f_{fc/100} + L_{empty} / 100 \cdot f_{fc/100} \tag{7}$$

If more than one parcel is delivered, energy consumption shared by each parcel can be calculated as [39]:

$$F_{p_i} = \frac{w_i \cdot l_i}{\sum_{i=1}^{n} w_i \cdot l_i} \cdot F_{delivery} \tag{8}$$

In Case 2: F_{ec} is calculated as:

$$F_2 = \left(L_1 + L_2 + L_3 \right) / 100 \cdot f_{fc/100} + \frac{w_i}{W} \cdot L_2 / 100 \cdot f_{fc/100} \tag{9}$$

As only one small parcel is delivered by each embedded delivery, in order to compare under the same condition, only one small parcel is considered per delivery, and the weight of parcel is $w_i \leq 5$ kg. For simplification purpose, the empty running distance L_m and parcel weight w_i are not involved in following numerical simulation calculation, only

vehicle performance is considered. Then, the calculated F_{ec} are convert to standardized energy consumption ($E_{T/W}$) and emission of CO_2 equivalents ($G_{T/W}$) for each scenario.

The percentage of saved energy and decreased CO_2 equivalents per delivery are calculated, comparing used petrol and diesel with electricity. One comparison calculation example is presented regarding petrol (p) and electricity (e) powered vehicle in TWT, other percentage is calculated with the same method.

$$E_T^{(p)} = f_{fc/100}^{(cv)} \cdot \frac{L_1 + L_2 + L_3}{100} \cdot e_T^{(p)} + f_{fc/100}^{(Ed)} \cdot \frac{L_2}{100} \cdot e_T^{(e)} \tag{10}$$

$$PE_{petrol-save} = \frac{E_{petrol} - E_{electricity}}{E_{petrol}} = \frac{\left(f_{fc/100}^{(cv)} \cdot e_T^{(p)} - f_{fc/100}^{(AEV)} \cdot e_T^{(e)}\right) \cdot \left(L_1 + L_2 + L_3\right)}{f_{fc/100}^{(cv)} \cdot \left(L_1 + L_2 + L_3\right) \cdot e_T^{(p)} + f_{fc/100}^{(Ed)} \cdot L_2 \cdot e_T^{(e)}} \times 100\% \tag{11}$$

$$PE_{embedded} = \frac{f_{fc/100}^{Ed} \cdot L_2}{f_{fc/100}^{(AEV)} \cdot \left(L_1 + L_2 + L_3\right) + f_{fc/100}^{(Ed)} \cdot L_2} \times 100\% \tag{12}$$

The numerical simulation is generated as following steps in Matlab:

1. Base data input, e.g., $f_{fc/100}$, $e_{T/W}$, $g_{T/W}$.
2. Generate random distance for L_1, L_2, L_3. Range of each is from 1 to 10 km.
3. Calculate fuel consumption of cases in each scenario.
4. Convert to standardized fuel consumption and CO_2 equivalents.
5. Calculate the ratio (percentage) and mode values.
6. Record results in percentage.

We have generated 10,000 random values for each travel distance L_1, L_2, and L_3, respectively, in order to obtain robust results. All calculation runs at least 10,000 times. The running cycles have been also changed to perform the sensitivity analysis. The robust result has been already obtained around 680–690 times, small differences exist in the critical values as the values are generated randomly.

By applying the numerical method, or the numerical simulation calculation, we found that vehicle travel distance ranges from 3 to 30 km ($L = L_1 + L_2 + L_3$), the single parcel delivery distance range from 1 to 10 km (L_2), compared with separated electric vehicle sharing and delivery, under the standardized calculation value, petrol and diesel vehicle consume around 69% and 63% more energy (TTW), around 27% and 14% more considering fuel production (WTW). Petrol and diesel vehicle produce around 59% and 52% more CO_2 equivalence (WTW). Embedded electric delivery is based on the same vehicle travel, thus is purely saving. The saving is around 7% in all (E_T, E_W, G_W), as the small electric delivery vehicles are considered in two scenarios.

The short distance delivery is considered for properties of crowdsourced delivery. However, in some cases, the long-distance vehicle sharing service is also available, e.g., travel from downtown to the airport. One example regarding standardized energy calculation results of distance $L_1 = 13$ km, $L_2 = 5$ km, $L_3 = 6$ km are presented in Table 9.

Table 9. Results of scenarios with defined travel distance.

		Fuel	e_T (MJ)	Sum	g_T (kg) (CO_2e)	Sum	e_W (MJ)	Sum	g_W (kg) (CO_2e)	Sum
Scenario 1										
Case 1	cv	**petrol**	46.368	**46.962**	3.485	**3.485**	54.288	**55.971**	4.147	**4.399**
		diesel	38.772	**39.366**	2.884	**2.884**	46.116	**47.799**	3.499	**3.751**
	Ed	electricity	0.594	-	0	0	1.683	-	0.252	-
Case 2	AEV	**electricity**	13.824	**13.824**	0	**0**	39.168	**39.168**	1.628	**1.628**
Scenario 2										
Case 1	EV	**electricity**	13.824	**14.418**	0	**0**	39.168	**40.851**	1.628	**1.880**

Ed	electricity	0.594	-	0	0	1.683	-	0.252	-
Case 2	**AEV**	**electricity**	13.824	**13.824**	0	0	39.168	**39.168**	1.628	**1.628**

'Sum' column is to show the summation of vehicle sharing and delivery. Accordingly, the comparison of standardized energy saving and CO_2 equivalents decreasing between cases are calculated and presented in Table 10.

Table 10. Standardized energy saving and CO_2 equivalents decreasing.

Per Parcel Delivery		Energy Saving (MJ)		CO₂e Decrease (kg)	
	Compared Fuel	e_T	e_W	g_T	g_W
Scenario 1: case 1 compare with case 2	petrol and electricity	33.138	16.803	3.485	2.771
	diesel and electricity	25.542	8.631	2.884	2.123
Scenario 2: case 1 compare with case 2	electricity	0.594	1.683	0	0.252
Scenario 1 case 1 compare with Scenario 2 case 1	petrol and electricity	32.544	15.12	3.485	2.519
	diesel and electricity	24.948	6.948	2.884	1.871

In order to present in one figure, standardized energy consumption per delivery (MJ) and CO_2e emission in 10 deliveries (10) are presented in Figure 15. The three-dimensional point is presented as (number of vehicle run, sum value in Scenario 1, value of saving); for example, the red circle petrol E_w point is (1, 46.962, and 33.138), the red blank circle petrol G_w point is (10, 43.99, and 27.71).
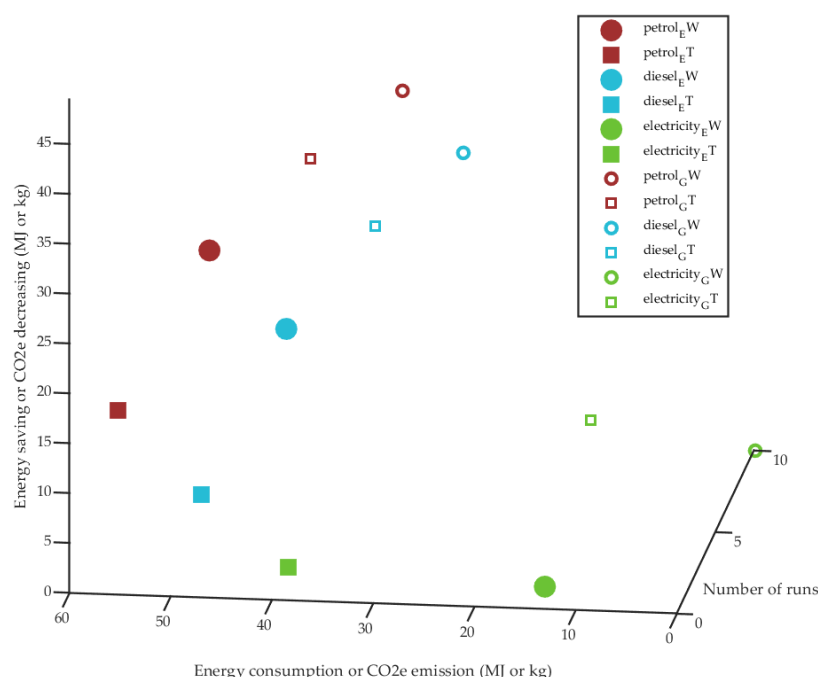
Figure 15. Result of energy consumption and CO_2e emission of one example.

Whatever from total energy consumption or saving point of view, the smaller values are shown by electric embedded delivery (green ones are in lower position). Shown as aforementioned numerical simulation results, the decreased percentage is robust, which is slightly influenced by the travel distance. The performance of electric vehicles is better. The energy consumption per delivery of drones and ground delivery service are compared [44], the small size based electric vehicle delivery is shown with lower consumption compared with other ground service. The energy saving of crowdsourced delivery is also

addressed [35]. As practices and research of crowdsourced delivery are promisingly on-going [9,10], from a long term point of view, embed delivery into electric vehicle sharing in travel chains could be the tendency of crowdsourced delivery, considering electric car-sharing service is already in operation.

7. Discussion and Conclusions

Comparing service concept proposed in literatures [3,4,7–9,29,30], 'On My Way' service of Amazon and DHL, we highlighted and summarized following points:

- Deliverers have to touch parcels.
- Neighborhood delivery and the grocery delivery model highly depend on the willingness-to-deliver of surrounding neighbors. The willingness is not investigated yet. In addition, deliverers have to detour in neighborhood approaches [7–9].
- Several deliverers are involved in parcel relay approach [7,9,29], which increase the difficulty of task coordination and delivery security.
- In 'share-a-taxi' model, the taxi driver has to handle both the passenger and parcel. The passenger can refuse to deliver parcel.

What are distinguished in this proposal:

- Parcel security is enhanced by the separated cabin.
- The joint of two services: one service user is another service server.
- Driver related problems are eliminated. Except waiting time window, the journey of passenger transit is not interrupted.
- An information system is proposed to track the delivery process.

Efficient operation of transportation services is highly assisted by information system, the emerging shared services are booming. MaaS is implemented as such an integrated service for travelers' convenience via mobile applications, which is not limited with passenger transit. Crowdsourced delivery is introduced as a platform-based service aiding last mile solution of logistics, to supplement the large volume traditional delivery. In addition, incorporation AVs into travel chain management may enhance MaaS operation. Taken these joint opportunities into consideration, we have elaborated the concept of crowdsourced parcel delivery service embedded into MaaS based on AVs, focusing on information management.

Parcel deliverer is the vehicle sharing service user, parcel receiver is the parcel delivery service user, the demand of embedded delivery is coordinated in the common platform. The passenger mobility as the priority remains, the delivery is proposed for energy saving purpose and to balance vehicle redistribution, to optimize the spaciotemporal utilization of vehicles. The main contributions are:

- The concept of service,
- The information system architecture model,
- The functional model,
- The matching conditions and energy consumption calculation per parcel delivery.

The key finding is that we present this novel service concept from a systematic point of view, and the estimated energy consumption calculations regarding per delivery have been provided. From practical concern, e.g., the development of AV technology and e-commerce, the applicability of this embedded service is quite promising.

We faced, as the lesson learnt, that data group identification in modelling approach is rather complex task, especially considering the enormous amount and types of data; thus, the most relevant data groups have been selected and presented in the three-dimensional functional model.

The information system proposal is the first step. One of the further research directions is to propose and solve problems of this service concept in a travel chain analysis, by developing mathematical modeling approaches. Accordingly, the detailed math problem with precise limitations will be summarized, the travel chain will be simulated, then

the mathematical modelling will be developed considering the modified searching and matching algorithms. Another research direction is to elaborate the information system for the combined charging and parking in framework of MaaS based on AVs, considering the increased charging demand of electric vehicles and decreased parking demand of AVs.

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