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A One-Way Car-Sharing Based Approach for Combined Shared Mobility of Freight and Passengers

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Abstract

Climate change stresses the need for research and development of innovative sustainable mobility solutions that provide reliable and convenient door-to-door services for both passengers and freight. The increase in urban population and the popularity of e-commerce further highlights the need for action. In this regard, crowd-shipping is often perceived as an efficient, cost-effective, and sustainable alternative (or complement) to the management of urban freight mobility through efficient utilization of current transportation capacities. In this framework, inspired by the concept of MaaS (Mobility as a Service) in integrating various forms of transport and transport-related services into a single on-demand mobility service, this paper proposes a car-sharing-based service for the combined mobility of passengers and freight. In doing so, *one-way car-sharing* and *crowd-shipping* concepts are integrated in order to serve part of the existing freight demand in a sustainable and cost-efficient way for users, societies, and the environment. An optimization model is proposed to optimally plan the activation of one-way car-sharing and crowd-shipping services and to determine the optimal number of vehicles to assign to them. Such decisions are aimed at minimizing the total imbalance by serving passenger and freight demand during different time periods. In doing so, the willingness of users to carry freight in their vehicles is also taken into consideration. The capability of the proposed approach is evaluated through representative numerical examples aimed at showing the impact of the model parameters on the solution.

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Keywords: crowd-shipping, shared mobility, integrated mobility solutions, sustainable mobility

1. Introduction

Shared mobility is a well-known concept, where the members of the sharing economies rent items from one another and share collective advantages Behrend and Meisel (2018). Such a concept is particularly important in terms of better management of urban mobility. Since one-way Car-Sharing (CS) is gaining increasing user acceptance, it has already proven to be effective in shifting private mobility to other solutions Ferrero et al. (2018). In addition, the circulation of shared vehicles will further increase once CS and other sharing services e.g., bike-sharing, ride-sharing, etc. reach

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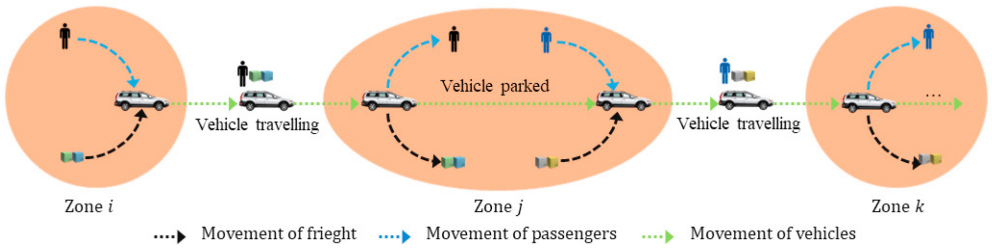


Fig. 1: Operational concept of a CW System comprising of one-way CS.

their full potential, especially through the introduction of autonomous vehicles Ma et al. (2017), leading to further augmenting the mentioned impacts.

Freight transport services hold the maximum share of urban transport, and thus contribute substantially to problems such as traffic congestion and environmental emissions Galkin et al. (2021). As a potential solution to alleviate this situation, Crowd-Shipping (CW) has already emerged as an innovative, flexible, sustainable, and cost-effective solution for Small and Medium-sized Enterprises (SMEs) through the utilization of existing transportation system capacities referred to as *free-floating capacities* Mittal et al. (2022). The integration of shared services with crowd-shipping seems a promising approach for the reduction of the adverse environmental impacts caused by conventional delivery vehicles Marcucci et al. (2017).

Researchers have explored the concept of crowd-shipping from different dimensions based on the three pillars of operation, supply, and demand. The existing barriers to the successful operation of crowd-shipping systems in terms of network effect and concerns over safety, security, and reliability were explored in Le et al. (2019). Moreover, different determinants for the performance evaluation of crowd-shipping users through questionnaire surveys were studied in Punel et al. (2018), whereas the performance comparison of different crowd-shipping services and related research was carried out in Pourrahmani and Jaller (2021). From the planning perspective, the willingness of metro users to act like crowd-shippers for last mile deliveries and the economic impacts of using metro services for crowd-shipping purposes in metropolitan areas was explored in Filippi and Plebani (2021). Lastly, from the implementation perspective, the effectiveness and advantages of integrating bike-sharing with freight delivery service based on the willingness of users were studied in Binetti et al. (2019) from a network design perspective.

To this aim, a novel system combining one-way CS and CW systems into a so-called *Ride Parcel* system is presented in this paper. Such a system is efficient in reducing environmental impacts and can potentially gain higher user acceptance through cost reductions both for users and operators.

In this setting, the proposed problem is formulated as a Mixed Integer Linear Programming Model (MILP) aiming at the activation of either CS or CW service in a zone and assigning the optimal number of vehicles to them. The global aim of the optimization model is to guarantee the maximization of served passenger and freight demand under different scenarios. In this framework, customers of the CS system have the option to carry freight in their vehicles, modeled by considering different scenarios of expected usage of CS and CW services.

The remainder of this paper is organized as follows: in Section 2, a set of assumptions to formulate the proposed MILP model and different constraints will be discussed. In Section 3, a general description of the example problem will be described which will be analyzed in Section 3.1. Finally, major conclusions will be presented in Section 4.

2. Problem Description

In this section, the mathematical programming problem for the optimal plan of the service will be presented.

2.1. Assumptions and notation

The proposed methodology is developed based on the following set of assumptions:

a) A one-way CS system is considered where each user is requested to book a vehicle (v) in the origin zone z_o declaring a pick-up time (t_0) and a destination zone z_d;

b) Only a given percentage (ω) of users is available to transport freight during their trip;

c) Freight can be loaded on vehicle v in z_o until t_0 and collected in z_d in the time interval $[t_0 + t_{od}, t_0 + t_{od} + T]$, where t_{od} is the estimated travel time from z_o to z_d, and T is a fixed time during which the vehicle v cannot be picked up (which may be expanded in case of late withdrawal of freights). An example of service operation is depicted in Figure 1;

d) CS and CW vehicles are able to carry the same maximum number of passengers, whereas CS vehicles cannot carry frights;

e) A recovery strategy for non-withdrawn freights, analogous to the usual vehicle relocation strategies, is assumed to be in place;

f) The demand for CS and for freight is assumed to be known in advance in each considered time period such that the proposed optimization model activates the service and distributes the CS or CW vehicles accordingly;

g) CS or CW depots are located at the parking facilities already existing in the study area;

h) Lockers with the parcels are located in the trunks of vehicles, such that pick-up and drop-off operations of the freight are carried out at the depots only;

i) The freight demand is handled through the operation of CW service which is a share of the total one and is characterized by small weights and volumes.

Based on a stated set of assumptions, the developed optimization model is explained in the following section.

2.2. Optimization Model

The proposed MILP model aims at activating either CS or CW service in each zone z along with the placement of CS or CW vehicles in the study area. The aim of the optimization model is to maximize the served passenger and freight demand based on the willingness of the passengers to carry freight in the vehicle in different scenarios determined by different parameter values. Then, to state the optimization problem, let:

- $\mathcal{Z}$ be the set of zones of the considered study area;
- $\mathcal{V}$ be the set of the potential CS and CW vehicles to be placed in the study area;
- $\mathcal{T}$ be the set of the considered time periods under analysis;
- $\mathcal{D}^{CS,t}$ and $\mathcal{D}^{CW,t}$ be the O/D demand matrices in each considered time period t for CS and CW vehicles, respectively;
- $x^t_{v,z}$ be a binary variable that assumes a value of 1 if a vehicle $v \in \mathcal{V}$ is activated to provide CS service in a zone z during time period t and 0 otherwise;
- $g^t_{v,z}$ be a binary variable that assumes a value of 1 if vehicle $v \in \mathcal{V}$ is activated to provide CW service such that the user is willing to carry freight in the vehicle, in a zone z during time period t and 0 otherwise;
- y^t_z be a binary variable that assumes a value of 1 if the CS service is activated in a zone z during time period t and 0 otherwise;
- h^t_z be a binary variable that assumes a value of 1 if the CW service is activated in a zone z during time period t and 0 otherwise;
- $\boldsymbol{x}, \boldsymbol{g}, \boldsymbol{y}$, and $\boldsymbol{h}$ are the vectors gathering the variables, $x^t_{v,z}$, $g^t_{v,z}$, y^t_z, and h^t_z, respectively.

Given such definitions, the optimization problem can be formulated as the minimization of the total imbalance between the passenger and freight demand and the available capacity provided by CS and CW vehicles,

$$[\boldsymbol{x}^\star, \boldsymbol{g}^\star, \boldsymbol{y}^\star, \boldsymbol{h}^\star] = \arg \min_{\boldsymbol{x},\boldsymbol{g},\boldsymbol{y},\boldsymbol{h}} \sum_{t\in\mathcal{T}} \sum_{z\in\mathcal{Z}} \beta \left| \mathcal{D}^{CS,t}_z - \sum_{\forall v\in\mathcal{V}} \lambda^{CS} \left(x^t_{v,z} + g^t_{v,z} \right) \right| + \left| \mathcal{D}^{CW,t}_z - \sum_{\forall v\in\mathcal{V}} \lambda^{CW} g^t_{v,z} \right| \tag{1}$$

where $\mathcal{D}_z^{CS,t}$ and $\mathcal{D}_z^{CW,t}$ represent the demand generated from zone z whereas λ^{CS} and λ^{CW} are the average numbers of requests satisfied by a single CS or CW vehicle, respectively. Such parameters are defined as $\lambda^{CS} = \pi^{CS} \cdot O^{CS}$ and $\lambda^{CW} = \pi^{CW} \cdot O^{CW}$, being π^{CS} and π^{CW} the probabilities that a CS or CW vehicle is available when requested, whereas O^{CS} and O^{CW} are the average number of passengers and parcels for each trip, respectively. Moreover, β is the weighing factor for CS service which ensures that the optimization model should give sufficient weight to CS demand as compared to freight demand such that CW service is only possible if a maximum number of CS users are served. The value of β must be suitably calibrated based on the case study and demand data sets.

The first term in (1) aims at obtaining a distribution of vehicles of either type in order to have, in each zone z and in each time period t, a sufficient number of vehicles able to satisfy the demand at the best. Similarly, the second term in (1) aims at obtaining a distribution of CW vehicles capable of satisfying the freight demand at the best. Note that the non-linearity introduced by the absolute values can be easily managed using a set of additional constraints and auxiliary variables.

The problem defined in (1) is subject to a set of constraints defining CS or CW system characteristics, with particular reference to passenger and freight demands according to the maximum available budget and their dependence upon the optimization variables.

First of all, CS and CW vehicles cannot be assigned to more than one zone z during each time period t but can be unassigned, ensured by the inequalities

$$\sum_{\forall z \in \mathcal{Z}} x_{z,v}^t \le 1, \quad \text{and} \quad \sum_{\forall z \in \mathcal{Z}} g_{z,v}^t \le 1, \quad \forall v \in \mathcal{V}, \forall t \in \mathcal{T} \tag{2}$$

In addition, considering the characteristics of zones, the maximum number of both CS and CW vehicles $Q_z^{\max}$ that each zone can accommodate is limited according to the physical capacity of a given zone z. To ensure this, the following inequality

$$\sum_{\forall v \in \mathcal{V}} x_{z,v}^t + g_{z,v}^t \le Q_z^{\max} \quad \forall z \in \mathcal{Z}, \forall t \in \mathcal{T} \tag{3}$$

must hold. Furthermore, the inequality

$$y_z^{t_j} \le 1 - h_z^{t_k}, \quad \forall z \in \mathcal{Z}, \forall t_j, t_k \in \mathcal{T} \tag{4}$$

guarantee that, in each zone z a service can only be activated as CS or CW. Given the constraints in (4), it is necessary to state that CS or CW vehicles can only be placed in zones z if the relevant service is activated and, conversely, no vehicles can be placed in non-activated zones. Such a goal can be expressed by means of the inequalities

$$x_{z,v}^t \le y_z^t \qquad \forall v \in \mathcal{V}, \forall z \in \mathcal{Z}, \forall t \in \mathcal{T} \tag{5a}$$

$$g_{z,v}^t \le h_z^t, \qquad \forall v \in \mathcal{V}, \forall z \in \mathcal{Z}, \forall t \in \mathcal{T} \tag{5b}$$

$$y_z^t \le \sum_{\forall v \in \mathcal{V}} x_{z,v}^t, \qquad \forall z \in \mathcal{Z}, \forall t \in \mathcal{T} \tag{5c}$$

$$h_z^t \le \sum_{\forall v \in \mathcal{V}} g_{z,v}^t, \qquad \forall z \in \mathcal{Z}, \forall t \in \mathcal{T} \tag{5d}$$

which relate the values of the variables y_z^t and h_z^t with variables $x_{z,v}^t$ and $g_{z,v}^t$, respectively. In particular, the equations in (5a) and (5b) state that no CS or CW vehicles can be assigned to a zone $z \in \mathcal{Z}$ during time period $t \in \mathcal{T}$ if the service is not activated therein, whereas equations in (5c) and (5d) state that if the service is activated in a zone $z \in \mathcal{Z}$ during a time period $t \in \mathcal{T}$, at least one CS or CW vehicle must be assigned to that zone during that time period.

Then to guarantee that each vehicle is univocally dedicated to a CS or a CW service, regardless of time and zone, it is necessary to state

$$\sum_{z\in\mathcal{Z}} x_{z,v}^{t_j} \leq 1 - \sum_{z\in\mathcal{Z}} g_{z,v}^{t_k}, \quad \forall v \in \mathcal{V}, \forall t_j, t_k \in \mathcal{T} \tag{6}$$

which guarantees that if a vehicle v is assigned in t_j to CS in at least one of the zones, it cannot be assigned to CW in any zone and in the LHS of (6) sums to 1 (i.e., v is assigned to CS in t_j) the summation in the RHS must be 0 (i.e., v can never and nowhere be assigned to CW) to avoid the contradiction $1 \leq 0$. Vice-versa, if the vehicle v is not assigned to CS (i.e., LHS sums to 0), it can be assigned to CW (i.e., the summation in the RHS is equal to 1) or cannot be assigned at all (i.e., summation in the RHS is equal to 0); in these last two cases, the inequality turns out to be $0 \leq 1-1$ or $0 \leq 1-0$, respectively. Note that the same result can be achieved by switching variables $x_{z,v}^t$ and $g_{z,v}^t$ in the equation.

To conclude, in order to avoid a surplus of CW vehicles in the region, the number of vehicles of such type is limited by the percentage ω of users that are willing to carry freights according to

$$\sum_{\forall v\in\mathcal{V}} \sum_{\forall z\in\mathcal{Z}} g_{z,v}^t \leq \omega \cdot |\mathcal{V}|, \quad \forall t \in \mathcal{T} \tag{7}$$

being $|\mathcal{V}|$ the cardinality of $\mathcal{V}$, i.e., the total number of available vehicles.

Finally, the total acquisition and management costs comprise realization and management costs for CS and CW service α_1 and α_2, respectively, as well as buying and maintenance costs for CS and CW vehicles α_3 and α_4, respectively, should satisfy the inequalities

$$\sum_{\forall z\in\mathcal{Z}} \left(\alpha_1 \min\left\{ \sum_{\forall t\in\mathcal{T}} y_z^t, 1 \right\} + \alpha_2 \min\left\{ \sum_{\forall t\in\mathcal{T}} h_z^t, 1 \right\} \right) + \sum_{v\in\mathcal{V}} \left(\alpha_3 \min\left\{ \sum_{\forall t\in\mathcal{T}} \sum_{z\in\mathcal{Z}} x_{z,v}^t, 1 \right\} + \alpha_4 \min\left\{ \sum_{\forall t\in\mathcal{T}} \sum_{z\in\mathcal{Z}} g_{z,v}^t, 1 \right\} \right) \leq B \tag{8}$$

being B be the total available budget. In such a constraint, the minimum function avoids relevant purchase, and maintenance costs for the same vehicle as well as the service activation cost in the same zone, to be considered twice during different time periods t. Considering, for instance, the first term, if $y_z^t = 1$ for more than one time period in zone z, then $\sum_{\forall t\in\mathcal{T}} y_z^t > 1$ and, in this case, the minimum is 1; on the contrary, if the CS service is never activated in such a zone, i.e., $y_z^t = 0, \forall t \in \mathcal{T}$, then $\sum_{\forall t\in\mathcal{T}} y_z^t = 0$ and, in this case, the minimum is 0.

Note that the *min* function can be easily linearized using a set of additional constraints and auxiliary variables.

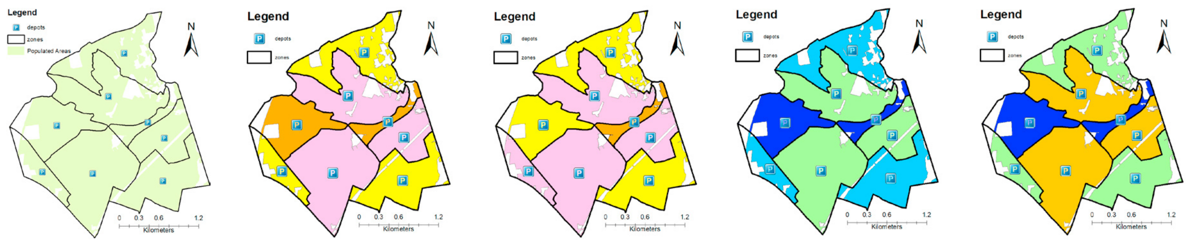
3. Numerical Example

The considered study area consists of 8 zones with a population of approximately 50,000 residents being distributed in the light green areas as shown in Figure 2(a) where the distribution of parking places is also put into evidence. Furthermore, two time periods t_1 and t_2 are considered to correspond to the peak and off-peak demands, respectively. Similarly, the total demand for CS and CW service is estimated as 34 passengers (Figure 2(b)) and 473 parcels (Figure 2(d)) during t_1 whereas 24 passengers (Figure 2(c)) and 316 parcels (Figure 2(e)) during t_2, according to the relevant O/D matrices reported in Table 1. Based on demand data sets, the value of $\beta = 90$ is calibrated, according to all considered scenarios and taking into account the significant differences in the CS and freight demand as represented by their O/D matrices.

In the considered case study, the total number of vehicles $|\mathcal{V}|$ is limited to 20 whereas $Q_z^{\max}$ is limited by the values in the vector [2 2 2 3 4 2 3 5], whose entries are sorted by zones. Coefficients $\alpha_i, i \in 1, ..., 4$ are estimated as 6.9k€, 14k€, 12k€, and 16k€. [1,2].

Finally, the total available budget is restricted to 400 k €.

[1] Average costs of parking area in Italy – in Italian, accessed in September 2023
[2] Average CS costs in Italy – in Italian, accessed in September 2023



(a) (b) (c) (d) (e)

Fig. 2: Distribution of depots (a), CS (b), and CW (d) demand during t_1 as well as CS (c), and CW (e) demand during t_2. CS Demand Colour legend: (0); (0 – 2); (2 – 4); (4 – 6); (> 6). CW Demand Colour legend: 0; (0 – 20); (20 – 40); (40 – 60); (> 60).

Table 1: Origin/Destination Matrices for people [users/hour] and freights [parcels/hour].

(a) $\mathcal{D}^{CS,t_1}$: People demand in time period t_1

	t_1							
Zones	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	–	1	0	1	0	2	0	0
2	0	–	1	0	1	0	0	0
3	1	0	–	0	0	0	0	1
4	0	2	2	–	0	0	0	0
5	1	0	1	0	–	3	4	0
6	0	0	0	0	0	–	0	0
7	1	0	0	2	0	0	–	1
8	2	2	0	1	1	2	1	–

(b) $\mathcal{D}^{CS,t_2}$: People demand in time period t_2

	t_2							
Zones	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	–	0	0	1	0	1	0	0
2	0	–	0	0	1	0	0	1
3	0	1	–	0	0	0	1	0
4	0	1	1	–	0	0	0	1
5	0	0	1	0	–	0	1	2
6	0	0	0	0	1	–	0	0
7	1	0	0	1	0	0	–	1
8	1	2	0	1	1	1	1	–

(c) $\mathcal{D}^{CW,t_1}$: Freight demand in time period t_1

	t_1							
Zones	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	–	10	2	8	4	12	4	6
2	0	–	7	0	9	1	2	8
3	3	5	–	2	0	0	0	20
4	13	15	14	–	2	3	4	4
5	15	10	13	5	–	12	14	30
6	10	1	2	5	0	–	2	5
7	15	3	9	14	0	7	–	8
8	15	13	5	27	17	14	44	–

(d) $\mathcal{D}^{CW,t_2}$: Freight demand in time period t_2

	t_2							
Zones	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	–	9	3	15	1	2	1	0
2	1	–	6	2	8	0	0	1
3	4	2	–	1	4	3	1	5
4	7	3	10	–	4	5	7	1
5	10	7	5	5	–	13	12	14
6	5	8	1	2	0	–	1	0
7	4	8	5	2	1	7	–	10
8	17	11	8	6	5	22	21	–

The analysis reported in the next section consists of 27 scenarios based on the combinations of different values of the parameters ω, λ^{CS} and λ^{CW}.

3.1. Results

For what concerns the achieved performances, let us consider first the demand satisfaction reported in Table 2(a) and Table 2(b) for passengers and freight, respectively. In such tables, the satisfaction percentages of the total demand, i.e., the sum of the demand in t_1 and t_2 are reported for different values of the parameters.

In these tables, it can be noticed that the percentages increase regardless of the λ^{CS} and λ^{CW} values as they represent the actual capacity of vehicles. Concerning the values of λ^{CS} and λ^{CW}, such a result is easily explained since they represent the actual capacity of vehicles. In more detail, the passenger demand satisfaction increases with λ^{CS} which is applied to both CS and CW vehicles, as expressed in (1). On the contrary, the freight demand satisfaction increases with λ^{CW}. The impact of the parameter ω directly depends on the constraint (7) which affects the maximum number of vehicles that can be assigned to CW. In fact, for each value assumed by λ^{CW}, an increase of ω corresponds to an increase in the number of CW vehicles that can be assigned to CW and, consequently, to an increase in the actual

Table 2: Percentage of satisfied demand for different values of λ^{CS}, λ^{CW}, and ω.

(a) Total people demand

$\lambda^{CS}/\lambda^{CW}$	ω = 50%	ω = 75%	ω = 100%
0.50/20	34.48	34.48	34.48
0.50/25	34.48	34.48	34.48
0.50/30	34.48	34.48	34.48
0.75/20	51.72	51.72	51.72
0.75/25	51.72	51.72	51.72
0.75/30	51.72	51.72	51.72
1/20	68.97	68.97	68.97
1/25	68.97	68.97	68.97
1/30	68.97	68.97	68.97

(b) Total freight demand

ω = 50%	ω = 75%	ω = 100%
50.70	76.05	76.05
63.37	88.72	88.72
76.05	106.46	106.46
50.70	76.05	76.05
63.37	95.06	95.06
76.05	98.86	98.86
50.70	76.05	76.05
63.37	95.06	95.06
76.05	98.86	98.86

Table 3: Total number of CS and CW vehicles in the two considered time periods for different values of λ^{CS}, λ^{CW}, and ω. The values are reported in pairs and *a*–*b* indicates that *a* vehicles are assigned to CS and *b* vehicles are assigned to CW.

	t_1			t_2		
$\lambda^{CS}/\lambda^{CW}$	ω = 50%	ω = 75%	ω = 100%	ω = 50%	ω = 75%	ω = 100%
0.5/20	10–10	5–15	5–15	10–10	5–15	5–15
0.5/25	10–10	6–14	6–14	10–10	6–14	6–14
0.5/30	10–10	6–14	6–14	10–10	6–14	6–14
0.75/20	10–10	5–15	5–15	10–10	5–15	5–15
0.75/25	10–10	5–15	5–15	10–10	5–15	5–15
0.75/30	10–10	7–13	7–13	10–10	7–13	7–13
1/20	10–10	5–15	5–15	10–10	5–15	5–15
1/25	10–10	5–15	5–15	10–10	5–15	5–15
1/30	10–10	7–13	7–13	10–10	7–13	7–13

capacity of the system for freight demand satisfaction, as reported in Table 3. On the contrary, the parameter ω does not affect the passenger demand satisfaction as in this case, vehicle type is irrelevant and both cases may be assigned to passenger demand.

As shown in Table 2(a) and Table 2(b), both passenger and freight demand types are never completely satisfied. Such results are due to the limited number of available vehicles $|\mathcal{V}| = 20$ and by their distribution in the zones further limited by the inequality (3). The effects are evident in Table 3 where it is easy to note that all the available vehicles are assigned in each scenario but, for instance, only $Q_1^{\max} = 2$ vehicles can be assigned to zone 1 even if the total demand is 6. More specifically, it is possible to see that, for any values assumed by the pair of parameters λ^{CS} and λ^{CW}, the number of CW vehicles generally increases with ω, according to the above-mentioned constraint (7). On the contrary, excluding the hardly constrained scenarios with $\omega = 50\%$, if λ^{CW} increases, the number of vehicles assigned to CW tends to decrease as expected, since each CW vehicle is able to carry more freight.

Regarding the budget limitation and its impact, the used budget varies from 363.6 k€ if $\omega = 50\%$ and for any values of λ^{CS} and λ^{CW}, to 397.8 k€ if $\omega = 100\%$ with different combinations of λ^{CS} and λ^{CW} values. Since in all cases, all available vehicles are assigned, these differences depend on the different mix of vehicles in each scenario; for instance, the biggest saving in the $\omega = 50\%$ scenario is due to the fact that no more than $\omega \cdot \mathcal{V} = 0.5 \cdot 20 = 10$ vehicles can be assigned to CW, which is characterized by higher costs.

To conclude, the performed analysis shows that the proposed planning approach can provide a good distribution of resources in order to satisfy both passenger and freight demand. This is considering the efficiency of the solution as all problems generated under the different scenarios have been solved by means of the Branch&Bound approach in less than 5 minutes.

4. Conclusion

This paper explores the possibility of converting existing car-sharing systems into mixed-use car-sharing/crowd-shipping systems to ensure the sustainability of freight delivery services. The proposed optimization model identifies the zones where CS service should be activated as CW along with the optimal number of CS or CW vehicles to be placed therein. Moreover, the impact of the user willingness factor, as well as the average expectancy of CS and CW service utilization, are also explored.

As reasonably expected, results show that the demand satisfaction increases with parameters ω, λ^{CS}, λ^{CW}, indicating the better distribution of both CS and CW vehicles. Nevertheless, it is worth underlining that the proposed approach is significantly sensitive to the values of its parameters that, require suitable calibration.

In conclusion, it is possible to state that the proposed model provides a basis for further exploration at the operational level. This emphasizes the need for a detailed analysis of the effects of vehicle imbalances, that usually characterize one-way car-sharing systems as well as a monetary cost-benefit analysis. Also, based on the results and computational analysis, for real-world size data sets heuristic solutions approaches may be necessary.

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