Logistics 4.0 & e-commerce: evaluating the impacts of smart keys on last-mile delivery

Seghezzi A.*, Siragusa C.*, Mangiaracina R.*, Tumino A.*

**Dipartimento di Ingegneria Gestionale, Politecnico di Milano, Via Lambruschini, 4B 20156 - Milano – Italy (riccardo.mangiaracina@polimi.it, arianna.seghezzi@polimi.it, chiara.siragusa@polimi.it, angela*

Abstract: One of the main challenges for last-mile logistics in B2C e-commerce are *failed deliveries*, i.e. those deliveries not completed due to the absence of customers at home. Among the high number of solutions under investigation to solve this issue, the smart keys based on Internet of Things (IoT) technologies seem to be very promising, and have been already adopted by some players. This study investigates the benefits achievable if the houses of the customers are equipped with such a solution. Benefits are assessed by comparing the delivery costs related to (i) the traditional home-delivery and (ii) the home-delivery with the adoption of the smart key. In particular, different levels of diffusion of this solution are considered, from 25% to 100% of the houses to be visited in a delivery tour. More precisely, two vehicle routing problems are investigated. The standard vehicle routing problem (VRP), that aims at minimising the travel distance only, and the vehicle routing problem with smart keys (VRPSK) that attempts to maximise the number of successful deliveries in a tour (considering both the distances and the probability of failed deliveries). The VRPSK is a development of the VRP with time windows (where a delivery is forced to occur in a specific time lapse). Results – based on the application of the two routing problems in a district of Milan – prove that the smart key is a valid solution to reduce failed deliveries and, consequently, delivery costs. If compared to the traditional home-delivery, the adoption of smart keys allows a delivery cost reduction between 3% and 11%, when respectively 25% and 100% of the customers' houses are equipped with smart keys. This work can be a starting point for investigating the potentialities of IoT technologies to improve the efficiency of last-mile logistics.

Keywords: Smart key; last-mile delivery; failed deliveries

1. Introduction

In recent years many countries have been experiencing the boom of two different phenomena, enabled by the use of digital technologies: B2C e-commerce and logistics 4.0.

B2C e-commerce is spreading all over the world, in many different sectors (Bertram and Chi, 2018). People are increasingly used to shop on the Internet, and one of the great benefits of online purchases lies in the possibility to get the products delivered at the doorstep. The easiness and convenience seen by the customers though entails huge complexities if considering the perspective of companies. As a matter of fact, this last stretch of the order fulfilment, referred to as "last-mile delivery", is very challenging. First, it is very expensive. Its costs may amount up to half of the overall logistics costs (Vanelslander et al., 2013). Second, customers have very compelling expectations in terms of service level performances: they want their products as soon as possible (Savelsbergh and Van Woensel, 2016). Moreover, a key issue companies have to deal with is the phenomenon of the so called "failed deliveries". A delivery fails when it cannot be completed due to the absence of customers at home.

Another phenomenon that is gathering increasing attention is referred to as the "fourth industrial revolution": industrial processes are enhanced through the interplay of information and operations technologies that enable the merge between physical and digital worlds. This new phenomenon applies to different fields of operations management, including logistics. There the paradigm is called "logistics 4.0", and it implies the application of smart technologies – e.g. internet of things, cloud, industrial analytics – to enhance the performances of the most critical processes in warehousing and transport (e.g. McFarlane et al., 2016; Wang, 2016).

At the intersection of the two mentioned research topics – i.e. last-mile delivery for B2C e-commerce and logistics 4.0 – there are some of the most promising innovative logistics solutions (e.g. picking robots for warehousing or drones for transport). Among them, there is the so called "smart key". The smart key is an IoT technology that allows the controlled access to houses, buildings and trunks. In the context of last-mile delivery, its success was led to the launch in the USA of "Amazon key for home" by *Amazon*. In this case, the courier accesses the customer's house relying on a smart key installed on the customer's door. In order to avoid safety issues, the delivery is registered by a smart camera and can be seen on real-time on the customer's smartphone. This in-home delivery solution has recently been introduced also by other players, such as *Yale*, *Walmart* and *Zalando*, both in the USA and in Europe.

The main reason behind its introduction by logistics providers and e-retailers is that it allows to avoid failed deliveries in the traditional home delivery. It represents a novel and promising alternative to other innovative solutions (Business Wire, 2017) such as on-appointment deliveries, or to the most diffused types of unattended delivery (e.g. parcel lockers, reception boxes, collection points). As a matter of fact, this IoT application offers more advantages to customers compared to the other types of unattended deliveries: reduction of theft, no extra-distance to be covered, and the possibility to use the same solution to ensure controlled access for other purposes (e.g. control housing staff access or children coming back home). The main barriers to the smart key adoption are the house architecture and people diffidence.

Anyway, the actual impact of this solution has not been investigated yet. Therefore, the aim of the present paper is to study the economic impact of this solution on last-mile deliveries, from a courier perspective. The remainder of the paper is organised as follows. The next section summarises the evidences emerged from the literature review, which is focused on last mile delivery challenges and contributions addressing the adoption of smart keys. The objectives and methodology adopted within the study are described in section 3. Section 4 describes the developed model, and section 5 illustrates the results obtained by applying the model. Results are then discussed, and, in the final section, conclusions are drawn, and research limitations are identified.

2. Literature review

Last mile delivery – i.e. the delivery of products ordered online to the final customer (Lim et al., 2018) – is a very critical process for B2C e-commerce players, being it one of the main elements of inefficiency (Xu *et al.,* 2008). Last-mile delivery is indeed the most expensive "leg" of the delivery process (Brown and Guiffrida, 2014), since the delivery problem is very complex. Orders are small and unpredictable, destinations may be very dispersed, and purchases can hardly be anticipated or planned (Edwards et al., 2011). Beside the optimisation of traditional deliveries, research efforts are increasingly devoted to propose and analyse "innovative" solutions (e.g. Lim et al., 2018; Ranieri et al., 2018; Mangiaracina et al., 2019). Also considering practitioners, the spread of B2C e-commerce has progressively led to the diffusion of new delivery methods, able to overcome some of the limitations related to traditional HD, such as the inability to saturate transport means and the high probability of failed deliveries (Pan et al., 2017).

As broadly regards innovative solutions in the last-mile delivery, unmanned aerial vehicles (UAV) is one of the main technologies addressed, together with autonomous vehicle, smart key, land local delivery robot and IoT enabling technologies. The delivery cost and the distance travelled can be reduced thanks to the trunk delivery, land local delivery robot or UAV (e.g. Murray and Chu, 2015; Boysen et al., 2018). Through their adoption, also the pollution and traffic congestion in the urban areas are reduced (e.g. Ranieri et al., 2018; Jennings and Figliozzi, 2019). Regarding IoT enabling technologies, RFId tag with wireless sensor network and GPS are used to monitor the position, the status of the products and the position of the truck. Artificial intelligence provides decision support systems for the routing of manual trucks or their combination with UAV with the objective of reducing the distance travelled and thus the transport costs. Thanks to smart key for trunk delivery, the distance travelled is reduced and the customers satisfaction increases as clients do not have to be present at the delivery and thefts are avoided (Reyes et al., 2017).

The implementation of the smart key allows, in particular, to face one of the main challenges of the last mile delivery, i.e. dealing with failed deliveries, which generate additional operating costs to the logistics service providers and dissatisfaction to customers (Xu *et al.,* 2008). The idea is offering customers the opportunity to have their parcels delivered inside their home – also called in-home delivery – without the need to be there. Apart from the application of smart key to the front door, there are other kinds of delivery services that can be realized through this technology: the in-garage delivery and the in-car (or trunk) delivery (BusinessWire, 2017). Smart key solutions belong, in particular, to the cluster of "unattended delivery" (vs attended delivery) (Mckinnon and Tallam, 2003). They represent a valid alternative to broadly solve the issues regarding efficiency: in a simulation conducted by Punakivi et al. (2001), it emerges that the cost of attended home delivery doubles the cost of the unattended one.

Papers addressing smart key application are few and are in particular related to trunk delivery, while there is a lack of contributions on the impact of the smart key for the traditional home delivery. Indeed, contributions about the smart door do not cite any effect on the logistics side but they focus on how this technology may improve the house safety thanks to IoT solutions. Regarding the trunk delivery, the orders are shipped into the car of the customer, who communicates its positions and the related time windows. Reyes et al. (2017) and Ozbaygin et al. (2017) reformulate the algorithm for vehicle routing problem (VRP) in which they consider the combination of trunk delivery and traditional home delivery. In this option, the authors registered a reduction in the total distance travelled and about 20% delivery cost saving because of the additional company flexibility in this hybrid scenario. Anyway, if the trunk location is very close or very far from the customer's home, the only trunk-delivery is not more convenient than the traditional home delivery, because the negative effect of the restricted time window set aside the advantages of the trunk delivery (Reyes et al., 2017). From a methodological perspective, the possibility of trunk deliveries leads to a fundamentally different variant of the well-known vehicle routing problem (VRP). The VRP has been extensively studied since its introduction in the early 1950s, and it "determines a set of vehicle routes to perform all (or some) transportation requests with the given vehicle fleet at minimum cost; in particular, decide which vehicle handles which requests in which sequence so that all vehicle routes can be feasibly executed" (Irnich et al., 2014). There is a plethora of VRP variants, including the VRP with time windows (e.g. Savelsbergh, 1985; Kolen et al., 1987; Dumas et al., 1991; Baldacci et al., 2012), the VRP with pickups and deliveries (e.g. Turkensteen, 2017), the dynamic VRP (e.g. Yu and Yang, 2017), to name just a few. In all these problem variants, the customer's delivery location, i.e. the location where the delivery occurs, is given (even if the decision maker may not have perfect information about it). When deliveries are made to the trunk of a customer's car, this constancy disappears, because the customer's car will likely be in different locations during the planning horizon. Literature presents two contributions on smart key applied to car, but none addresses the in-home delivery.

3. Objectives and methodology

Based on these premises, the academic literature shows great room for research works aimed at evaluating the benefits – in terms of efficiency enhancement – of implementing smart key in last-mile deliveries (in particular in in-home delivery). Accordingly, the ultimate goal of this paper is estimating the reduction in the last-mile delivery cost deriving from the application of such solution. In other words, this paper aims to answer the following research question:

RQ - What is the impact on last-mile delivery cost of introducing the smart-key, if compared to a traditional delivery?

In order to reach the aforementioned objective, this work relies on the development of an analytical model, and more in detail of a revised version of the traditional VRP, whose aim is to minimise the travel distance. The VRPSK (Vehicle Routing Problem with Smart Key) considers the possibility of the customers' homes to be equipped with smart keys (accordingly having a different impact on the delivery accomplishment).

To get numerical insights needed to answer the research questions, the model was later applied to a setting based in a district of the city of Milan. After considering a base case scenario, some sensitivity analyses were run to investigate the effect of a different adoption level of this solution.

To support the model development and application, two additional methodologies were used:

- Literature review: besides identifying the main gaps, the review of extant literature allowed to ground the research in current knowledge, both concerning VRP formulations and smart last-mile delivery solutions.
- Analysis of secondary sources: the analysis of websites, reports and journals for logistics practitioners was useful to get an understanding about the main implementations, and their characteristics. Considering such a novel solution, excluding white literature could result in missing significant contributions that – due to the time needed for an academic paper to be published – are still not present in grey or black ones.

4. Model

The solution proposed by the present paper is reported with the acronym VRPSK, the VRP with the presence of Smart Keys. First of all, it has to be noticed that authors relied on a VRP spreadsheet solver developed by the University of Bath (UK), which is employed by several small companies and can be personalized for the authors' purposes (Erdoğan, 2017). The VRP spreadsheet solver is an open source solver developed in VBA, which has the objective to solve multiple variants of the VRP thanks to the possibility of selecting different options through the user interface. Thus, it was possible to personalize it for the scope of the research. Relying on this tool was considered consistent with the fact that this research represents a first study in the field, and that the final aim is to have a first esteem of the effects the use of smart key could have on operational costs of the courier.

4.1 Model description

The VRPSK thus consists of an adapted version of the vehicle routing problem with time window (VRPTW), and the objective is twofold: minimise the travelled distance and maximise the probability of successful deliveries. To pursue these objectives, two different time windows are associated to customers: one for the *customers with smart key*, the other for the *customers without smart key*. As a matter of fact, the algorithm tries to serve the customers with smart key in the time window where the probability of successful delivery for customers without smart key is below the average.

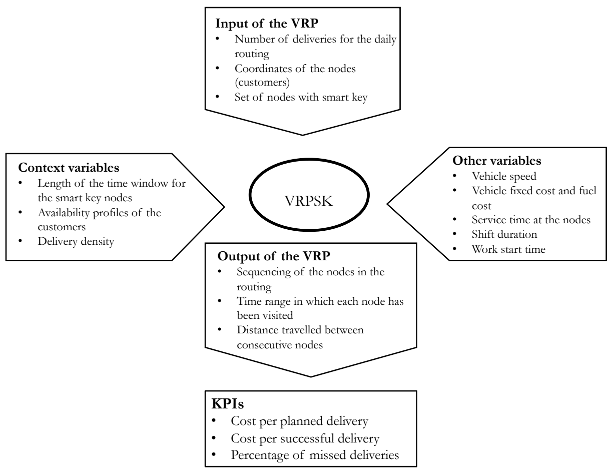


Figure 1: Model structure

Figure 1 - whose main components and characteristics are aligned to previous works in the field of logistics for e-commerce, e.g. Seghezzi et al. (2020) - shows the structure of the model. Briefly, the algorithm receives in input the number and locations of customers to be visited in the daily routing and an ID which label whether they own a smart key or not. Along with the inputs, other parameters related to specific scenario, e.g. the vehicles or the shift, are provided. The VRPSK algorithm works and finds the

optimal routing. The output it returns is used to compute the main KPIs, fundamental for the evaluation of costs and performances of this routing.

Basing on the average availability profile, time windows should be now associated to each customer. A time window for a customer *i* represents the time span in which that customer should be served. It covers some time ranges and it is characterized by a lower bound a_i and an upper bound b_i. Even time range has a lower and an upper bound, a_{tr} and b_{tr}.

For customers with smart key, the criteria to define the time windows are the following:

$$a_i = a_{tr} \text{ } where \text{ } tr = min(tr) \mid Ph_{tr} < \overline{Ph_{tr}} \text{ } \forall i \in V_{SK} \wedge Psk \in (0,1)$$

$$b_i = b_{tr} \text{ } where \text{ } tr = max(tr) \mid Ph_{tr} < \overline{Ph_{tr}} \text{ } \forall i \in V_{SK} \wedge Psk \in (0,1)$$

The time window should start from the earliest time range in which the probability of successful delivery Ph_{tr} is lower than the average Ph_{tr} and should last till the latest time range presenting the same condition. A customer equipped with smart key can be associated to one time windows only: more time windows during the day are not allowed in this version of the model. The customers without smart key, instead, receives a time window which starts and ends with the daily shift – without thus forcing the delivery in a specific *tr*.

The constraint imposed on the time window is soft, which means that it is not mandatory to serve a customer precisely in the assigned time window: it may occur that, for time constraints, the van is not able to serve all the customers in the predefined time windows. The time window can be violated as long as a penalty proportional to the amount of violation is paid. This is visible in the objective function below.

$$\text{Min} \sum_{(i,j)\in A} \sum_{k\in K} c_{ij} \cdot x_{ijk} + \sum_{j\in V_C} \sum_{k\in K} m \cdot x_{0jk} + \pi \cdot \sum_{i\in V} v$$

The first two addends represent the travel costs for the routing. The first refers to the fuel cost proportional to the distance travelled: c_{ij} is the fuel cost to be sustained to cover the arc (i,j) multiplied by the binary variable x_{ijk}, equal to 1 if the vehicle k covers the arc (i,j) between two nodes. The second addend is the multiplication between *m*, the fixed cost defrayed for the activation of a vehicle, times the binary variable x_{0jk}, which is equal to 1 if the vehicle k covers the arc from the depot to node j. The third addend represents a fictitious penalty cost: it is the sum of all the penalties paid for the time windows violation. A penalty occurs indeed when the delivery in a node has been performed outside the time window indicated for that node. Relying on this construction, the algorithm selects a customer to be visited by making a trade-off between the smaller distance and the smaller violation. Given that the smart-key-customers are more likely to be visited in the predefined time window, in which the probability of successful delivery for customers without smart key is low, the percentage of successful delivery is optimized too, along with the travel cost minimization.

In the end, impacts deriving from the implementation of smart keys are assessed by computing (i) the cost per successful delivery and (ii) the percentage of missed deliveries.

An important consideration has to be pointed out regarding constraints of the employed VRP. All the constraints the objective function is subjected to are available in (Erdoğan, 2017). What has been explained in this section are the peculiarities the authors included in the VRP available in (Erdoğan, 2017), since the open source version allowed to make adjustments in order to investigate peculiar situations.

4.2 Model application

The model was applied to a real case, which was tested in five different scenarios. Table 1 indicate the percentage of smart key diffusion *Psk* considered in each scenario.

Table 1: Scenarios of smart key diffusion

Scenario	A (base case)	B	C	D	E
Psk	0%	25%	50%	75%	100%

In order to get results, 12 runs were performed for each scenario. The application reproduces the daily delivery routing of one vehicle in a real district of the city of Milan, the Vigentino area.

On average, a van is able to perform 80 deliveries in 8 hours in the city of Milan. Since the vehicle should depart from the depot, visit the 80 customers scheduled for the day, and then, return to the distribution centre, 81 geographical points are needed. For this reason, 80 sets of latitude and longitude are randomly generated in the routing area to ensure a homogenous distribution. Additionally, the coordinates of a real depot far 4.2 km from the routing area are considered. In this way, the graph of the nodes is complete, and it is possible to proceed with the availability profile.

Three different classes are considered in the population, hypothetically families, students and working people. Each of them has a different availability profile, which were estimated for the purpose of the study: they do not indeed come from empirical data. Assuming, for sake of simplicity, that each one of the 3 classes constitutes one third of the population, this data can be used as weight to compute the average availability profile. Indeed, this vector is obtained as the weighted average between the availability profiles of the classes. The final result is: Ph=[0.94, 0.86, 0.86, 0.88, 0.86, 0.88, 0.96, 0.97], and it corresponds to a distribution of the probability of successful delivery along the day from 9am to 6pm, as the one illustrated in Figure 2. The average of these 8 values is equal to 90%, which is in line with the data provided by express couriers about the probability of successful delivery for a daily routing in Milan.

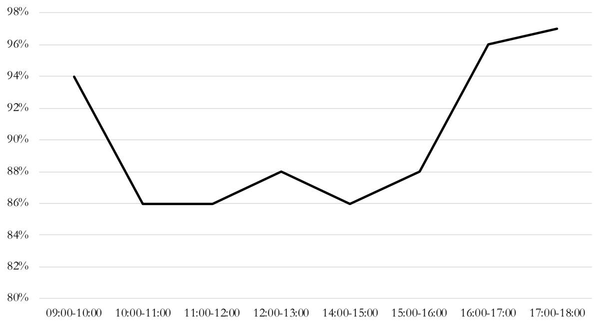


Figure 2: Successful deliveries

Once the availability profile is defined, the time window's length for customers with smart key is defined. Applying the criteria defined in the model development section (§4.1), it results a time window set to [10:00-16:00]. This means that the algorithm behind the VRPSK tries to visit customers with smart key in this specific time span.

The application of the VRPSK returns the path followed by the vehicle in the routing area, node by node, providing also the arrival time and departure time for each customer visited. In the end, KPIs are computed. It first counts the number of customers visited in each time range and distinguishes among them the customers without smart key. Thanks to this calculation and the availability profile provided before, it is able to deduce the expected number of missed deliveries in that routing. From here, all the major indicators defined in the model can be derived.

5. Results

Results show that smart key is a promising technology in improving last-mile delivery efficiency. The more it is adopted by customers, the lower are the number of missed deliveries and the cost per successful delivery sustained by the courier.

5.1 Base case

The traditional home delivery, represented in the scenario A (sk 0%), presents around 9 failed deliveries which correspond to a percentage of missed delivery of 11%. Thanks to the introduction of smart key, adopted by the 25% of customers in scenario B, this percentage lowers to 7% and the failed deliveries become 6. The percentage of missed delivery continues reducing even in the scenario C (sk 50%) and D (sk 75%). The 50% of smart-key-customers brings a 4% of missed deliveries which coincides to 3 missed deliveries, while the 75% reduces the failed deliveries to less than 1.

The cost per successful delivery (CPSD) lowers as well, with the increase of smart key adoption. However, it decreases at a lower rate compared to the percentage of missed delivery, as shown in Figure 3.

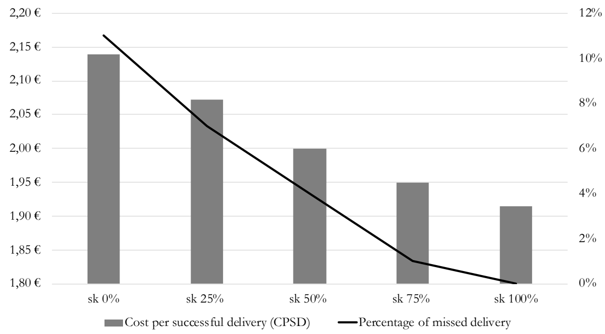


Figure 3: CPSD and percentage of missed delivery

The CPSD starts with a value of 2.14€ in the traditional home delivery, it diminishes to 2.07€ and 2€ respectively in scenario B and C, 1.95€ in scenario D and it reaches 1.91€ in the scenario E, where all the customers are equipped with smart key. Therefore, the courier may gain a saving of 10% from the base scenario the best one.

However, supposing that smart key is going to spread gradually among customers, significative benefits may be gained even in the intermediate scenarios. The highest reduction of the CPSD is the one recorded passing from a 25% smart key diffusion to 50% and it is equal to -3.48%. For higher percentage of smart key adoption, the savings obtained from scenario to scenario are lower because of a saturation effect, but they are still significative. They are -2.52% from scenario B (sk 25%) to C (sk 50%) and -1.75% from scenario C (sk 50%) to D (sk 75%).

5.2 Sensitivity analysis

Sensitivity analyses were performed to test the robustness of VRPSK and to grasp insights on which is the most suitable application context for smart key. For these purposes, it was examined the impact of two parameters: (i) the time window's length and (ii) the availability profile.

Time window's length – As regards the time window's length, it was considered the base case in which the time window is [10:00-16:00]. This base case was compared to the widening case in which the time window is extended to [10:00-17:00] and to narrowing case, where the time window is set to [10:00-15:00]. These variations produce limited effects on the CPSD and on the percentage of missed delivery.

However, it was measured that a shrinkage of the time window to [10:00-15:00] is beneficial only in the scenario B (sk 25%). This occurs because a more extended time window would not ensure to cover the time ranges with the lowest probability of successful delivery, causing a rise in the missed deliveries and, in turn, on the CPSD. When the percentage of smart key diffusion grows to 50% and 75%, the best time window is [10:00-16:00]. The wide time window [10:00-17:00] is never the most convenient one: it brings an increase in the CPSD since the problematic time ranges in terms of probability of successful deliveries are not covered. These findings are summarized in Figure 4, showing the CPSD in all the cases across the different scenarios.

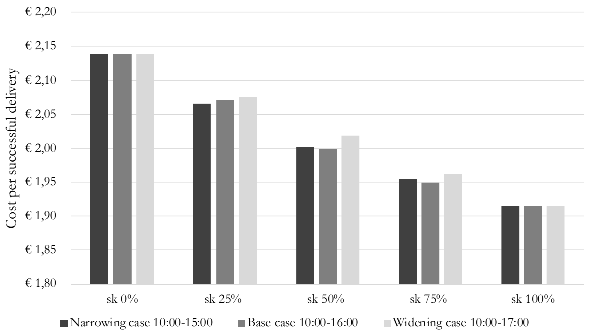


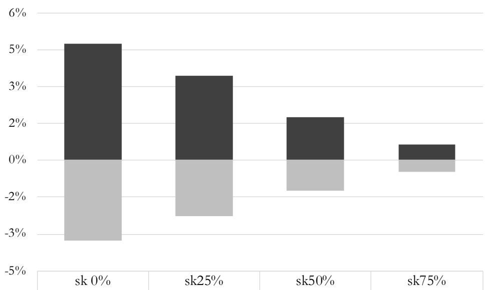
Figure 4: different time window's lengths

Availability profile - Two cases are discussed with respect to the base case, in which the average probability of successful delivery is 90%:

- Case α results in an average probability of successful delivery of 86%.
- Case β leads to an average probability of successful delivery of 93%.

Case α is less convenient than the base case, because the CPSD and the expected number of failed deliveries increase. At the contrary, the Case β records lower CPSD and less failed deliveries.

Figure 5 displays the savings and the extra costs respectively in Case β and Case α with respect to the base case. The higher is the presence of customers with smart keys, the lower is the effect of the variation of the availability profile on the CPSD.



	sk 0%	sk25%	sk50%	sk75%
Savings (Case β)	-3,27%	-2,29%	-1,24%	-0,46%
Extra cost (Case α)	+4,75%	+3,43%	+1,76%	+0,64%

Figure 5: Variations of CSPD

6. Conclusions

The main effects on logistics providers deriving from the introduction of the smart keys are in terms of delivery cost reduction and decrease of the percentage of missed delivery. More in detail, the application of the model shows that the higher the smart key diffusion is, the lower the percentage of missed delivery. Therefore, serving customers equipped with smart key results in an enhancement in the service level that impacts on the entire set of customers, not only on those ones who own this smart technology. Since the number of failed deliveries diminishes, the overall delivery cost improves. In particular, the cost per successful delivery decreases along with the diffusion of smart key as well. Of course, the highest decrease is obtained switching from the scenario AS-IS to the best scenario in which all the consumers are equipped with this smart technology. The reduction in the delivery cost is more than 10%, which is a very substantial saving in the context of last-mile delivery. However, smart key has demonstrated to be advantageous also in more realistic scenarios with a saving of 3.15% in Scenario B, 6.53% in Scenario C and 8.90% in Scenario D, in comparison to the traditional home delivery.

Beyond the results, the present work provides worthy implications to academics and practitioners. On the academic side, the VRPSK model represents the first preliminary study that quantitatively assesses couriers' benefits of delivering to smart-key-customers. On the other side practitioners, such as couriers and e-retailers, may find the model useful to get insights on reducing the inefficiency of their last-mile delivery and increase the service level provided to their clients.

Despite the usefulness for both practitioners and academics, the present work presents some limitations which suggest potential directions for future research. First, the model considers an average availability profile of the customers, which is the result of a weighted average between the availability profiles of 3 classes of consumers. Second, an interesting development may be the definition of an availability profile for more classes of customers or the assignment of an availability profile to each client. Data mining system could be exploited to gather data on customers' habits. By the way, this will result in a more accurate delineation of the probability of successful delivery along the day. Third, the VRPSK allows the definition of a single time window for each customer, without the possibility to define multiple time windows. In order to exploit the presence of smart key customers in the routing, a future contribution can develop an ad-hoc VRP with multiple prioritised time windows for each client without smart key. Time window could be prioritised according to the home attendance of the person himself. In the end, it could be interesting to compare the case of the smart key not with a traditional home delivery, but with on-appointment deliveries.

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