A network design model for food ordering and delivery services

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Abstract: The remarkable developments in e-commerce offer more flexibility and alternative shopping experience to busy people, to such an extent that the best choice in the future for having a meal may be to have it delivered at home. Food ordering and delivery is not a recent business, but it scaled up in the last few years, thank to several successful "logistics apps" and online platforms that enabled online meal purchasing from a wide range of restaurants, promising fast and reliable deliveries of food within city limits. Those revolutionary, original and efficient takeaway services, such as Just-eat, Deliveroo, Deliver Hero and others, gained popularity both for their business success and for class actions related to the employment conditions. In this paper, we first analyse how do these emerging companies work, providing a special focus on the logistics aspects. In particular, we analyse the operations related to the order pick-up and delivery process, performed relying on large networks of self-employed contractors (i.e. bike drivers). Analysing the network, we recognise as a critical factor the location from where the carriers depart for performing the service. In fact, the carrier has a limited time to pick up and deliver the orders; thus, the distances between the carrier's departing point, the restaurants and the customers play a substantial role in determining the service offer. We formulate an optimization model that provides insights into the network design process. The model is an extension of the maximal covering location problem aimed to determine the location and the number of carriers' departing points. The objective function is to maximise the demand covered. This model can be further extended to include other service aspects.

Keywords: food delivery optimization, supply chain network design, urban logistics, cover model

1. Introduction

Freeing up time from must-do tasks, and enabling people to focus on more enjoyable or productive activities, is one of the key driver of e-commerce success(Devaraj, Fan, & Kohli, 2002). In fact, online shopping has become ever more indispensable to many people with busy schedules, who have a growing need for services for a wide variety of goods (Emeç, Çatay, & Bozkaya, 2016). The remarkable developments in e-commerce and new business models relying on it, offer more and more flexibility and alternative shopping experience for consumers, which have rapidly changed their preferences in the last decade.

E-commerce is no longer relegated to standard goods; nowadays, also "premium" goods, i.e. goods such as organic food, specialty gifts, etc. that offer higher value to consumers and higher profit margins to retailers can be ordered on-line and delivered at home. Even e-grocery, i.e. the process of purchasing groceries and grocery products online, is recognised as more convenient and timesaving than the traditional grocery channels, because consumers do not have to leave their home to buy products and can do that at any time of the day (Cagliano, Gobbato, Tadei, & Perboli, 2014).

In the same way, meal planning and cooking are now transforming into e-services: a new series of meal-related online platform has recently emerged. Recognising that people care about time saving and food quality, these companies provide a modern, e-based food ordering and service delivery, capturing customers that are so busy that their best choice for having meal might be to have it delivered at home.

At the beginning, these companies entered the market as intermediary, offering just a connection between "hungry customers" and restaurants providing delivery services themselves with their own resources. Progressively, some of these intermediary companies introduced additional services, such as the delivery within the city area and the possibility of tracking the orders.

Providing the delivery service, which includes both the order pick up from restaurants and the delivery to the customers' front door, creates substantial benefits for restaurants and for customers, as well as for the intermediary companies (usually identified as e-commerce, online platforms). Nevertheless, it implies that the intermediary platform must take the responsibility of all the logistics aspects of the urban shipment. A further explanation of all the different available services and their characteristics is included in Section 2. Nevertheless we will focus our attention only on those companies providing support for the ordering and the delivery phases. In particular, we find interesting the analysis of companies such as Deliveroo and Foodora, since their carriers perform delivery with bikes. Delivering by bikes implies several relevant aspects: in terms of flexibility within the city, it relieves problems associated with traffic congestion, parking, and ZTL restrictions; in terms of pollution, it provides a sustainable solution; in terms of costs, it does not require high investments. However, it implies also organizational criticality to manage (e.g., number of carriers, limited capacity, etc.).

This paper addresses the problems related to the delivery service offered by the intermediary companies, and provides a support in the network design process. In particular, this paper addresses the strategic locations of the carriers (i.e. usually cyclists) in order to maximize the service availability. In fact, the carrier has a limited time to pick up and deliver the orders; thus, the distances between the carriers' departing point, the restaurants and the customers play a substantial role in determining the service levels and offer.

In this paper, we propose an application of the maximal covering location model to the new emerging meal ordering and food-delivery platform, providing a work that is innovative for two main reasons:

- it contributes to the knowledge of new business model into the e-commerce plethora, analysing those new and original services;
- it provides a support to the service providers in the contest of the network design decisions, defining the optimal number of places from which start to perform the service, and which customers should be serviced from which point with respect to the chosen restaurant.

The paper is structured as follows: Section 2 introduces the context discussed in the paper. We briefly describe the new emerging phenomena of food ordering and delivery platforms, and we provide a summary on past research both in the supply chain network design (SCND) field, as well as on pick-up and delivery problem. Section 3 defines the problem we address and the adopted perspective. It also contains the mathematical formulation of the proposed optimization model. Section 4 presents the outputs of a numerical test and explains how results can support the service provider's decisions. The last section concludes the paper, highlighting the model's limits and possible future research extensions.

2. Background

2.1 Food delivery platforms' phenomena

The intuition that grocery shopping, meal planning and cooking are considered by a part of the population as a chore, led many companies to offer services aiming at relieving busy people from such a burden.

As shown in Figure 1, there are three different duties that food providers could take on: food order, food cooking, and food delivery. With respect to the different combinations of these elements, it is possible to define and classify the different types of service they offer. In particular, the real revolution in this context comes with the possibility for online purchasing, which provides support for enhancing the traditional way of having a meal, as well as takeaway services, with more efficient solutions.

The firsts companies established in the market mainly relied on online applications, and operated as online marketplaces matching diners to restaurants that usually were already performing the delivery service with their own carriers. The intermediary company, in this case, provide the software and the web portal for processing customers' orders. Examples in this area are Just Eat, Deliver Hero, and Grubhub.

Later, services have been extended to offer the delivery from restaurant to a customer's front door, focusing both on the ordering service and the logistics aspect of the shipment. For examples, companies such as Deliveroo, Foodora, and Postmates provide the bridge between restaurants and consumers through an online platform to place the order, and a fleet of cyclists for the delivery. These companies try to enhance the service adding further functionalities, such as the traceability of the meal.

The last generation of food delivery start-ups offer a fully integrated service: they develop their own app through which consumers can order a limited range of meals cooked from them, and they also deliver it with their own fleet. In this area, we can classify companies such as Spring, Maple and Spoonrocket.

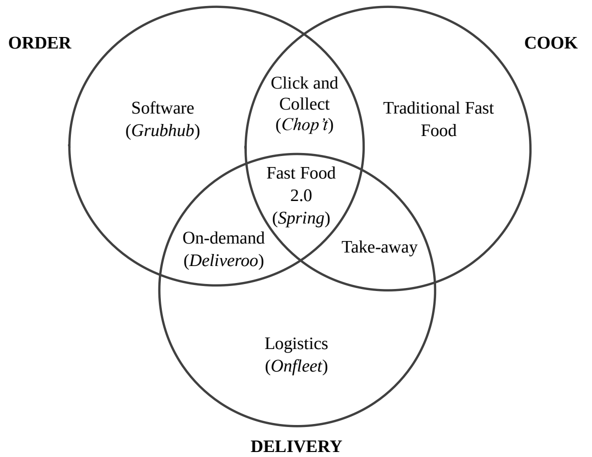

Figure 1 – Classification of food delivery per services provided (Mignot, 2015)

This paper focuses on companies providing the food delivery service and the software for the ordering phase (i.e. "On demand" companies in Figure 1). The reason is that they are the only one that need a strategic organization of network and fleets in order to perform the service. Table 1 summarizes the main figures of the top players, which rely on:

- reliable ITS systems that connect customers, restaurants and carriers. They provide (most of the time) a support to the carriers in defining the best routes;
- partnerships with a wide number of restaurants, ensuring a high-density network of food offers and variety;
- large networks of self-employed contractors (carriers) for order pick up and delivery (usually with bikes or motorbikes);
- low fixed costs associate with the physical asset.

Table 1 - Main figures of the "On-demand" services

	Established in	#Restaurants (000)	#Countries	Delivery service
Justeat	**2001**	**64**	**13**	**From 2016**
Deliveroo	**2013**	**6**	**13**	**Yes**

Deliver Hero*	**2011**	**270**	**40**	**Depending on sub brand**
Postmates**	**2012**	**4**	**27**	**Yes**
Uber-eats	**2015**		**22**	**Yes**

*Deliver Hero encompasses: Foodora, Foodpanda, Hungry House, Lieferheld, pizza.de, Yemeksepeti and Baedaltong.
** Postemates service incudes delivery of other kind of goods too.
All data are taken from the companies' web site and press releases.

As well as for service providers, benefits are clear for all the actors in the chain:

(1) customers can choose from a wide variety of food, and get it delivered at home quickly;
(2) restaurants can focus on the core business, delegating the delivery to third parties and increasing their visibility to increase their revenues;
(3) riders enjoy flexible work. Nevertheless, as well as for their success, those company raised lot of rumours for the protests, strikes and class actions by workers that seem to be popping up as quickly as new apps. Main complaints and discontents are related to wages and payment structures, insurance treatments and mispresented flexibility (Stern, 2016). Additionally, negative feedbacks with respect to the length of the delivery are not such a rare event. Sometimes they raise from the customer side, who receive cold food, later than expected. Other times, complaints rise from the carrier side, who may have to go across the city for one single delivery. (Paton, 2017)

Among the different reflection that may emerge, what we would like to underline is the need of a more strategical and efficient management of the supply chain, and the coordination of fleets along the network.

2.2 Overview on past research

Our work can be referred to the Supply Chain Network Design (SCND) discipline, which aims at determining the structure of supply chains, dealing with many and various decisions that go from the tactical level, such as distribution, transportation and inventory management policies, to the operational decisions, such as fulfilling customers demand and routing problems.

The field has been comprehensively reviewed by Farahani, Rezapour, Drezner & Fallah, (2014). Thanks to an analysis of the voluminous literature on the topic, their work mainly contributes to the literature highlighting the effects on SCND of the competitive environment that has developed over recent years, and makes a synthesis on the literature in the field of SCND. They recognised as one of the most important decision the location of the facilities in different tiers of the chain.

The specific problem of facility location has been investigated by Melo, Nickel & Saldanha-da-Gama, (2009) who identify models and the key features in supporting decision making at a strategic level into the SC planning. They also analysed the methodologies to solve the problems: regarding the approaches that has been developed in the SCND field, optimization and simulation have been widely applied as appropriate methodologies into the strategic supply chain planning.

Objective functions into the SCND models are found to be different in various studies but, traditionally, the objective function in such problems is mostly monetary (e.g. minimize the total cost, or maximize the overall profit). However, recently new paradigms have emerged in the field of supply chain, and SCND models under these different objective functions should be considered (Farahani et al., 2014). For example, to be successful in the face of fierce competition, and to meet the growing demand for time-definite services, delivery companies must design their delivery networks to reliably and efficiently meet their promised delivery times (Chen, Campbell, & Thomas, 2008). One family of model used when an efficient and effective service must be provided over a wide area with spatially distributed demand, are the covering models. A review is proposed by Li, Zhao, Zhu, & Wyatt, (2011) in the contest of the emergency response facility location.

Moreover, with the growth of the e-commerce, the design of the supply chain from the order picking at the supplier up to the delivery to the shopper's doorstep becomes more and more valuable. Several works have addressed the pick-up and delivery optimization (Parragh, Doerner, & Hartl, 2008), and they are in nature mostly focused on Vehicle Routing Problem (VRP). In fact, the general pick-up and delivery problem (GPDP) is about creating routes for carrying out a number of transportation requests using a fleet of vehicles (Savelsbergh & Sol, 1995).

In the field of food delivery, the literature deals with the traditional e-grocery, identifying its success factors (Punakivi & Saranen, 2001) and is focused most of the time vehicle routing delivery optimization (Emeç et al., 2016; Yanik et al., 2014). Indeed, the problems e-grocery faces are the ones of pick-up and delivery models.

Some work has been performed on the fast-food delivery services (Tobing, 2016), as well as on the importance of the ITS systems in those business (Cagliano et al., 2014), but no one addressed the type of platforms we are studying. In fact, we recognise that food ordering and delivery models are characterized by a series of features combined in such a way that differentiate their needs and their supply chain network from the ones of e-grocery shipping or delivery pick-up problems, even with lot of similarities.

Starting from these considerations, our research contributes to define the criticality of the logistics aspects related to the services, and underlines the differences between those problems and the once already studied. Furthermore, the paper proposes an application of a covering location problem in this contest, which tries to addresses some of the problems those type of services faces.

To summarise the main peculiarities, we recognise that each delivery:

- has a real-time service requests and delivery assignment to the carriers, who must accept immediately the request;
- differently from an usual delivery and pick-up model, has a single pick up point;
- it is performed individually, meaning that each carrier takes just one meal per shipment (i.e. the delivery has a single delivery point);
- has a specific, usually tight, time constraint.

Additionally, the service is not related to a high activation cost of the depot: it does not require a fixed warehouse to depart from, and the cost of equipment in terms of transportation means is low respect to the traditional delivery service. Most of the time, the transportation vehicle procurement is completely delegated to the employees.

3. Problem definition

The approach proposed in this paper attempts to provide a decision support tool in the SCND for service providers operating in the online meal ordering and delivering business. From their standpoint, the aim is to maximize the demand covered while ensuring an efficient service in terms of time. Thus, the fundamental issue we want to address in this kind of food delivery, is the maximisation of the platform’s potential market thanks to the formulation of an optimization model.

By simplifying the service provided by these companies, and to have a unique view on the mechanism behind the delivery, we define the main steps that characterize it. A customer looks for its favourite meal on one of the available platforms, and when he sends the order, carriers working for the intermediary company, nearby the location receive an alert. Through the ITS system, and according to the carriers’ availability, the delivery is assigned to one of them, who has to reach the restaurant, pick up the meal, and reach the customer, within a certain amount of time.

Analysing this process, we recognised that the limited time interval usually guaranteed for the delivery from the order placement (i.e. 25-30 minutes in some cases) restricts the number of restaurants a customer can virtually patronize. As a consequence, the number and locations of the places where the carriers should wait for a delivery order became critical factors. In fact, such a location can greatly affect the extent of the offer to the customers in terms of reachable restaurants.

Later on, we will refer to these location points as “depots”. A strategic allocation of these depots is a crucial decision to enable the platform to reach the demand. In fact, the proposed model helps the service provider to answer to these basic questions: (1) How many depots and where should they be activated in order to maximise the covered demand? (2) Which customers should be served from which depot with respect to the chosen restaurant?

This type of approach enables us to consider also the customers point of view, who receives the meal within the expected time frame and can be considered satisfied for the service reliability. Moreover, it implies that the carrier is also considered; in fact, the model ensures that the distances travelled rely in a specific range, that does not exceed a predefined length.

The following sections describe both the assumptions for the model and the mathematical formulation.

3.1 Model assumptions

Covering location problems, which seeks to reach the maximum population which can be served within a stated service distance or time, given a limited number of facilities (Church & Revelle, 1974) resulted suitable for our purpose. In particular, we take into consideration the target location coverage model, which objective is to cover a set of subjects, and not an entire area, since we can identify customers as a set of specific points.

Moreover, it is reasonable to think about depots as specific areas in a city, such as squares or parks. This simplifies the model for two main reasons: first, it enables us to design the model as discrete, and second, it makes the set of the possible location well defined. Location problems are most of the time modelled as discrete (Farahani et al., 2014), and this simplification does not represent a limit of the model.

Usually, coverage problems compute the area covered defining circular areas around the starting point. The model we propose, instead, has to consider the fact that the carriers reach first of all the restaurant and later the customers. Thus, the cover demand depends also on the distances between depot and restaurant, and not only from the distances between the restaurants and the customers. This consideration has been taken into account also in the definition of the time constraint: food delivery platforms state a maximum time for the delivery, thus the total length of the carrier path, that is the sum of the two distances, must be covered in a time lower than the available amount of time. At the end, the general framework under the problem can be visualized as depicted in Figure 2, where three different known set are identified: one for the starting points, one for the restaurants, and the last one for the customers. The diagram identifies the usual carriers path, and the distances between two different points belonging to the sets can be easily computed.

As a starting point, the depot location problem we propose benefits from the application of the following assumptions:

- the number of carriers in each depot is set equal to one, and each carrier can serve one customer place at a time. It means that the carrier leaves a depot, and picks up a single order to be delivered at a single destination;
- customers have no specific requirements on the number of restaurants from which they can be served, thus to consider a point covered and the demand fulfilled, it is enough that that destination points can be reached by at least one restaurant (1-coverage);

- no route considerations are included: for each path, we have defined the distances between the different destinations (depot, restaurant, customer) as the average time needed to travel from one point of the chain to the other.

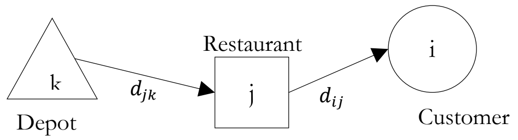

Figure 2 – Graphic representation of the model framework

3.2 Model formulation

Once the problem has been discretised, and all assumptions have been made, the model makes use of the following parameters:

- $I = \{1, \dots\dots n\}$: Set of delivery points (i.e. customers)
- $J = \{1, \dots\dots m\}$: Set of pick up points (i.e. affiliate restaurants)
- $K = \{1, \dots\dots k\}$: Set of candidate depot points.
- d_{ij}: distance between delivery point $i \in I$ and pick up point $j \in J$. The distance can be expressed in time units.
- d_{jk}: distance between pick up point $j \in J$ and depot $k \in K$. The distance can be expressed in time units.
- $Dmax$: maximum distance that can be travel by each carrier. The distance can be expressed in time units, and represents the maximum time the customer is willing to wait for the delivery.
- D_i: population density of node $i \in I$. It is representative of the fact that modelling each point as a client does not consider the possibility that in the same location could live more than a single person. Therefore, the density parameter represents multiple clients in the same location point.
- e: activation cost for each depot. It is representative of the fact that activating a node means that one carrier is operating in that node, and he has a related fixed cost. The number of depot points is used in the model as the only cost factor that enters the decision process.
- E : maximum expenditure (or maximum number of depots to activate; in this case, the activation cost is put equal to 1)
- c_{ijk}: defines the coverage of node $i \in I$ served from depot $k \in K$ passing through restaurant $j \in J$, considering that the total length of the path must be no longer than $Dmax$. Formally:

$$c_{ijk} = \begin{cases} 1 & if \;\; d_{ij} + d_{jk} \leq Dmax \\ 0 & otherwise \end{cases} \quad (1)$$

The necessary decision variables are defined as follow:

$$x_k = \begin{cases} 1 & if\ node\ k \in K\ is\ activated \\ 0 & otherwise \end{cases} \quad (2)$$

$$y_i = \begin{cases} 1 & if\ node\ i \in I\ is\ covered \\ 0 & otherwise \end{cases} \quad (3)$$

The first decision variable x_k is a binary variable which identifies active depot nodes. Variable y_i represents the coverage of node $i \in I$ considering all the active depot $k \in K$.

The objective is to maximize the covered demand (equation 4), and the overall model can thus be formulated as follows:

$$\max Z = \max \sum_{i \in I} D_i \cdot y_i \quad (4)$$

Subject to:

$$s.t. \quad \sum_{k \in K} \sum_{j \in J} c_{ijk} \cdot x_k \geq y_i \quad \forall i \in I \quad (5)$$

$$e \cdot \sum_{k \in K} x_k \leq E \quad (6)$$

$$x_k \in \{0,1\} \ \forall i \in I \quad (7)$$

$$y_{ij} \in \{0,1\} \ \forall k \in K \quad (8)$$

The equation (4) defines the objective function as the maximization of the number of reached customers, weighted in accordance to the density of population in a specific place.

Constraint set (5) ensures that if a node $i \in I$ can be served from a restaurant $j \in J$ by at least one carrier departing from a depot $k \in K$ within the time $Dmax$ (and thus, c_{ijk}=1), then that node $i \in I$ is covered.

Constraint set (6) stipulates the limit on the maximum number of active depots. Finally, constraints (7) and (8) enforce the binary nature of the variables.

4. Numerical testing

The model has been implemented and tested using the GAMS software with different sets of data, using a mixed integer-programming solver (CPLEX). A random sample of data including 100customers, 20 restaurants and 10 candidate depots has been used to set the baseline results. An optimal solution has been reached in less than a second and 27 iterations of the MIP, with an AMD processor with 10 cores at 1.80GHz.

Given the assumptions of the model, the results maximise the demand covered, using all the depots that can be activated. Thus, we run the model 10 times, changing the constraint (6), which sets the maximum expense, and we compared results.

In particular, our interest was to identify the benefit of the activation of each single depot, and give a tool that enables a service provider to compare that benefit with the activation cost of the depot. Figure 3 is representative of the situation: in black, the number of customers that can be served activating different depot. The green line shows the percentage of increase of these served customers. As it is possible to notice, the green line decrease in a non-linear way, and after the activation of four depots, the percentage slow down rapidly until reaching zero.

In this example, we can say that there is no benefit in activate more than seven depots, and other considerations could be made on the trade-off between cost and benefit for the activation of at least two depots, that can vary respect to the different corporate polices and preferences.

Another extremely useful information provided by the solution of the model is the location of depot points. In fact, the solution gives the exact information of the specific depots to activate that have known position by assumption. Both the numerical result and the graphic representation of the situation can be used in order to make changes in the initial set of depot points *K*. Indeed, some points can be excluded, since they do not produce any benefit, and on contrary, some others can be added in more proper positions.

Considerations can be made also changing the time constraint on the deliveries. As a matter of fact, increasing the time frame, it is possible to serve more customers with the same fixed number of depot. As a supportive example, Figure 4 shows the results with the activation of five depots, with four different values of $Dmax$, and reports the relative increment in the covered demand. The outcomes can consistently vary in response to a small change in the time, e.g. customers that can be reached, with a change between twenty and twenty-five minutes, increase more than 100%.

This kind of data enables also a consideration of covered customers in accordance with changing both in the number of depots and in the delivery time. The following Table 2 shows the comparison of the decisions to open four, five or six depots and the different times allowed for the delivery. We can notice, for example that in some cases there is no benefit in the choice of activate six depots instead of five (i.e. 25 and 35 minutes)

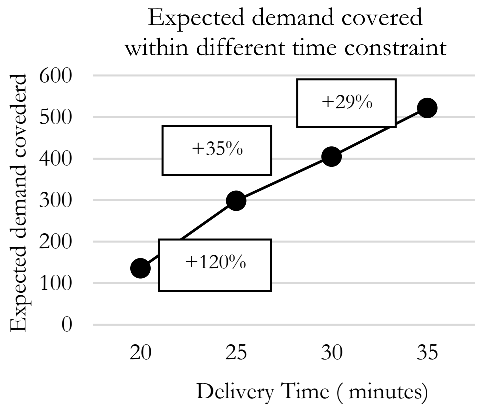

Figure 4 – Representation of the coverage changes due to a variation in the delivery time

Table 2 – Sensitivity analysis of covered demand performed varying the number of depot and the delivery time

		Number of depots		
		4	**5**	**6**
Delivery time	**20**	**21%**	**24%**	**24%**
	25	**46%**	**53%**	**53%**
	30	**67%**	**71%**	**74%**
	35	**86%**	**92%**	**92%**

Such results can substantially differ according to the different initial set of customer points and their geographical position and density, and clearly such decision has to be made taking into account the customer opinions and their willingness to wait for their meals, that can differ from one country to another, and even between cities. Nevertheless, the presented model associated with a good analysis of results, represents a supporting tool for the service provider to made meaningful decisions.

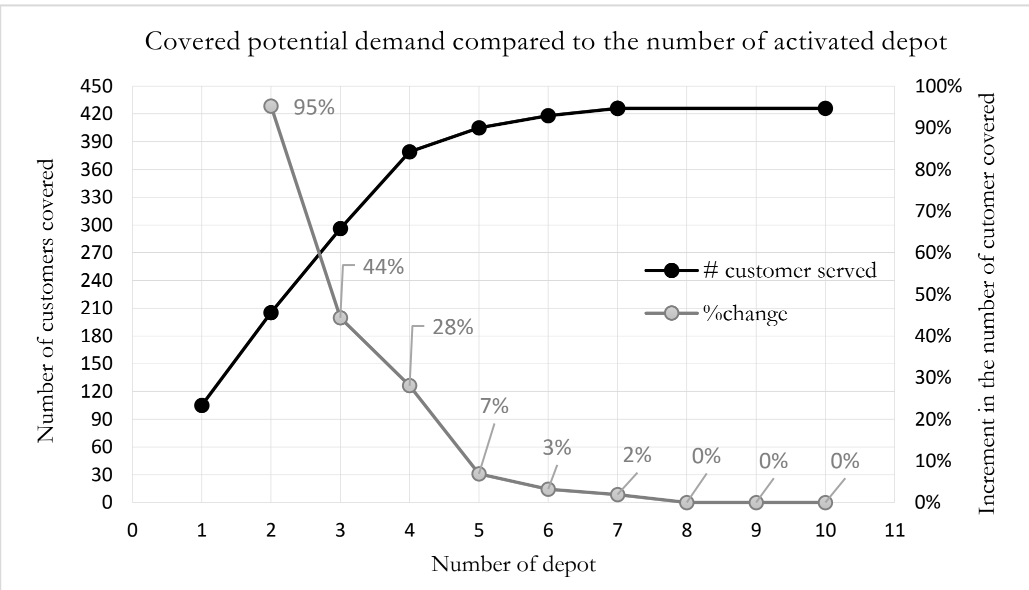

Figure 3 – Graphical representation of the benefit of depot activation in terms of potential customers, for $Dmax$ equal to 30.

5. Conclusions

The research presented in this paper concerns the analysis of the emerging services related to online meal ordering delivery, and their supply chain network. It recognises the location of depot points in the city as essential for the satisfactory operation of the food ordering and delivery system. At the end, the paper provides the formulation of a model that gives suggestion on the optimal position of the depots, assuring that the total travelled distance is limited, maximising the number of the platforms' potential customers.

A natural extension of the proposed model is the multi-carrier case, as all the platforms operate with a high number of personnel. Thus, after having defined the location of the depots, it would be coherent defining the size of the fleets in each depot. Cost functions can also be exploited. The model takes into account only a single fixed cost related to the activation of each node, but it can be considered that the carriers' wage depends on the number of shipment they perform and thus define cost of depots taking into account the number of customers that can be reached from each depot can help the service provider to have a more realistic view.

Moreover, the quality of the solution could be evaluated comparing the proposed model's solution with a different approach, in which there is no a predefined space for the waiting time and carriers ride in the city.

Further research may focus also on improving the model considering other aspects of the quality of the service. The model we proposed addresses the time constraint, ensuring that the platforms can reach the largest market possible within that time. Nevertheless, this focus is not the unique of a service provider: it is important for companies to satisfy the client to retain current customers and attract new ones leveraging on different factors. More specific, in this case, it is possible to consider the quality of the service in relation to the number of different restaurants that can reach a single customer, providing to him a variety of choice.

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