Dark, cloud and ghost kitchens: a logistics perspective

Arianna Seghezzi*, Chiara Siragusa*, Riccardo Mangiaracina*, Alessandro Perego*, Angela Tumino*

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

Abstract: In recent years multiple countries have witnessed the dramatic diffusion of the so-called "on-demand food delivery", i.e., a model based on online platforms offering the delivery of freshly prepared meals from restaurants to the customers' home. In these ecosystems, novel solutions referred to as "Kitchens for Delivery" are being created, which are aimed to fulfil these orders. Differently from traditional restaurants, these are kitchens dedicated to the preparation of online orders only, with no offline customers.

This being the context, the present research has a twofold goal. First, identifying and describing the major different models existing in the field (i.e., Dark, Cloud and Ghost Kitchens). Second, estimating their performances from a logistics perspective, by means of an evaluation of their impact on the on-demand food delivery logistics problem.

The implemented approach is multi-method, as it combines: (i) the analysis of (black, grey and white) literature, to understand the state of art and map the main solutions; (ii) a simulation study, to assess the changes implied by introducing Ghost Kitchens into the network in terms of delivery performances; (iii) interviews with practitioners, to validate and interpret the results.

The research is expected to have both academic and managerial implications. Considering academia, it sheds light on a field that is under-investigated in literature, proposing a classification of extant models, as well as a model to estimate their logistics implications. Considering industry, it provides an estimation of the impact that implementing Ghost Kitchens could have on the most significant logistics performances.

Keywords: on-demand food delivery, logistics, e-commerce, ghost kitchens

I. INTRODUCTION

In recent years, the on-demand food delivery– i.e., the delivery of freshly prepared meals from restaurants to the customers' home – has been experiencing an astonishing growth (Seghezzi et al., 2022). The increasing portion of millennials and digital natives in the adult population, the frenetic working rhythms, and the need for fast and easy solutions, together with the increasing rental rates in big cities and the rise of the Gig Economy, have pushed the food delivery business towards the digitalization (He et al., 2019). Traditionally, food is prepared in the kitchens of restaurants, which are not designed to effectively and efficiently manage a great number of additional meals ordered online (Chhabra and Rana, 2021).

As a result, novel solutions compared to traditional restaurants are being created, which are referred to as Kitchens for Delivery. They are kitchens dedicated to the preparation of online orders only, with no offline customers (Hakim et al., 2022). To manager their presence online, they usually rely on aggregators/platforms that provide them an ordering system and delivery service, in exchange for a percentage of their revenues (Rinaldi et al., 2022).

While different studies exist in the on-demand food delivery domain focussed on restaurants (e.g., Muller, 2018; Seghezzi et al., 2022), the present research aims to address the novel – and still under-investigated – topic of Kitchens for Delivery, to shed light on this emerging model. More specifically, a review of the literature revealed two main research gaps in the area.

First, there is a lack of a clear identification of the different business model typologies that all go under the name of Kitchens for Delivery. There is no clear distinction between business models, as well as the roles the players have in the different configurations. Moreover, extant studies do not show a shared vision on their definitions, which are sometimes overlapping if not contrasting.

Second, there is a shortage of research estimating the impact that introducing these new solutions have on logistics performances. Henceforth, despite it is well recognized that the distribution problem for on-demand food delivery changes if compared to traditional restaurants (due to the possibility to aggregate more points of origin in the same tour), it still remains unclear how the routing is affected by Delivery Kitchens, and a quantitative estimation of their effects is missing.

II. OBJECTIVES AND METHODOLOGY

Based on these premises, the objective of the present research is to investigate the Kitchens for Delivery from a logistics perspective, with the aim to fill both the identified gaps. The followed steps are:

- identification of the major dimensions along which the Kitchens for Delivery models may be classified, and the subsequent univocal definition of the business models and description (based on these classification axes);

- analysis of the implications of the introduction of Delivery Kitchens (and in particular of Ghost Kitchens) from a logistics perspective, especially on the routing and distribution problem;
- discussion of the performances of the different models from a more qualitative and comprehensive point of view.

The selected approach is multi-method, and it combines four main methodological components:

(i) Literature review: a review of academic papers was accomplished to understand the state of art of the knowledge on the topic, as well as to better shape the research objectives.

(ii) Analysis of secondary sources: given then scarcity of academic studies addressing the Kitchens for Delivery, white papers, company reports and websites of players operating in the sector were consulted.

(iii) Simulation study: a simulation was developed and applied, aimed to assess the changes in terms of delivery performances and costs entailed by the introduction of Ghost Kitchens into the network.

(iv) Interviews: an expert in the field, managing a Ghost Kitchen, was interviewed, in order to gain the managerial perspective, collect data, and validate and discuss the obtained results.

Methods (i) and (ii) were mainly devoted to the identification and analysis of the business models; methods (iv) was mainly aimed to estimate the logistics performances of the Ghost Kitchens; method (iii) was used as a complementary approach for both the objectives.

III. BUSINESS MODELS

As anticipated, the first step was the identification of the five main dimensions along which it is possible to classify the different "Kitchen for delivery" models, allowed by the review of the literature. Figure 1 summarizes both the dimensions and the main alternative options for each of them.

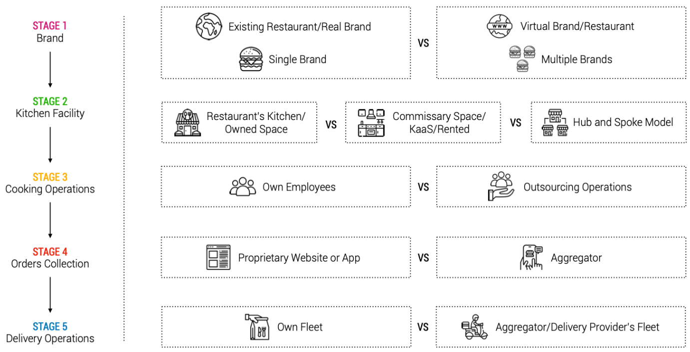

Fig. 1: Classification axes for Kitchens for delivery

1. Brand: the brand of the Kitchen for Delivery can be either an existing one (e.g., the name of a chain of restaurants), or a new one. In this second case, it can have a physical presence, with a storefront for takeaway for example, or just be present online (virtual brand or virtual restaurant). The choice of the brand is also related to the number of brands: a single owner may have a single brand or multiple virtual brands served from the same kitchen.

2. Kitchen Facility: the choice of the kitchen facility opens three main options. First, the kitchen (or anyway owned space) of the restaurant. This is the classic "single" kitchen model where a brand/a bunch of brands under the same owner chooses a dedicated space in the kitchen of a restaurant, or a completely new space, set-up for the production of food for delivery only. Second, the commissary or rented space (KaaS - or a Kitchen as a Service), which is a sort of co-working space where brands rent a kitchen space optimized for the delivery production. Third, the hub and spoke model, that is the less common and more complex, which consists in a central kitchen (hub) where all the delivery meals are prepared and pre-cooked, and then delivered to many "local" kitchens (nearer to the final customers), where the chefs complete the cooking and packaging before the final delivery.

3. Cooking Operations: cooking operations include the procurement of raw material and the preparation of food, cooking and packaging. The brand can opt for relying on own employees, a dedicated team, or outsourced employees (usually employees of the kitchen owner, to whom they provide the recipes and the knowhow needed to replicate their dishes). There may also be a mixed modality, where the procurement is outsourced but the cooking staff is not: this is usually the case of Cloud Kitchen, where by aggregating the procurement it is possible to obtain advantages in term of costs.

4. Orders Collection: the collection of orders is the first touchpoint with the customer, and has therefore to be designed to optimize the entire customer experience. The methods typically used to collect orders online are two. On the one hand, an own website or app – where the brand owner develops its own application/website to collect the orders – with the advantages of the high level of customization, the avoidance of competition once the client enters the system and the absence of royalties that are usually paid to aggregators. On the other hand, relying on aggregators, which are online two-sided platforms that connect delivery restaurants, that to be featured pay a percentage of their sales, to final customers; it is the easiest solution, especially for a starting business. In some cases restaurants rely on both.

5. Delivery operations: the choice of the delivery system is based on the strategic choice made by the brand, but is also related to the choice made in terms of ordering system. In case the brand has its own ordering system, it is usually able to provide the delivery with its own fleet of riders (employees). Conversely, if the choice is to exploit the aggregators, there may be two main alternatives: some aggregators provide the ordering and delivery together with a fleet or riders, in exchange for a percentage of the order value; other aggregators provide instead the ordering system only, and let to the brand owner the choice of using an own fleet or the fleet provided by the aggregator. The delivery is the only physical touchpoint with the customer in the entire experience, and it accordingly strongly impacts the perception and reputation of the brand.

Based on the analysis of these five dimensions and on the possible options, a shared and complete view of the models in the market may be derived.

Dark Kitchen: it is the first model, that gave rise to the whole “Kitchen for Delivery” phenomenon. A dark kitchen is a “kitchen in the kitchen”: a restaurant decides to enter the food delivery business by dedicating an area within the existent kitchen to the food-delivery preparation only (single brand).

		DARK KITCHEN		
		Traditional	Virtual	Outsourced
Brand	number	single brand		
	typology	real brand (restaurant brand)	virtual brand	
	owner	single company (physical restaurant owner)	single company (restaurant owner/third company)	single company (outsourcing operations to a restaurant)
Kitchen Facility	owner	physical restaurant owner		
	typology	dedicated space in the restaurant kitchen		
Cooking Operations	procurement	restaurant owner	restaurant owner/ brand owner	restaurant owner
	staff	restaurant owner	restaurant owner/brand owner	restaurant owner
Orders Collection		proprietary website/app and/or aggregator(s)		
Delivery Operations	model	delivery only/takeaway	delivery only	
	fleet	self delivery/via aggregators		
	Examples	Un posto a Milano (Milano)	Golocius at Nyx Hotel; Pica Dark Kitchen (Milano)	-

Fig. 2: Dark kitchen

Cloud Kitchen: a cloud kitchen is a co-working space where an owner (usually an aggregator, real estate company or entrepreneur in the food sector) builds a space with multiple kitchens (Gosai and Palsapure, 2020). The set-up is optimized for the delivery, and they are made available for rent to brands operating in the sector. The Cloud Kitchen acts therefore as a “service provider”, with the provided services ranging from cleaning services, to a proprietary platform for orders and fleet, to support in the strategy and marketing activities (menu selection, promotions, etc.). In some cases cloud kitchens act as “incubators" for new brands.

		CLOUD KITCHEN	
		Shell	Fully Stacked (KaaS)
Brand	number	multiple brands	
	typology	real/virtual brand(s)	
	owner	multiple companies	
Kitchen Facility	owner	3rd party provider (aggregator, real estate company, etc.)	
	typology	dedicated empty kitchen in a shared space (barely minimum infrastructure)	dedicated equipped kitchen in a commissary/shared space
Cooking Operations	procurement	brand owner	brand owner o KaaS provider
	staff	different brand owners	
Orders Collection		proprietary website/app and/or aggregator(s)	
Delivery Operations	model	delivery only/takeaway	
	fleet	self delivery/via aggregators	
	Examples	Kuiri (Milano)	Glovo Cook Room (Milano)

Fig. 3: Cloud kitchen

Ghost Kitchen: this is an encompassing model, consisting in a kitchen aimed at the preparation of food for delivery only. The brand owner decides to set up the kitchen in a dedicated facility, with one or various workstations depending on the number of virtual brands to be proposed to the market. The procurement and cooking staff is made by own employees, while the management of orders and deliveries may rely on either an own system or an aggregator. This model combines the pros of the two previous ones, but it is also the most complex in terms of structure, initial investment and costs.

		GHOST KITCHEN		
		Single Brand (or Independent or Pod/Pop up)	Multi Brand (or Brand House)	Hub and Spoke Model
Brand	number	single brand	multiple brands	single/multiple brand(s)
	typology	real/virtual brand(s)		
	owner	single company		
Kitchen Facility	owner	brand owner		
	typology	dedicated equipped kitchen in a proprietary space		central kitchen ships semi-cooked dishes to smaller outlets that cooks before shipping
Cooking Operations	procurement	brand owner		
	staff	brand owner		
Orders Collection		proprietary website/app and/or aggregator(s)		
Delivery Operations	model	delivery only		
	fleet	self delivery/via aggregators		
	Examples	Foorban (Milano)	Helbiz Kitchen; Ktchn Lab; Delivery Valley (Milano)	-

Fig. 4: Ghost kitchen

Based on the above, the Ghost Kitchens model emerges as a comprehensive model, representative of the major logics behind the Kitchen for Delivery paradigm, and was therefore used as the case for the subsequent analyses.

IV. Simulation Study

The “traditional” on-demand food delivery problem is very challenging, as it requires to deliver a prepared meal from a point of origin to a point of destination, thus requiring one-to-one travels. Delivery Kitchens reduce the complexity of the delivery problem, by aggregating many restaurants/pick-up points into the same location. While different studies cite the expected effects of their implementation, quantitative estimations in this direction seem to be missing, and are therefore the aim of the simulation study (which was implemented through Q-GIS software).

To evaluate the performances of Delivery Kitchens, two configurations are compared: a traditional network where an aggregator is in charge of the pick-up and delivery of the orders from many affiliated restaurants, and a network where riders pick-up and deliver starting from a single Ghost Kitchen. The considered implementation context is the city of Milan. Milan is the second-largest city in Italy, and it has always been capturing the interest of logistics scholars, who have been selecting it as the implementation scenario for their studies (e.g. Akhavan et al. 2020). This is true especially if considering on-demand food delivery (e.g. Seghezzi and Mangiaracina, 2021), due to the high adoption rate by Milan citizens.

The simulation analysis is made by means of a simulation in Milan (Italy), applied through Q-GIS software. The simulation is characterized by the following assumptions:

First, Static Simulation: it is assumed that at "time zero" (i.e., before the start of the simulation) all the orders are already available and assigned to riders before they start their delivery trip, and no other orders arrive after the rider left his point of origin.

Second, Orders: riders deliver meals by bicycle, following the fastest (and not the shortest) path, and restaurants take orders through the aggregator platform, from locations that are no further than 15 minutes by bike. Orders must be delivered within 35 minutes from the pick-up.

Third, Riders: riders, starting from different PoO inside the delivery area, are assigned by proximity to restaurants (and so to orders).

Fourth, Batching Policy: riders can visit multiple locations and do multiple pick-ups during a delivery trip; each stop for pick-up or delivery takes on average 3 minutes.

All these assumptions are based on the logics that are actually implemented in the on-demand food delivery scenario, as well as both in line with papers in the field (e.g., Seghezzi and Mangiaracina, 2021) and confirmed by the interviews.

The simulation has been approached by incremental steps, as illustrated in the following.

Sim 1.1 - one Ghost Kitchen vs 2 Delivery Restaurants (1 rider, 5 orders in the same block): in this case the comparison is between a Ghost Kitchen receiving 5 orders all coming from the same neighbourhood, delivered by one rider that aggregates the 5 orders, versus a network where the same orders are randomly placed to two Delivery Restaurant, still with one rider performing deliveries with batching.

Sim 1.2 - one Ghost Kitchen vs 3 Delivery Restaurants (1 rider, 5 orders in the same block), with the same criteria as Sim 1.1.

Sim 2.1 - one Ghost Kitchen vs 2 Delivery Restaurants (1 rider, 5 orders in random locations): the simulation case is the same as Sim 1.1, but with the orders coming from random locations (thus increasing the routing complexity).

Sim 3.1 - one Ghost Kitchen vs 20 Delivery Restaurants (multiple riders, 20 orders in random locations): the last case considers 20 orders delivered by 5 riders in the Ghost Kitchen Case (each rider aggregates a maximum of 4 orders); conversely, in the traditional they are delivered by one rider each without batching in the Delivery Restaurant (as it typically happens in reality).

The performance results are evaluated in terms of:

- Total Travel Distance (km): Total distance travelled by the rider(s) to complete the delivery trip, from the rider point of origin (PoO), to the delivery of the last order at the point of destination (PoD).
- Total Travel Time (min): Total time spent by the rider(s) cycling (stop time excluded).
- Total Delivery Time (min): Total time spent by the rider(s) to complete the delivery trip, from the moment he/she leaves the PoO to the moment the last order is delivered (stop time included).
- Delivery Time (min): Time spent by the rider to complete the delivery trip, from the first pick-up point to the delivery of the last order (stop time included). This metric is used in few cases to offset the effect of the different initial Rider PoO - Pick-up Point path.
- Total Travel Time order X delivered: Total time order X takes to be delivered to the PoD, starting from the pick-up.

The algorithm applied when selecting the routing is the shortest path tree Dijkstra's algorithm, applied to travel times. Only in the Sim 2.1, for the Delivery Restaurant case with batching allowed, it was chosen to discard the shortest path tree in favor to the path minimizing the orders travel time, in order to be able to respect the 35 minutes delivery time-constraint from the restaurant to the final PoD.

The key results obtained through the simulations (summarised in Figure 5) allow to derive some insights about how performances change when replacing a traditional network of restaurants with a Ghost Kitchen-based network.

- the batching policy strongly impacts the delivery performances; in the case where batching is applied, the results are 10-20% better if compared to the same case without batching.

- The total distance travelled by the riders when substituting a network of Restaurants with a Ghost Kitchen is lower, since either the number of pick-up points decreases (batching case), or the number of riders increases (no batching case). In general, the reduction in distance varies from around 10-20% (when both the solutions apply batching) up to 40% (if there is no batching in the traditional case).
- The reduction in the travelled distance for the Ghost Kitchen case varies from 15-30% (when both the solutions apply batching), up to 40% (if there is no batching in the traditional case).
- Also the total delivery time, which is the parameter affecting costs the most, is reduced by 15-30% (when both the solutions apply batching), or 40% (if there is no batching in the traditional case).

		N° of Riders	N° of Orders	N° of Pick-up Points	N° of PoD	Total Travel Distance		Total Travel Time		Total Delivery Time		Delivery Time	
Sim 1.1	Ghost Kitchen	1	5	1	1	4,16 km	5,83%	16,13 min	29,08%	22,13 min	30,29%	13,52 €	36,14%
	Delivery Restaurant	1	5	2	1	4,42 km		22,75 min		31,75 min		21,17 €	
Sim 1.2	Ghost Kitchen	1	5	1	1	4,47 km	-2,36%	20,27 min	29,47%	26,27 min	35,52%	17,27 min	51,18%
	Delivery Restaurant	1	5	3	1	4,37 km		28,73 min		40,73 min		35,37 min	
Sim 2.1	Ghost Kitchen	1	5	1	5	7,19 km	19,88%	35,53 min	15,56%	53,53 min	15,14%	46,23 min	19,80%
	Delivery Restaurant	1	5	2	5	8,97 km		42,08 min		63,08 min		57,65 min	
Sim 3.1	Ghost Kitchen	5	20	1	20	28,72 km	47,25%	142,48 min	42,87%	217,48 min	41,13%		
	Delivery Restaurant	20	20	20	20	54,45 km		249,4 min		369,4 min			

Fig. 5. Simulation results

These results have been then turned into an economic evaluation of the costs of the two options for each simulation, by assuming a 12.5€ average hourly cost for the rider, based on the collective agreement for Italy between AssoDelivery and UGL (Unione Generale del Lavoro). Still, the results confirms the previous considerations, given that the cost was calculated based on the total delivery time (Figure 6).

		Hourly wage	N° of Riders	N° of Orders	Total Delivery Time	Total Cost	Cost per Order	Improvement with Ghost Kitchen
Sim 1.1	Ghost Kitchen	12,5€/h	1	5	22,13	4,61 €	0,92 €	30,30%
	Delivery Restaurant		1	5	31,75	6,61 €	1,32 €	
Sim 1.2	Ghost Kitchen	12,5€/h	1	5	26,27	5,47 €	1,09 €	35,50%
	Delivery Restaurant		1	5	40,73	8,49 €	1,70 €	
Sim 2.1	Ghost Kitchen	12,5€/h	1	5	53,53	11,15 €	2,23 €	15,14%
	Delivery Restaurant		1	5	63,08	13,14 €	2,63 €	
Sim 3.1	Ghost Kitchen	12,5€/h	5	20	217,48	45,31 €	2,27 €	41,13%
	Delivery Restaurant		20	20	369,4	76,96 €	3,85 €	

Fig. 6. Economic analysis

V. Delivery Kitchen Logistics Performances

In addition to the displayed results, a more complete set of Key Performance Indicators, aimed to inspect different aspects of the business, was created in collaboration with the interviewed expert. As a matter of fact, the manager highlighted the importance of a more comprehensive evaluation of the different Kitchen for Delivery configurations from a qualitative perspective. The defined indicators may be clustered into two main groups: cost-related and time-related.

Considering costs, they are: avg. number of orders per day, avg. order dimension/amount per order, avg. cost per order, avg. number of orders per delivery trip. Considering Time, they are: order cycle time, avg. travel time/distance per order.

Since the four business models can take place in real companies in slightly different ways, the most general case is considered for the evaluation:

I. Ghost Kitchen: kitchen space dedicated to the production of many virtual brands under the same company;

II. Dark Kitchen: proprietary virtual brand served through a restaurant kitchen;

III. Cloud Kitchen: rent space with different virtual brands under different owners;

IV. Traditional Model: single restaurant that provides the takeaway/delivery option.

The outcome of this quantitative analysis are summarized in Figure 7 and discussed in Table 1 (which first presents the analysed dimensions, and then discusses how each of them varies in the different models).

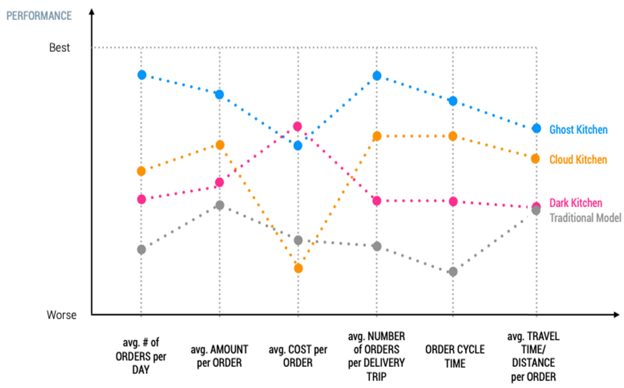

Fig. 7. KPIs

avg. number of orders per day	The higher the number of orders the kitchen receives, the better the performances.	
	I	*Ghost Kitchen*: this model allows to serve a high number of brands from the same kitchen, through an optimization of the whole process.
	II	*Cloud Kitchen*: this model exploits a rented kitchen, optimized for delivery, in a commissary space, but allows to serve a lower number of brands than a ghost kitchen from each kitchen.
	III	*Dark Kitchen*: it serves only one virtual brand, through a dedicated space in the kitchen of a single restaurant, to avoid congestions.
	IV	*Traditional Model*: Food dedicated to the online business is prepared in the kitchen of the restaurant.

KPI		Discussion
avg. Order dimension		The higher the dimension of the orders, the better the performances.
	I	*Ghost Kitchen*: if the ghost kitchen allows the customer to order from more than one of their brands in the same order, the dimension of orders can significantly increase.
	II	*Cloud Kitchen*: to increase the order dimension, the single brands may exploit the marketing support of the cloud kitchen, together with advertising through aggregators, offered in terms of "combined" menus.
	III	*Dark Kitchen*: to increase the order dimension, the single brands may exploit advertising through aggregators, as well as "combined" menus and offers.
	IV	*Traditional Model*: here the marketing effort is made through traditional channels and offers, together with the direct customer interaction during the order (and thus it is typically the least effective case).
avg. cost per order		The lower the average cost per order, the better the overall economic performances of the company.
	I	*Ghost Kitchen*: through the provision of multiple bands, the company can define the menu to optimize ingredients and wastes.
	II	*Cloud Kitchen*: the rent of the space decreases the fixed costs, but it is still expensive. Nonetheless, the space is optimized for cooking for delivery, and in some cases the cloud kitchen is able to reduce expenses (marketing, but also supply).
	III	*Dark Kitchen*: the space is optimized for delivery; the costs are those of a traditional restaurant and may be optimized by providing also home delivery.
	IV	*Traditional Model*: the space is not optimized for delivery, so the number of orders that can be managed is lower.
avg. number of orders per delivery trip		This indicator is significant for delivery providers or for kitchens that serve customers with proprietary fleet: the higher this number, the lower the cost associated with a single order (as the overall cost of the tour may be allocated to a higher number of deliveries).
	I	*Ghost Kitchen*: given the high number of brands serving from the same kitchen, it is possible to aggregate orders from a high number of virtual brands.
	II	*Cloud Kitchen*: the number of kitchens in the same hub depends on the available space, but the riders can anyway collect more orders at the same time.
	III	*Dark Kitchen*: the possibility to aggregate orders is real only if the number of orders is significant.
	IV	*Traditional Model*: aggregation is possible only with a high number of orders.
order cycle time		The shorter the order cycle time, the faster the delivery time seen by the customer, and thus the better the service.
	I	*Ghost Kitchen*: cooking operations are optimized.
	II	*Cloud Kitchen*: also in cloud kitchens, cooking operations are optimized, even if less than for ghost kitchens.
	III	*Dark Kitchen*: also in dark kitchens, cooking operations are optimized, even if less than for dark kitchens.
	IV	*Traditional Model*: the cooking happens together with the cooking operations of the restaurant.
avg. travel time/distance per order		This indicator is significant since it affects costs, and so the lower the better.
	I	*Ghost Kitchen*: the possibility of aggregation reduces travel time and distance when batching a high number of orders.
	II	*Cloud Kitchen*: overall the orders per day are fewer than they are in the ghost kitchen case, but there is still the possibility to aggregate orders (accordingly reducing travel time and distance).
	III	*Dark Kitchen*: orders could be enough to apply batching from the dark kitchen or batching with multiple restaurants through aggregator.
	IV	*Traditional Model*: it often happens that orders are not sufficient to apply batching, and thus single order delivery is needed

Table 1: Discussion of KPIs

The Dark Kitchen is typically chosen in two cases: first, if a restaurant owner wants to exploit the excess capacity in the kitchen (in terms of space and employees) to provide home delivery under the restaurant brand or under a new virtual brand. Second, if an entrepreneur wants to enter the on-demand food delivery business with an innovative virtual brand, or to reach a new delivery area with an already existing brand, renting a portion of the kitchen space to cook for this brand. In both the cases, the Dark Kitchen could be a definitive option, or just a temporary one, used to pivot the business idea or to test a new area of the city.

Considering the Cloud Kitchen, it works as a sort of incubator. Brands deciding to join pay a (typically monthly) fee in order to have the possibility to work in a kitchen space that is optimized for the delivery, and equipped with the needed appliances and utensils. The Cloud Kitchen company also generally provides support in marketing and, in some cases, also in procurement (for both food and packaging), thus enabling cost reduction for the single brands thanks to economies of scale. Renting a space in a Cloud Kitchen is accordingly the best solution for new entrants in the market, which need support for activities that go beyond the cooking, as well as for brands that are no longer able to satisfy the demand through a Dark Kitchen. This solution usually comes at a higher cost than Dark Kitchens, and so the amount of daily orders needed to optimize costs is higher. Nonetheless, by aggregating many brands in a single point of origin, the batching and the delivery are more efficient (and thus cheaper).

Finally, the Ghost Kitchen is a sort of all-encompassing model, combining the advantages of the two previous solutions, but also the increasing costs of initial investment and running the business for the company. It is composed by a larger kitchen (around 100m2), whose dimension is justified only by the management of several brands (even up to 30) or by a massive order production from an establish brand (e.g. in given areas McDonald's opted for serving customers through these kitchens, not being able to fulfil the request through traditional restaurants anymore). The advantage when providing multiple brands is that procurement and waste management can be optimized by studying the menu in such a way that the same ingredients are used in multiple meals, thus reducing the demand variability. The number of workers is higher than it is in the other models, in order to be able to serve an higher demand. Even for this solution, aggregating multiple orders in a single point of origin allows to reduce delivery costs.

Based on the above, it is not possible to identify a single "best" model, while the different configurations may better suite specific situations. Nonetheless, all of them allow for the improvement of logistics performances if compared to the traditional network made by restaurants.

VI. CONCLUSIONS

The present research reached the proposed objective by (i) identifying and clarifying the definition of the different business models, (ii) evaluating the performances associated to the different solutions, by initially focusing on the distribution network trough simulations, and subsequently (iii) identifying and qualitatively evaluating the key performances in terms of both costs (average number of orders per day, average order dimension, average cost per order, average number of orders per delivery trip) and Time (order cycle time, average travel time/distance per order), as well as discussing the factors that push toward the selection of a model rather than other one.

This work has some limitations, which suggest directions for future research developments. First, the small scale considered in the simulation: the number of orders, riders and restaurants considered in the experiment is limited, and further works could be aimed at increasing them. The same applies to the number of implemented simulations, which was driven by limitations in the used software. Second, the type of simulation: while the used simulation is static, it would be interesting to analyze how the outcome could vary considering the dynamic component of the model. Third, the fixed maximum delivery time: the maximum time frame within which an order needs to be delivered was set to 35 minutes, but other experiments could be made varying this value depending on the type of food. Fourth, the transportation mean: the hypothesis was that riders were driving a classical bicycle, and further works could include also motorcycles as well as riders moving by car.

To conclude, one additional result of the present research, which is particularly interesting for the managerial community, consists in two suggestions that could be applied to current distribution network, derived analyzing and discussing the outcomes of the simulations with practitioners. On the one hand, the batching policy. As shown, batching orders is advantageous for the distribution network, in particular when delivering meals that do not have any particular constraints for delivery (e.g. cold food such as sushi). The possibility to aggregate orders or to visit multiple pick-up and delivery points during a single delivery trip of the same rider allows to reduce travel distances and times, together with costs. Many aggregators do not apply any batching policy, or at least they do not fully exploit its potentialities. A second point regards riders that come to a Restaurant or to a Ghost Kitchen: when riders reach the pick-up point, they are already assigned to the orders, and in case the order is not ready on time (due, for instance, to kitchen congestion) they have to wait before collecting their order. A simpler and more efficient approach could be the "first come, first served" approach, with the first rider reaching the kitchen assigned to the first order ready for delivery. This would allow to reduce the waiting time for both riders and customers, also avoiding congestions and noise on the public land in front of the restaurant.

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