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Optimization based on Innovative Models for Online Food Delivery and Supply Chain Management

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Abstract

The demand for home food delivery services has spread since 2010, but only as a result of the pandemic wave due to COVID-19 and the related restrictive measures of lockdown and distancing imposed by public authorities, has there been a real behavioural change in consumption patterns. The rapid digital transformation that has affected, among others, the food delivery sector has brought out the need to analyse the business models present on the market and identify the main Key Performance Indicators that influence the choice of adoption by the user. Therefore, after a careful review of the available literature, this paper aims to develop an algorithmic simulation model that contemplates the minimization of delivery times and costs. The optimization of the food delivery service, in addition to ensuring higher profit margins for the service company, guarantees a better customer experience for the user.

Keywords: Food Delivery; Modeling & Simulation, Machine Learning

1. Introduction

As of 2010, e-commerce and business to consumer (B2C) services have been continuously expanding across all sectors. However, only in the last 4 years has there been an unprecedented revolution in global economic activity, driven by different factors both environmental, such as the COVID-19 pandemic, and process, such as the combination of business innovation, strategy, and new technologies. The choice of many economic sectors has been to digitize and outsource different parts of their value chain, to focus exclusively on their core business and ensure that high levels of productivity are maintained (Alvarez-Palau et al. 2022). In particular, this attitude has spread in the restaurant sector, where the incorporation of information and communication technologies (ICT) has marked a turning point in the relationship between restaurant and customer. The growing popularity of home delivery applications has led to a significant growth in the demand for home meal delivery which, according to experts, is projected to reach $223.7 billion by 2027 (Simoni and Winkenbach, 2023).

The development of a new market, complementary to that of traditional catering, has allowed the entry into the market of new players, whose main ones are GrubHub, Doordash and Uber Eates in the United States, Swiggy and Zomato in India, Ele.me and Meituan in China, Deliveroo and Foodora in Europe.

The rapid digital transformation of economic activity is characterized by a frenetic pace of change and innovation, and it is at the same speed that consumers are adapting their consumption habits, for example by compensating for the lack of time necessary to prepare meals with the request for food directly at home. To be such, the behavioural change imposed by contemporary society must be accompanied not only by a development of transport networks and a predisposition to an ever-greater use of technology, but also by a re-evaluation of existing business models (Chotigo and Kadono, 2021). The two main models existing in the food delivery market correspond respectively to the choice of restaurants to internalize the home delivery service, which would remain under the control of the restaurant itself, or to entrust it to third party companies, specialized in logistics services. In the second case, it is the phenomenon also known as 'platformization of deliveries' (Bivona, 2022) and provides that, once a purchase order has been submitted to the application, riders who meet specific criteria, such as geographical proximity or a favourable status on the platform , are immediately notified: the first to respond receives the assignment of the service (Alvarez-Palau et al., 2022). The procedure consists in collecting the order at the restaurant and delivering it to the consumer's home (usually to be done within an hour), who bears the burden of shipping. Once the distribution is completed, the rider is ready to accept new orders. In exchange for his service, the rider receives a fixed fee for each delivery, while the delivery company charges the restaurant a fixed monthly fee.

Since these food delivery applications are constantly expanding in terms of number of users and geographical area served, many restaurants have invested in food delivery at least as much as they did in traditional business (Chotigo and Kadono, 2021).

Given this ever-growing trend, the issues addressed in this paper are the following: the first concerns the identification of the key factors that determine and influence customer satisfaction in relation to the use of food delivery services; the second aims to create a simulation model of the food delivery system in which, starting from the two Key Performance Indicators (KPIs) most determined by the analysis of the literature, we arrive at an optimization of the process (Bruzzone et al., 2007) in terms of customer satisfaction.

The rest of the document is divided with a section in which we proceed with the analysis of the available literature, a section that explains the methodology used to achieve the set objective, another section that analyses the results emerging from the simulation model. Finally, the last section sets out the main considerations and draws the conclusions of the paper.

2. Literature Review

The literature review aims to investigate the different approaches used to achieve the optimization of the delivery service and deepen the main KPIs related to the choice to adopt home food delivery services through food delivery applications.

The continuous change of the technological context makes obsolete part of the available literature, already sparse in itself. In addition, given the fact that the COVID-19 pandemic seems to have marked the turning point in food delivery, a thorough review of the most recent sources, deemed of most interest, is presented below.

Among the scientific researches considered, the one that has most investigated the issue relating to KPIs in the food delivery sector is the study conducted by Chotigo and Kadono (Chotigo and Kadono, 2021). The authors carried out a comparative analysis of the crucial factors that encouraged the use of food delivery applications before and after the pandemic in Thailand. The data collected indicates that user satisfaction is mainly influenced by the following aspects: price value, social influence, habit, trust, convenience, and application quality. Within the same line of research, Al Akasheh (Al Akasheh et al., 2022) propose to develop a systematic method capable of analysing and predicting the main KPIs on the supply side, through the classification of some KPIs already present in the literature and the regression analysis to determine other new ones. From this study emerged the following results: the cost for delivery, the difference between the estimated delivery time and the delivery time provided by Google Maps API, the relationship between delivery cost and distance traveled by the rider. On the other hand, according to the research conducted by Siddhartha and Doreswamy (Siddhartha and Doreswamy, 2022) the demand for food delivery is constantly focusing on the trade-off between on-time delivery for a better user experience and a lower cost per delivery, in order to increase profit margins. Similar results emerged in the research of Alvarez-Palau (Alvarez-Palau et al., 2022). The processing carried out on the data from the Glovo platform suggests a positive linear correlation between the waiting time and the cost of the delivery which reaches a coefficient of determination R^2 equal to 0.57 and a Pearson correlation index equal to 0.76, values sufficient to be able to assume the relationship as linear. In the paper produced by He (He et al., 2019) the optimization mode of the operational management of food delivery restaurants was investigated. The data analysis yielded a similar result to previous research: "when the respondents selected O2O takeaway ordering and delivery services, they mainly focused on two factors, waiting times and food quality"; the latter, however, cannot be taken into consideration because it is not a variable that is controlled by the food delivery company.

The results of a further qualitative study (Ray and Bala, 2021) focused on the issue of user-generated content to investigate the factors that influence the adoption of food delivery services, revealed that trust, price-benefits and app-interactions are the key elements on which the choice to rely on the food delivery service is based.

Finally, the latest scientific research (Wang, 2022) considered addresses the numerous challenges that counteract the rapid rise of food delivery platforms. The study in question is based on the construction of a tripartite evolutionary game model between platforms, restaurants, and consumers and on the analysis of factors that influence users' adhesion to a food delivery platform from the viewpoint of the expected benefit. The most influential parameters detected in this survey concern the ways to improve the quality of the service, in terms of fast delivery times.

Despite the lack of literature available on this topic, in most of the researchers analysed appear as determining factors in the choice of ordering food at home the variables waiting time and cost of delivery. For this reason, as shown in Figure 1, the simulation model described below is focused on the optimization of costs and delivery times.

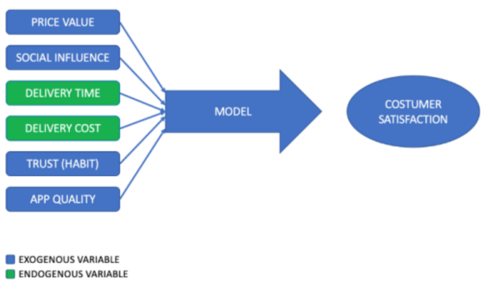

Figure 1

3. Model description

To achieve the objective based on the KPIs identified, a model has been adopted that allows to play on the variables to be introduced (priority, distance and means used). For this purpose, a mathematical algorithm is used that is able to satisfy the food delivery company in optimizing delivery times and costs, responding to the customer's need in terms of satisfaction.

The approach with the algorithm for finding the shortest route between two nodes, implemented with the k-NN regression for the search for customers closest to the current delivery, is also consistent with the need to identify, due to the selectivity of orders according to the distances to be traveled, the most suitable means of transport to use and the most convenient route to follow to carry out the service and reach the destination according to the criteria of previously established selectivity. It is shown below how this algorithm offers the answer to the need.

In the light of the literature on the subject and due to the limited possibilities of data, we intend to propose a simulation based on a simple algorithmic model that contemplates the delivery times and costs by a food delivery service company on behalf of a single restaurant (Bruzzone, et al., 2016).

It is considered that the company transports food products at home through bikes and electric scooters, introducing the 'green' element of environmental sustainability as a characterizing factor of the service. The goal is to optimize the process and analyze performances.

Starting from the location of the restaurant (called base), it is therefore intended to consider the achievement of customers in relation to the booking order, the distance of the customer from the base and the relative choice of means of transport, and the time needed to reach it.

The transport service provider has a certain number of vehicles (electric bikes and scooters) at its disposal to meet demand but must equip itself with a suitable tool to achieve its optimization objectives. To facilitate the scenario, it is imagined that the restaurant receives and organizes orders in relation to established territorial areas.

To finalize the study, we build a rules-based model created with the Python programming language, in which for each order received a priority-based on-demand is established (Siddhartha and Doreswamy, 2022) and an eligibility of subsequent orders identifying the shortest path for delivery.

We identify an area of interest for the transport of food to customers and imagine creating an annular surface of radius r within which the delivery is made by riders by bike. Otherwise, orders are fulfilled with the use of scooters.

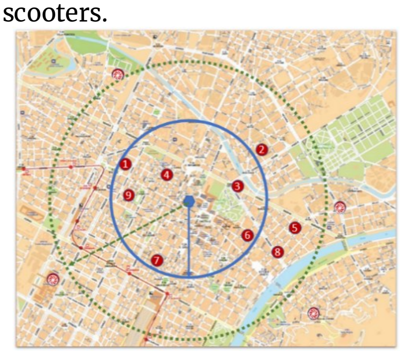

Figure 2

A simulation model is by its nature error-prone and limited in time compared to reality. The algorithm to achieve the desired objectives is by its nature subject to hypotheses, assumptions, limits or constraints due to its peculiarities and also to the available resources.

Since we do not first have a database from which to draw information relating to the locations of customers and the distances between them and from the base, we have the constraint that this data is obtained randomly. Furthermore, the constraint due to the limited capacity of the number of vectors (resources) have also to be considered, which results in setting a value to the number of nodes and connections between them.

There are therefore some initial assumptions to take into account. To differentiate the two types of carriers used, we established a maximum distance of action for deliveries with the bike. Furthermore, considering the constraint of the number of riders available (and therefore the containment of costs), the possibility of making multiple deliveries (but still limited in number) for each individual rider are contemplated. In addition, the nodes and their random connections have assigned values and a selectivity is established based on the priority and position of the first order (Dijkstra, 1959) and the subsequent ones, to be defined with reference to the distance from the base and belonging to the same proximity group (eligibility cluster). However, it is possible that during the execution of the program, further useful or necessary parameters for its implementation are contemplated.

3.1. Shortest path and classification

Once the libraries and sources are imported, we create the classes of nodes (vertices), arcs and graphs, returning the graph and its connection between the visited vertices (connected graph and strongly connected graph).

Since the data of the real distances of the potential customers from the starting point (base) are not known, in the absence of a database we imagine a random selection of customers by creating coordination nodes. To have a simulation map we assign a number of nodes and connections of the itinerary and create a graph that represents nodes and arcs (paths, itineraries, road or routes) connected randomly. We get a picture of the most strongly connected graph to which to associate customers. To obtain the shortest path in a weighted graph, which represents road networks, we use an algorithm capable of satisfying this need (Bruzzone et al. 2009).

A type of algorithm for this purpose was conceived in 1956 by computer scientist Edsger Wybe Dijkstra (Dijkstra, 1959; Hamilton, 2017; Frana, 2020). This algorithm exists in many variants. Dijkstra's original algorithm found the shortest path between two given nodes, but a more common variant fixes a single node as the 'source' node and finds shortest paths from the source to all other nodes in the graph, producing a shortest-path tree (Gass and Fu, 2013).

We define the algorithm to find the shortest path between two nodes which gives me the length of the route to follow to visit the nodes with the shortest path starting from the extraction of the Minimum element from the heap. We establish a maximum distance to travel by bicycle to identify the radius r nearest neighbour of the customer at the base and the relative circle which allows us to establish whether I reach it by bicycle or scooter. Thanks to the k-NN regression we identify the customers' orders that it's possible to satisfy (eligible customers), assigning a maximum number of nodes per delivery vector and indicating with [-1] if the delivery it's not supported by that means of transport. Now we are able to know the distances from the base and understand by which means of transport to fulfill the order.

At this point, we define the priority based on the order selectivity list (nodes' eligibility).

To know the shortest path referred to the first priority assigned according to Dijkstra's algorithm, we define the shortest nodes and costs. Once the shortest route has been identified, we use the k-NN regression algorithm to find the customers closest to the delivery and assign them to the 'current' delivery.

Various algorithms are used to create classification and regression models, including linear regression, logistic regression, SVM, Naive Bayes, Neural Network, decision tree and k-Nearest Neighbours. Since in Machine Learning (ML) there are no best models that surpass all the others (no free lunch) and the efficiency is based on the type of distribution of the training data (learning data distribution), this study limits itself to using the one considered most suitable for achieving the goal (Al Akasheh et al., 2022).

Compared to logistic regression, k-NN is a model that supports non-linear solutions and is one of the most used techniques in ML, while for example Neural Networks would require large training data. It is a non-parametric, supervised learning classifier, which uses proximity to make classifications or predictions about the grouping of an individual data point.

The rationale behind k-NN is to explore your neighbours, assume the test datapoint is similar to them, and derive the output; therefore, we look for k neighbours and arrive at the forecast. Since the average of the k closest data points is computed as the output, there is no training involved and during testing the k neighbours with minimum distance participate in the regression.

This model also has the advantage of being a simple model with few hyperparameters to adjust (the k value or how many neighbours participate in the algorithm and the distance function, where the most used similarity function is the Euclidean one), while a disadvantage could be that of a high computational cost during runtime if the sample size is large.

3.2. Optimization

To add new clients to the priority of the first client (priority of the first client and connected client nodes) we refer to the regression line using the k-NN regression algorithm, which contemplates the vertices that are closest to the drawn line (regression line) to reach the first customer respecting the shortest path.

Using the algorithm, we obtain a new list of customers to reach, updated according to the distance from the base and in close proximity to the identified regression line; moreover, we establish how many nodes should be involved for each individual rider, for example we decide that they shouldn't be more than three.

In Figure 3 is shown the scope of delivery to customers in relation to the regression line. In this case we are able to optimize delivery times and costs. We proceed by assigning the maximum number of deliveries to a single transport carrier with reference to the distances from the regression line.

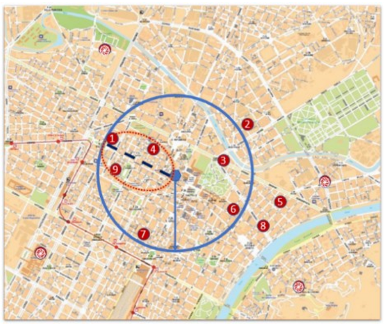

Figure 3

Then we continue with the creation of a new list of orders (with a new regression line) for a new rider, thus proceeding with the sorting of deliveries by bike among the various riders available in relation to the eligibility requirement of priority of orders over distances referred to the regression line.

By setting an average hourly travel speed, the regression algorithm provides its result. The same goes for delivery to customers further away (distances greater than radius r) for which the scooter is used, also assuming in this case an average hourly travel speed to obtain the total delivery time with reference to the orders placed by customers.

Ultimately, the delivery orders are satisfied according to the distance analysis and the distribution between the transport carriers. Since we have assigned a maximum number of orders to each carrier, a corrective factor is introduced on the random model - where even the orders assigned to the transport carrier are random - to standardize delivery costs.

4. Results and discussion

Any model created, even if it is as precise and complete as possible, is always an abstract representation of a process or an event and therefore it's not considered perfect in terms of certainty of results. In fact, there may be many unpredictable or unexpected variables (position or contingency factor) for which it may be necessary to introduce some corrective parameters; in our example, traffic, weather conditions, an unexpected event or an accident could change the routes, waiting times and achievement of our goal.

In any case, the model allows the decision maker to predict possible scenarios in relation to the assumptions adopted, the variables assigned, and the outputs recorded.

It is therefore possible to obtain information on the use of carriers in relation to the assumption of the distance established for the choice of the means of transport to be used.

As already mentioned, if the data entered at the outset are fixed, known and real and not random (for example, with a distance database), the obtained results are static and don't change randomly.

The choice of random delivery provides different results on times and costs; in the example considered we identify the customers [1, 2, 3, 7, 12, 14] served by bike and the customers [4, 5, 6, 8, 9, 10, 11, 13] served by electric scooter. The results obtained in the simulation make it possible to evaluate the choices made and what optimization is achieved.

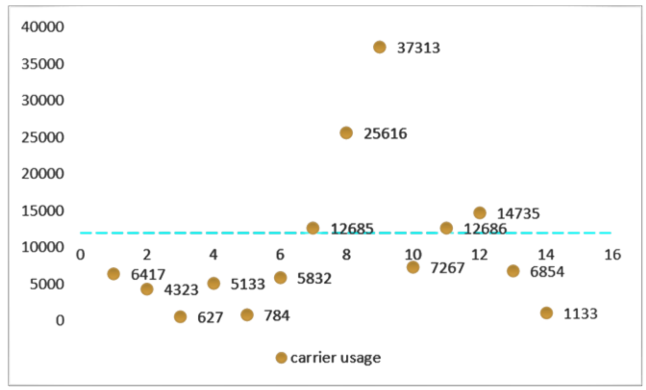

Figure 4

Analyzing the results through the lens of the KPIs identified in the introduction, we find a different response on delivery times and costs, offering an assessment on the lower consumption of resources. At the end of the food order, production and delivery process, it is possible to check the project output relating to customer satisfaction (CSAT) to understand the quality of the service offered by the company and identify any critical issues, weaknesses and strengths.

The latter analysis aims to improve customer satisfaction and increase customer loyalty. Furthermore, the consumer experience assessment allows companies to identify areas in which to concentrate efforts to improve the quality of service and make the entire delivery process more efficient. Since the food delivery sector is characterized by increasing competitiveness, the quality of the services offered helps the company not only to emerge, but also to stand out from competitors. In this perspective, it is necessary to formulate a balancing analysis of the internal and external benefits of the quality system (right time, low cost and price, customer satisfaction), compared to system costs.

CSAT is quantified with several metrics, which provide very valuable data and insights, even adding the brand reputation context, as described in Figure 5.

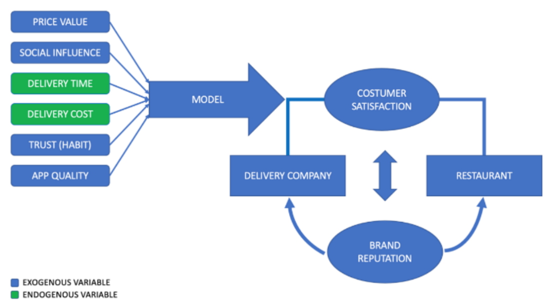

Figure 5

5. Conclusions

Considering an environmental context in which this kind of service was initially born in an almost pristine Blue Ocean, but which due to emerging competition is becoming a Red Ocean, customers to 'capture' or 'keep' become a survival element for the company (Kim and Mauborgne 2021).

In this perspective, the randomly identified customers represent the 'population' of the market or the 'competition' of the market, while the customers identified according to the assigned order of priority, depending on their proximity (regression) and distance from the base, represent a 'new market', generated thanks to a development of the research action on delivery to conquer - recalling Michael E. Porter - a competitive advantage in terms of cost reduction (cost leadership) and service differentiation (delivery differentiation), generating customer satisfaction (brand reputation).

This model - which is implemented by inserting parameters and variables relating to indicators of interest - is therefore a useful tool for the decision-maker to evaluate and adopt the strategy that best meets their needs, with the prospect of further enhancing and qualifying your own service.

In fact, the food delivery company tries to adopt a cost strategy by optimizing transport and not affecting the final price to the consumer and a strategy based on the service quality through the alternative of choosing the transport carrier to increase performances and better satisfy the customer. At the same time, it tries to stand out by offering a totally 'green' delivery service to stimulate the customer's environmental awareness.

The proposed research underlines how it is possible to create an optimization model based on priorities in the food delivery logistics services sector. Following a careful analysis of the available literature, it emerged that the main factors that stimulate the adoption of the take-away food service and improve customer satisfaction are waiting times and delivery costs, respectively. The developed algorithmic model makes it possible to identify the shortest route among those available according to the distance and assigns the order to the rider equipped with the most suitable means of transport (bikes or electric scooters) according to previously established selectivity criteria.

The limits deriving from the adoption of a simulation model consist in a rather abstract representation of the analysed process, in which some unpredictable or unexpected variables, such as traffic, are not taken into consideration. However, the analysis of the results obtained shows a different response on delivery times and costs, offering an evaluation of the choices adopted and the level of optimization achieved.

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