Use of agent-based simulation modeling in the vehicle selection process in the E-commerce industry

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ABSTRACT
In view of the significant increase in e-commerce in Brazil, in which the consumption of products has been consolidated thanks to expanded access to communication technologies, which have become more popular. In this context, there has been a growing concern about the resources used in the final phase of delivery (known as the "last mile") and the increased use of urban areas for the operation of delivery vehicles, making it imperative to search for new solutions to reduce the costs and impacts of the last mile. However, implementing and testing new projects to address these issues often comes with considerable costs. To mitigate these testing costs, professionals involved in last-mile logistics projects have begun to adopt simulation tools. Among these tools, agent-based simulation has been shown to be efficient in solving last-mile challenges. This is due to the variety of stakeholders involved in this complex landscape, including the local community, customers, carriers, stores, sales platforms, and more, each with their own goals and objectives. It is worth noting that the choice of the most suitable vehicle for each situation in the delivery system may vary. The paper in question uses agent-based simulation as a method to analyze the feasibility and performance of various types of vehicles used in the delivery of e-commerce products.

Keywords: E-commerce, Agent-based simulation, Delivery vehicles, Delivery locker.

1 INTRODUCTION

The COVID-19 pandemic has had a significant impact on the service sector worldwide due to the restrictions imposed to curb the spread of the virus and save lives. In this context, e-commerce has experienced a considerable increase in demand in Brazil, as well as in many parts of the world, with double-digit growth rates. This was driven by several factors. First, increasingly democratic access to communication technologies has allowed more people to shop online. In addition, the price difference between online products and those available in physical stores has encouraged even small businesses to expand their business to the virtual environment, which has resulted in a wide availability of products online. However, this increase in demand has also brought challenges, especially related to the final phase of delivery, known as the "last mile". Resources spent on the last mile and the impact on land use due to the operation of delivery vehicles have become growing concerns. Therefore, it is necessary to search for new solutions to minimize the costs and impacts associated with the last mile. In this context, research and development of more efficient delivery strategies, as well as the utilization of innovative technologies such as electric vehicles and more sustainable delivery methods, can play a key role in solving these challenges and promoting more responsible and sustainable e-commerce (ALVES, 2019).

As a result, there was an increase in the demand for e-commerce in Brazil, in addition to several other countries, especially in 2019, 2020 and 2021 due to the impacts generated by COVID-19, which led the decade 2011 to 2020 to be a turning point in the use of e-commerce, making it viable, because, with the Brazilian territorial extension, the expansion of e-commerce slowed down. E-commerce has the advantage over traditional means of commerce a wide variety of products with more affordable prices, giving consumers greater freedom of choice, however, e-commerce still has a large market to conquer within the Brazilian territory, waiting for its logistical problems to be solved (CRUZ, 2022).

During the covid-19 pandemic, e-commerce earned 7.385 trillion reais, values that far exceed the nominal GDP of many countries, which attracts the attention of authorities in several countries for the improvement of the transport system, in Brazil this revenue reaches 38.8 billion reais, achieving this result growing on average more than 20% per year, This demonstrates a global trend and also in the Brazilian territory. The main influence is the reach of 79.1% of the Brazilian population with internet (FARIAS, 2021).

With spending increasing in the final phase of delivery, companies have sought ways to reduce last-mile costs using technologies. One of these approaches is the implementation of delivery lockers, which aim to reduce the number of trips that companies need to make to complete a delivery, avoiding delivery failures by consumers. This, in turn, was resulting in an increase in the number of trips needed to make deliveries (ALVES, 2019).

To reduce operating costs, various delivery vehicle options are employed. However, assessing the impact of each vehicle individually can be costly. Therefore, it is common to resort to simulation to circumvent the costs associated with testing. This helps to make the choice of vehicle more reliable in terms of cost efficiency.

1.1 *WORK OBJECTIVES*

The purpose of this article is to understand how the various types of vehicles used in the transportation of e-commerce products in the central region of Belo Horizonte can adapt to the delivery system through "Delivery Lockers". As a specific objective, it is intended to:

- Collect data on the use of vehicles and delivery systems, in view of different demands and scenarios present in the bibliographies;

- Simulate according to data collected, possible delivery vehicles in the central region of Belo Horizonte-MG, Brazil;
- Compare the performance of vehicles considered monetary values and successful delivery efficiency;
- Evaluate the simulation results of the delivery system based on delivery lockers;

2 LITERATURE REVIEW

Articles from the Web of Science, Elsever and Google Scholar databases were searched with the terms simulation, agent-based, ecommerce and delivery lockers.

During the covid-19 pandemic, responsible for major impacts on the service sector, due to operating restrictions, in this scenario, the increase in the consumption of items through e-commerce was consolidated from the access to communication technologies that have been becoming popular, and due to the price difference between online items compared to items in local stores, This has led small businesses to sell their products online, which has also contributed to the offer of online products. One of the great uses of Agent-Based Modeling and Simulation (MSBA) is the simulation of the target audiences of a company that demonstrate in their behavior a great reaction to their own opinions, cultures, habits and many other variables that can be modified within the agent. As such, MSBA is ideal for the service industry. Seeking to measure the total distance traveled by agents, the time spent by them, and the number of successful orders in such scenarios. Among the simulated scenarios, there were scenarios that stood out with lower operating costs, where it was concluded that the best scenario for DL were scenarios that had a daily order rate of 480 orders, with a DL utilization of 45% and one with the exclusion of three delivery attempts (ALVES; PEAR TREE; LIMA, 2023).

In the vehicle selection process, there are several variables that need to be analyzed, however, such variables are not taken directly from the vehicle parameters, which in turn need to be tested, and evaluated according to the distance traveled, the number of deliveries made, among other variables, however, the vehicle testing process is costly due to the need to purchase the vehicle. To solve the best fleet of last-mile vehicles, agent-based simulation is used through the anylogic® program that improves the quality of the agents and the simulation, improving the simulated system. The feasibility of the use of conventional tricycles in the last mile can be confirmed through the use of agent-based simulation, using statistical techniques to improve the results, in an attempt to find the most environmentally healthy vehicle, and the importance of electric tricycles in reducing environmental impacts is concluded, but it is still possible to observe the increase in cost due to the cost of electric vehicles (AZAD et al., 2023).

Lyu es al. (2022) determines that in order to make use of discrete event simulation, it is necessary to program stakeholders in order to ensure the simulation quality of their interactions, in the cost analysis of a system, different routes and their certain activity costs can be tested in a last-mile merchandise delivery system, with a view to minimizing your costs, distance traveled, and delivery successes.

Simoni et al. (2020) determine which simulation scenarios are ideal to test situations in which this new scenario is applied, in the model in question, to the congestion situation and taken into account when simulating the effects, thus making it possible to analyze the effects of congestion on the type of delivery addressed, taking into account *crowdshipping* delivery models (delivery made by people who do not belong to the company), determining the cost of a fleet of vehicles or people who make use of public transport, in both cases people are heading to the delivery location. As a result, agent-based simulation proved to be efficient in the scenario study process.

According to Bell et al. (2023), when analyzing several methods of solving problems in the last mile, in order to find the best solution to the problem, the use of agent-based simulation to test several methodologies proved to be extremely efficient since it was possible to test it simultaneously, saving resources by analyzing the cost and delivery time from the use of a fleet with electric propulsion through simulation software Deterministic PTV VISUM, the results showed significant reductions in economic and ecological impact, as well as opportunities to improve the quality of life in the city.

According to Sawik et al. (2023), simulation processes that involve network optimization require the carriers' algorithms to be at the mercy of ensuring the shortest possible distance traveled by the vehicles, reducing the number of failures, the time required and the costs, making it possible to develop them in a more robust way, necessary for simulations in the e-code sector and evaluate demands, costs and revenues of the simulated system. The procedure uses an APL mathematical model integrated into a simulation framework optimized with IBM's CPLEX API for Java, due to compatibility with Java-based Anylogic® software, obtaining simulation results over the next 3 years.

The impact of the use of fast and flexible delivery strategy on the total cost of the e-commerce delivery system with the use of simulations through python software, seeking to analyze output variables related to environmental impacts through the distance traveled by the delivery vehicles where an increase in the distance traveled was observed as the number of fast delivery increased (NOGUEIRA et al., 2022).

Reiffer et al. (2021) evaluates the impact of last mile in the urban transport sector, with the use of simulation integrated optimization with the use of the software logo, in the delivery process delivery lockres were used to improve the delivery process, however, the practice of three attempts was used to predict a delivery scenario located in the city of Karsbruke in Germany. To reduce operating costs, 10% of the population was simulated treating the other portion of the population as equivalent and symmetrical.

Calabro et al. (2022) develop a new simulation model that compares two delivery methods, namely: home deliveries and the use of delivery and collection points, seeking more sustainable scenarios achieved through the variation of the amount of DL implemented in the delivery model. Thus producing a decrease in operating costs, failed deliveries and emission of polluting gases, the objective is to find a balance between the operator's cost, the quality of customer service and the environmental impact, considering design factors such as the density of Package Delivery Points (CDPs). It is implemented in the NetLogo programming environment and involves four types of agents: customers, delivery vehicles, packages, and CDPs. The main input parameters of the model relate to geometric aspects of the service area, characteristics of demand and supply, as well as the duration of the simulation.

Through the use of agent-based simulation, the use of drones for the process of delivering goods in the last mile, seeking to minimize the impact of carriers on local traffic, seeking to increase their fluidity by increasing the delivery rate for the delivery model. However, it was evident that the impacts on the reduction of environmental costs are considerable, as well as the reduction of congestion in the region, however, to make the use of drones for last-mile delivery, a network with distribution points closer to customers is needed to make the process more viable, making it necessary to have a larger number of customers per square meter (BALASSA et al., 2023).

Agent-based simulation is a dynamic simulation that influences the current situation of the models, making the model closer to the actual results of the future project. With the simulations, it is possible to understand how that society behaves and inhabits. The travel time can become longer with a greater number of vehicles on the road, with more dynamic models in the face of different options and decisions that can be made by a stakeholder (ALHO *et al.*, 2017).

Simulation models are efficient in aiding decision-making, since they are able to create predictions with a high reliability rate, deepening the simulation of variables related to the agents present in the media that interfere with the final agent.

3 METHODOLOGY

The current research is of the simulation type, as it aims to understand the behavior of different vehicles in relation to the delivery system "Delivery Lockers" in the surrounding region of the city of Belo Horizonte. This system will be approached in a dynamic way, which means that it will be represented at all times, with variables that behave continuously, that is, some variables change over time.

For the modeling of this simulation, the AnyLogic(R) software was used, which offers several advantages, including the ease of creating models of the agents that make up the system, allows the manipulation of these agents, and offers a user-friendly programming language based on JAVA, which focuses on object orientation. In addition, it offers the option of modeling through flowcharts, simplifying the modeling process, it also offers several features aimed at the interaction of agents in a dynamic system and considers a set of pre-programmed actions.

The truck simulation model also relies on a network search algorithm, being the nearest neighbor model that proves to be effective for the proposed simulation model. For the simulations, the scenario with a failure rate of 5% was selected, with a daily order volume of 240 daily orders and a DL deployment rate of 22.5%.

3.1 COST ANALYSIS

Based on the research of Alves (2019), we can define total production costs as the sum of costs that encompass expenses with operations. These costs can vary depending on the amount spent for each type of vehicle, including costs such as fuel, labor, outside expenses, lodging costs, and others. In summary, Alves' research provides a framework for calculating the total production costs related to different types of vehicles, considering factors such as fuel consumption, distance traveled, and fuel price. Equation 1 to calculate the total cost (Cc) is the result of multiplying the consumption per kilometer (Cc), the distance traveled (Dc) and the price of fuel (Pc).

$$Cc = Cc \times Dc \times P_c \quad (1)$$

The labor cost is defined based on the time spent by the employees (Cmb). The total cost of travel time is equal to the monthly income of the carriers (Es), and numbers of vehicles used (Nv), with the cost in relation to the time provided for in Equation 2 (ALVES, 2019).

$$C_{mb} = E_s \times N_v \quad (2)$$

The costs of another delivery (Cree) are calculated from the producer of the reshipment costs (Ge), failure quantity (Qf), and is represented by Equation 3 (ALVES, 2019).

$$Cree = Ge \times Q_f \quad (3)$$

The costs of hosting items in the DLs (Ghos) in Equation 4 is the production of the cost per unit stored (Cu) and the quantity of orders delivered through the DLs (Qpdl) (ALVES, 2019).

$$Ghos = Cu \times q_{pdl} \quad (4)$$

With this, the total cost becomes the sum of the costs found in the previous functions, so we have that the total cost is represented by Equation 5 (ALVES, 2019).

$$Ctotals = Ghos + Cree + Cmb + C_c \quad (5)$$

Variables used for costs are described in Table 1.

Table 1: Vehicle-Related Costs

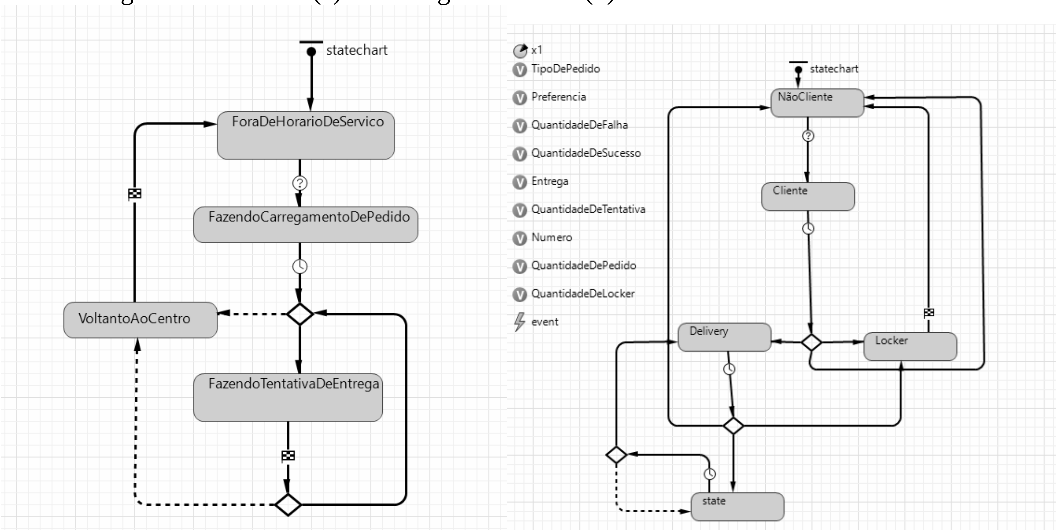
Costs	Value
Wage	R$4,000.00
Fuel price	R$5.51
Diesel price	R$5.84
Cost of energy	R$2.99

Source: The authors

3.2 SIMULATION MODELING

The modeling of the simulation was done in Anylogic(R), which brings as an advantage the ease in modeling the agents that compose it, anylogic(R) allows the manipulation of the agents, creating a neural network in a simple way, and a friendly programming language, based on JAVA (language that has its focus on the object), bringing an option of modeling through flowchart, facilitating the modeling process, so anylogic(R) has several features focused on the interaction of agents, on top of a dynamic system, considering a set of pre-programmed actions. The simulation model of the customers represented by Figure 1 (a) where the actions of the customers are shown to be quite simplistic, however, demonstrate the need for an individual simulation of each customer. With this, through simulation we can define from the process that the operating costs. Testing motorbikes and tricycles with different load capacities. Where the simulation model for the distributor is presented in Figure 1 (b).

Figure 1: Customer (a) on the right and truck (b) on the left simulation flowchart



Source: The authors

The distribution vehicle model needs to have in its components a load distribution model among customers so that it is efficient, being able to use the search model in graphs of the nearest neighbor. The customer agents must have a robust model of opinions capable of reacting to the change of scenario that occurs in the model, the distributor agent has as its main objective to prepare the cargo of the vehicles according to the capacity and need for delivery, the model of the city or simulation zone agent, involves must seek, bring all the variables that can help in decision making.

For the simulation, 7 vehicles were adopted, with different loads and displacement speed, where three scenarios were simulated with the vehicles in Table 2.

The truck simulation model also relies on a network search algorithm, being the nearest neighbor model that proves to be effective for the proposed simulation model. For the simulations, the scenario with a failure rate of 5% was selected, with a daily order volume of 240 daily orders and a DL deployment rate of 22.5%.

Table 2: Capacity of simulated vehicles

Vehicle	Maximum Load(Kg)
Mercedes-Benz Accelo 815	3000
Conventional Tricycles 1	300
Cargo Bikes 125 c	68

Source: Authors

The number of vehicles was determined and classified according to the total load and need, and the quantity of each vehicle is described in Table 3.

Table 3: Number of vehicles used in the simulation.

Number of vehicles	Truck	Tricycle 300p	Moto 125
Day	5	6	9
Night	2	2	2

Source: The authors

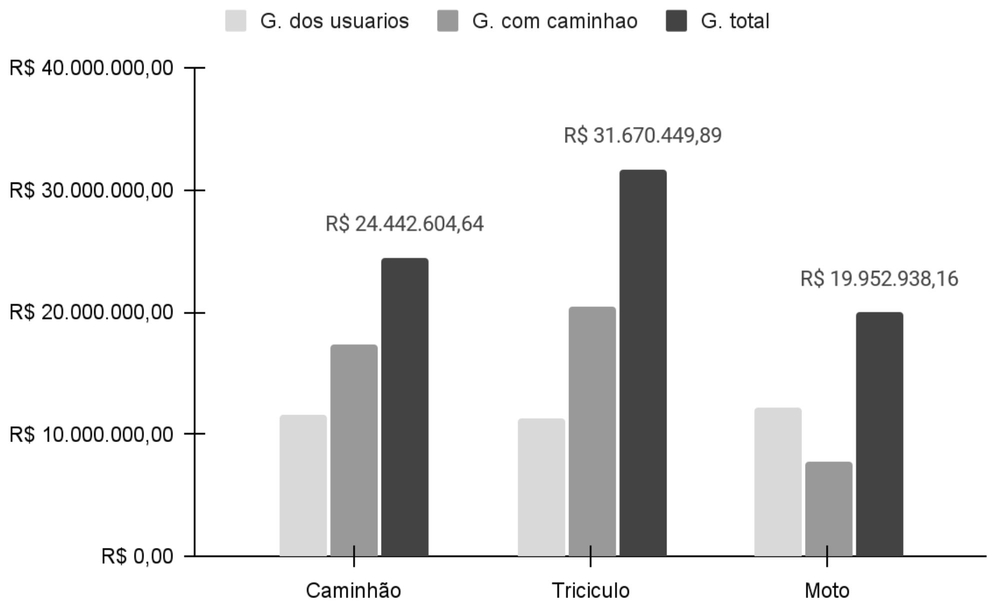
Vehicle speeds change as the type of vehicle changes, measures taken based on the benefit that each type of vehicle has. To compensate for the reduced or increased capacity, a larger number of vehicles was deployed so as not to occur a reduction in the total load capacity. For the simulations, the scenario with a failure rate of 5% was selected, with a volume of 240 daily orders and a delivery locker deployment rate of 22.5%. With a simulation made from the vehicles mentioned in Table 1.

4 RESULT

The simulation results point to a decrease in the total costs of the system, especially on the part of the company, when the model they use motorcycles to distribute products is adopted, but as the load capacity decreases, the vehicle becomes less ideal for deployment along with the implementation of DLs. However, night transport has as a villain a greater insecurity compared to the normal system.

We can see that when we adopt a scenario with a failure rate of 5%, with a daily order volume of 240 daily orders and a DL deployment rate of 22.5%, using the results of Figure 3 for the experiment, we can see that part of the costs that are passed on to the customer.

Figure 3: Cost of customers and delivery company



Source: The authors

The simulation results point to a simulation of the total costs of the system, mainly by the company, when the model they use motorcycles to distribute products is adopted, but as the load capacity decreases, the vehicle becomes less ideal for implementation along with the implementation of DLs, therefore, It is ideal in the operation of DLs the use of a secondary vehicle, for deliveries in DLs. This vehicle has a higher load capacity and operates at night, avoiding traffic and congestion. However, night transport has as its villain a greater insecurity compared to the normal system. Table 4 shows the distance traveled by customers and the carrier.

Table 4: Distance Traveled in Km by Customers and Carrier

Vehicles	Customer	Enterprise
Truck	28309.36	16178.45
Tricycle 150p	26606.99	121119.48
Moto 125	29586.38	50600.25

Source: The authors

The number of failed orders varies greatly according to the vehicles, according to Table 5, we can observe how much the type of vehicle interferes with the company's delivery capacity, being the number of deliveries made, the number of failed deliveries and the number of orders that customers had to pick up at the distribution center.

5 CONCLUSION

The simulations carried out revealed that as the load capacity of vehicles decreases, it becomes necessary to establish time windows to maintain the quality of deliveries. This is due to the need to return to the distribution center more frequently, not only for the drones, but also for the smaller vehicles, in order to optimize operating costs. For smaller vehicles, it is crucial to implement a denser distribution of delivery points, with a focus on serving the local public. However, this approach presents logistical challenges, considering the increase in the total distance traveled by the smaller vehicles.

It is worth noting that despite this increase in distance, smaller vehicles consume less fuel. Therefore, the delivery capacity must be balanced according to demand and planned in such a way as to allow all deliveries to be carried out within the service period of each delivery employee. The use of motorbikes has proven to be efficient in the delivery process, although there has been an increase in the number of delivery failures, due to the increase in demand. For future research, it is advisable to carry out tests in generic scenarios in order to explore a wide range of parameters that can indicate what are the requirements necessary for the viability of different types of delivery and vehicles. This would help create a literature base that describes the applications of models in diverse contexts. These models can later be extended to real-world scenarios, allowing the identification of the application limits of DL services. Some of the parameters that can be explored in future research include: Minimum orders, population density, failure rate, travel speed.

In addition, there is a clear need for research on the cost of offsetting carbon emissions. With the increasing focus on sustainability and environmental concerns, understanding the cost required to offset the carbon emissions associated with delivery services is critical. These surveys can provide valuable insights for the optimization and planning of delivery systems, contributing to the efficiency and sustainability of delivery operations in an ever-growing e-commerce context.

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