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THE IMPACTS OF THE PANDEMIC ON URBAN FREIGHT DELIVERIES: A CASE STUDY IN A BRAZILIAN CARRIER

Silva, K. O. A. N.[*]; Lima, R. S.[*] & Alves, R.[**]

[*] Industrial Engineering and Management Institute (IEPG), Federal University of Itajuba (UNIFEI), Itajuba, MG, Brazil

[**] Institute of Science, Technology and Innovation, Federal University of Lavras (UFLA), São Sebastião do Paraíso, MG, Brazil

E-Mail: kaique.silva@ifsudestemg.edu.br, rslima@unifei.edu.br, robertaalves@ufla.br

Abstract

The COVID-19 pandemic led to changes in shopping behaviour, resulting in higher than expected growth in e-commerce. All this influenced the expansion of freight transport in urban areas and had a significant impact on last-mile deliveries by carriers, whose demand increased significantly. The objective of this study was to analyse last-mile deliveries during the COVID-19 pandemic from the perspective of e-commerce freight carriers. This was done using a hybrid simulation model, i.e. discrete event simulation (DES) and agent-based simulation (ABS). An increase in the number of deliveries increased the number of kilometres travelled, fuel costs, CO_2 emissions, number of trips and vehicle utilisation. Comparative scenarios with delivery lockers are simulated, demonstrating improved operation for all simulated variables. The results of this study can be used to better plan e-commerce delivery operations during future pandemic events.

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Key Words: Simulation, E-Commerce, Last-Mile Delivery, Urban Cargo Transportation, COVID-19, Hybrid Simulation Model

1. INTRODUCTION

The COVID-19 pandemic, declared by the WHO for the beginning of 2020, has led to changes in shopping behaviour, resulting in the growth of e-commerce beyond expectations. All this has influenced the expansion of urban freight transport (UFT) and has had a significant impact on last-mile delivery by carriers, whose demand has increased significantly [1]. The adoption of the delivery system has been one of the main means found to guarantee the maintenance of organisations and to meet the needs of customers. However, this reality has created a number of logistical problems for transport companies, which have had to adapt their operations [2].

The global growth of e-commerce has been predicted at 20.7 % for the year 2020 [3], the pandemic of the new coronavirus has significantly increased this figure. According to a report by [4], in 2020, approximately 301 million e-commerce transactions will be carried out by more than 79.7 million people in Brazil alone. According to [5], there has been a 10-year growth in just 8 weeks, with over 60 % of global consumers stating that their shopping behaviour has changed during the pandemic [6]. In 2021, the same sector will reach a turnover of BRL 182.7 billion, a growth of 27 % compared to 2020, with growth in all Brazilian regions [7]. It is also predicted to reach BRL 6.54 trillion by 2022, indicating a sustained migration to online shopping [8].

This new reality posed challenges to business sectors that led to the bankruptcy of many companies and required the search for solutions that could guarantee or even mitigate these effects [9, 10]. The distribution channels of many industries have undergone structural, operational and performance changes [1, 2]. In this sense, understanding the effects of the COVID-19 pandemic in order to propose initiatives and mitigate these effects are crucial factors for the UFT sector.

The use of modelling and simulation (M&S) is an important tool for pandemic studies. Simulation models can be used to inform all decision-makers about the scale, impact and evolution of the pandemic, while they can also be designed and implemented to support public initiatives and responses to the pandemic [11]. These systems allow analyses to be carried out through comparative scenarios without interfering with the real system, and their use to study UFT systems has increased in recent years.

Some authors have attempted to analyse and understand the behaviour of e-commerce deliveries during the COVID-19 pandemic using M&S [1, 8-9]. However, it is noted that the literature is still in its infancy and more studies are needed to understand and measure the impact of the pandemic on e-commerce transport operations. As demand grows, there have been discussions among transport researchers and professionals about initiatives to deal with the increasing number of e-commerce goods deliveries [7, 9, 12].

In this study, we conduct a scenario analysis before and during the COVID-19 pandemic to understand the impact on last-mile e-commerce deliveries, using a hybrid simulation model (HSM), which is a combination of discrete event simulation (DES) and agent-based simulation (ABS). The scenarios were modelled from the history of deliveries in June 2019, 2020, and 2021, provided by a carrier in the city of São João Del Rei – MG, for comparison purposes. Finally, scenarios with the use of delivery lockers (DLs) were simulated and some indicators were analysed to verify the operational benefits for the carrier.

Planners, decision makers and delivery service providers can use the results of this analysis to gain some useful insights for better planning of e-commerce operations during future pandemic events. The paper is structured as follows: section 2 provides a literature review, section 3 details the development of the model, simulations and results, and discussion. Finally, the conclusion, limitations of the work and suggestions for future research are presented.

2. LITERATURE REVIEW

M&S refers to a computational model of a system of interest, which may be existing/realistic or imaginary/futuristic, and its execution occurs through a series of experiments designed to understand that system [13]. Its ability to replicate system behaviour and interactions between modelled components makes it an attractive tool for performance evaluation, inference or prediction [14]. As such, computational simulation can be broadly categorised as discrete event simulation (DES), system dynamics (SD), agent-based simulation (ABS), or a hybrid of these techniques (e.g. DES and SD, ABS and DES) [15]. Each simulation method is known to be effective for a specific set of problem types.

A DES model represents the system whose state changes at discrete points in time and estimates expected performance measures under uncertainty, whereas SD modelling is better suited to understanding the non-linear behaviour of complex systems using stocks and flows (often in conjunction with differential equations), especially when state changes occur continuously over time [9]. Compared to the two previous approaches, ABS is useful for modelling a system from the agent's point of view, allowing the modelling of heterogeneous and autonomous agents acting independently in the environment, as well as the emergence of self-organisation [7].

Hybrid Modelling and Simulation (HMS) refers to the combined use of discrete and continuous simulation approaches, such as SD, DES and ABS, in a single simulation study. This type of simulation makes use of interdisciplinary approaches, including interdisciplinary research paradigms, frameworks, methodologies, techniques and tools for one or more phases of a simulation study (e.g. conceptual modelling, model implementation, model execution, and model development scenarios) to produce the best possible representation of the system of interest. This type of simulation approach has attracted the interest of some researchers in recent years [1, 2, 12, 16]. Bae et al. [13] emphasised the importance of using HSM to model logistics systems, allowing researchers to model the particularities of a given system or systems that are difficult to analyse, which DES or ABS cannot do alone, and therefore through interdisciplinary approaches. These methods, when combined, lead to advantages in modelling logistics systems, more faithfully representing real systems and helping to evaluate initiatives for UFT [7].

Among the initiatives studied for the e-commerce UFT, the use of DLs has gained prominence in the literature. Suwatcharachaitiwong et al. [17] investigated the use of DLs in drug distribution through convenience stores to minimise operating costs using a genetic algorithm. Gonzalez-Varona et al. [18] proposed a B2C delivery model reusing old newspaper kiosks as DLs in Valladolid, Spain. Cardenas et al. [19] compared the costs of this initiative with assisted home deliveries. Melkonyan et al. [20] explored the sustainability potential of DLs through dynamic system simulation and multi-criteria decision making applied to a food network in Austria and found economic viability. More recently, Masteguim and Cunha [21] evaluated the use of pick-up points in the city of São Paulo and found that it is possible to achieve cost reductions in operations when considering this type of delivery.

There is a growing interest in the literature on issues related to DLs. However, it is not known what impact the implementation of this initiative can have on operators, although it has been successfully installed in several cities. We seek to investigate the benefits of using DLs, considering HSM as a technique to support the analysis.

3. METHODOLOGY

We modelled and simulated the scenarios following the steps proposed by [22, 23], which include three main phases: (i) identifying the system or problem situation, (ii) building a conceptual model, and (iii) building the computational model.

3.1 Problem formulation

The simulation is intended to support carrier-related decisions that take into account the impact of a COVID-19 pandemic. All modelling was based on data from the one operator that volunteered to participate in this study. The company is part of a franchise network that already has more than 500 units in about 5,000 communities in Brazil. The model was developed for São João Del Rei, MG, Brazil, for validation purposes, as this is where the selected operator concentrates most of its activities. However, we have developed a model that can be parameterised and adapted to different locations by adjusting the input parameters of the model.

3.2 Conceptual model

The model considered two agents interacting in an e-commerce delivery process: (i) carriers and (ii) customers. The simulations started with customers making e-commerce purchases and waiting for their orders at home. The carrier receives the ordered goods, usually transmitted via an e-commerce shop, processes them and then collects the orders.

The conceptual model (Fig. 1) was developed using Integrated Definition Methods – Simulation (IDEF-SIM) [15, 24, 25] and presented to a group of experts in the field of urban transport, including researchers and people responsible for delivery and routing processes for e-commerce carriers. According to the experts, the final conceptual model adequately represented the system. After validating the conceptual model, we proceeded to build the computational model.

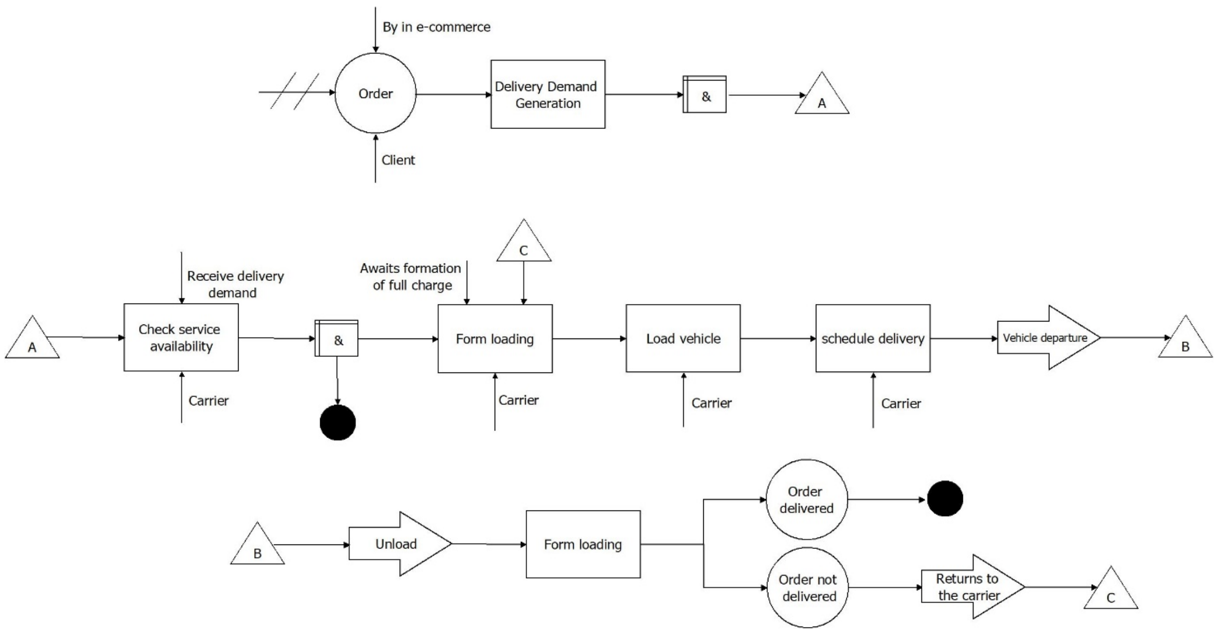

Figure 1: Conceptual model.

3.3 Simulation model

The model has been implemented using Anylogistix® (ALX). The software allows the creation of models to analyse and solve a wide range of supply chain management problems, enabling experiments to be carried out and analysis of results through a combination of simulation and optimization approaches. The proposed model is an HMS as it uses ABS and DES together. The agents, called customers, carry out the actions of initiating the demand and waiting for the delivery at home, interacting with the carrier by generating the demand for deliveries. The transport agent, on the other hand, receives the customer's request and starts its processes of load formation, loading the vehicle, listing the addresses to be visited and departure of the vehicle for delivery, during all working hours. DES is used to model changes in the state of the general environment, such as receiving demands and carrying out carrier delivery operations, which affect the system as a whole. ABS is used to model the individual behaviour of agents within this environment. Agents interact with each other and respond to discrete events simulated by DES. The software also includes a GIS (Geographic Information System) map. The model is provided by OpenStreetMap. This allows simulations to be run using geo-referenced environmental data, and can define and retrieve current locations on agent maps, and move agents at specified speeds from one location to another along existing routes [26, 27].

The verification and validation of the computational model was carried out in two steps, as suggested by [28]. First, the logic and elements of the computational model were compared with the logic and elements of the validated conceptual model. Then, in the second step, a validation experiment was performed in the simulation section to check the current scenario for data inconsistencies and to show the problems found in the validation view of the ALX layout. After verifying the computational model, we then validated the model. We used face-to-face validation, a widely used technique proposed by [22]. The simulation animations and results were presented to the managers of the e-commerce companies. Based on the animations we presented to them, they confirmed that the agents' actions and interactions were indeed consistent with real-life processes. Table I shows the input parameters of the model.

All input data in Table I were obtained from the carrier. In the implemented computational model, the carrier CD has a fixed location on the map. Customers were randomly created in each of the six main neighbourhoods of São João Del Rei and two districts, i.e. Rio das Mortes and Santa Cruz de Minas. Customer and demand modelling, taking into account the number of deliveries per day and the demand for deliveries before and during the pandemic.

Table I: Model input data.

Agent	Parameter	Value
Clients	Orders	Variable according to the scenarios.
	Location	Random
Carrier	No. of vehicles	2 (before the pandemic) and 3* (during the pandemic)
	Vehicle capacity	Lorry: 10 m^3 Fiorino: 7 m^3 Motorcycles: 2 m^3
	Speed	Normal (10; 20) km/h
	Delivery history	Variable according to the scenarios.
	Pollutant emissions	0.68 kg CO_2/km (Truck)
		0.21 kg CO_2/km (Pickup)
	Fuel costs	BRL 0.69/km (Truck)
		BRL 0.52/km (Pickup)
Requisites	Parcel weight	2 a 10 kg
	Volume	Triang (0.1; 1; 0.6) m^3

*Motorcycles were added during the 2020 scenario pandemic.

The carrier has 3 delivery vehicles, i.e. 1 lorry and 2 pick-ups. During the pandemic (scenario 2), a motorbike was added to the fleet to help with deliveries. This information, together with the load capacities and average speeds of the vehicles, was entered into the model. The Milk Run tool in ALX was used to manually schedule deliveries in each simulated scenario, reproducing the deliveries made by each company vehicle at each location according to the delivery schedule provided by the company. This tool allows you to reproduce the routes taken by the company's vehicles, taking into account your first in, first out delivery policy and truck loading. It is important to note that there has been no optimisation of the model's routes to reproduce the carrier's deliveries in each scenario. All this information and the interactions between the agents were modelled in tables in the software.

Modelling the links between the transporter and the customers and defining the transporter's transport policy so that the transporter's vehicles serve all customers. Emission factors were taken from a CETESB 2021 report. Fuel was modelled using diesel with an average price of BRL 4.50 per litre and an average km/l for each carrier vehicle. The model was limited to deliveries from Monday to Saturday, from 09:00 to 17:00.

After inputting the model data, four groups of scenarios were simulated. The first group of scenarios (A, B, C and D) simulated the deliveries made in 2019, 2020 and 2021, based on real data provided by the Carrier. For the sake of comparison, June was taken as the reference month for all scenarios. This is because June 2020 had the highest delivery peak during the pandemic, allowing a comparative analysis of the delivery impact under both the pandemic and non-pandemic scenarios in 2020.

Scenario A (2019) represents a non-pandemic scenario with 2160 deliveries. Scenarios B and C (2020 and 2021) represent pandemic scenarios with 4733 and 2655 deliveries respectively. Scenario D, represents a scenario for the year 2020, using a 20 % growth forecast for the e-commerce sector in the absence of a pandemic, for comparison with the other scenarios [3]. The second, third and fourth groups of scenarios (A2, B2, C2 and D2, A3, B3, C3 and D3, and A4, B4, C4 and D4) simulate situations in which the carrier uses DLs to deliver the goods through customer engagement, in order to evaluate the benefits of implementing this initiative. Fig. 2 shows the design logic of the scenarios.

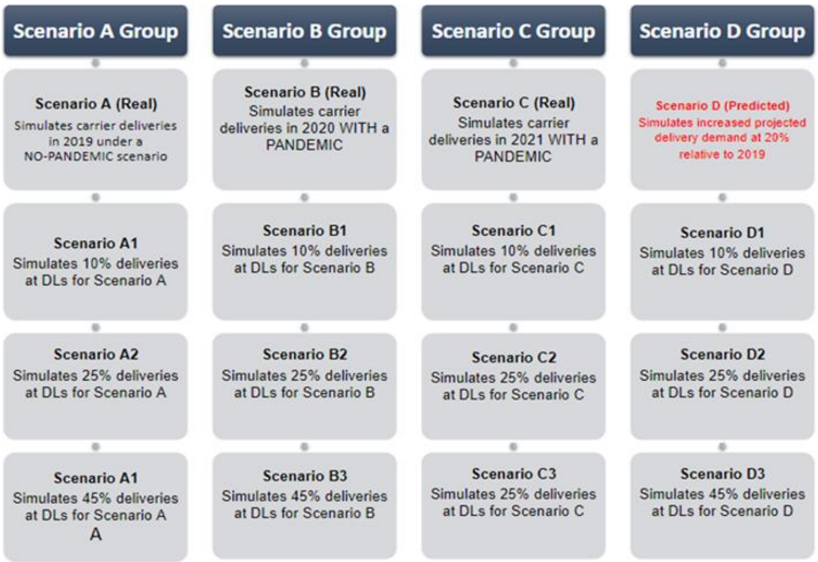

Figure 2: Design logic of the scenarios.

First we present the results and comparisons for Scenarios A, B, C and D. Then we present the results of the scenarios where DLs were used and analysed against each previous scenario for comparison. In all scenarios, the model outputs were kilometres travelled by carrier, transport volumes, fuel costs, vehicle occupancy rates, number of trips and CO_2 emissions. Finally, the results were used to calculate some indicators for analysis.

4. RESULTS

Ten replications were simulated for each scenario over one month. Table II shows the results of the simulation.

Table II: Simulation results.

	Real			Predicted
	Scenario A	Scenario B	Scenario C	Scenario D
Kilometres travelled (km)	4835.26	9959.24	6056.6	5965.56
Total volumes transported (m^3)	1226.60	2678.60	1511.10	1470.90
Fuel costs (BRL)	1497.74	2606.83	1961.31	1685.92
Number of trips	227	675	252	263
CO_2 emissions (kg)	1096.24	1544.49	1134.44	1206.88
Vehicle occupancy rate (%)	68	82	77	72

As validated by the carrier, it was observed that before the pandemic, the occupancy rate of its vehicles was around 60 % (Scenario A). However, due to the significant increase in demand for deliveries of more than 100 %, vehicles with a higher occupancy rate began to circulate to meet the deliveries (Scenario B). Fuel costs and the distance travelled to make deliveries also increased significantly during the pandemic, by more than 100 %. The significant increase in demand made it possible to take advantage of idle capacity in the fleet, and with the purchase of a motorcycle, the company was able to meet the daily delivery schedule within the expected timeframe, avoiding delays and rescheduling.

Comparing Scenario A with Scenario D, it was found that in the absence of the COVID-19 pandemic, the impact on vehicle kilometres travelled, volume transported, fuel expenditure, number of trips and CO_2 emissions would be higher by 23 %, 20 %, 13 %, 16 % and 10 % respectively. However, the increase in demand for deliveries would allow fleet utilisation to be increased from 68 % to 72 %. The occupancy rates for lorries in these scenarios remain at around 74 % and 80 % and for Fiorinos at 62 % and 67 % respectively. These results therefore indicate that, in the absence of a pandemic, the carrier could maintain its operations to meet demand without the need to acquire new vehicles, since there would be idle capacity in the fleet that could be used.

If we compare the impact of the pandemic in 2020, represented by Scenario B (which incorporates the real data) and Scenario D, which simulates what was expected for that year, we find that the volume transported increased by about 82 % and the number of vehicle kilometres travelled by 60 %. The number of trips doubled and emissions increased by about 30 % due to the increased demand. In order to meet the demand, the haulier included the use of a motorcycle to assist with deliveries in scenario B. The estimated vehicle utilisation increased from 72 % to 82 %. This increase is largely due to the use of motorcycles, which kept their utilisation rate at 100 % due to the increased demand and their low load capacity.

In 2021 (scenario C), the results confirm a decrease in the demand for deliveries compared to 2020 (scenario B). The distance travelled by vehicles and the volume transported decreased by about 37 % and 44 % respectively. The number of journeys was reduced by 63 %, leading to a reduction in fuel costs and emissions of around 30 %. The utilisation rate of the company's fleet was again lower and there was no need to use a motorcycle for deliveries. In this scenario (about 80 % for the truck and 93 % for the Fiorinos). Such results also confirm the findings of [28], who state that with the gradual resumption of face-to-face activities, the relaxation of non-pharmacological measures and the time spent at home, it is likely that once the pandemic is "over" (or becomes endemic, for example), some of this increase in demand for e-commerce will be reversed.

4.1 Simulation of scenarios with DLs an indicator analysis

Having analysed the first set of scenarios, we then simulated three further sets of scenarios to evaluate the use of DL during deliveries in the first four scenarios. This was done using the ALX Greenfield Analysis (GFA) environment. The GFA analysis is based on the centre of gravity method, which is a commonly used network design method for solving site (facility) installation problems, and was used here to indicate the best locations for installing DLs. The output of the analysis is approximate optimal locations for new facilities. Further information can be found in [14]. The number of DLs in the model was 5 per 100,000 inhabitants, which is common practice in places where these systems are already in operation [7]. As São João Del Rei has a population of around 90,000, 5 DLs were allocated between the installation sites for the set of customers served. Fig. 3 shows the GFA results for the DL locations.

With the proposed locations for the DLs, it was possible to maintain an average distance of 854 metres between the installation location and the group of customers served, and between the DLs and the carrier. With the lockers located and the analyses carried out, a further twelve scenarios were simulated to compare the benefits of the delivery operation. Factors of 10, 25 and 45 % were considered for the variation of deliveries in the DLs (Fig. 4).

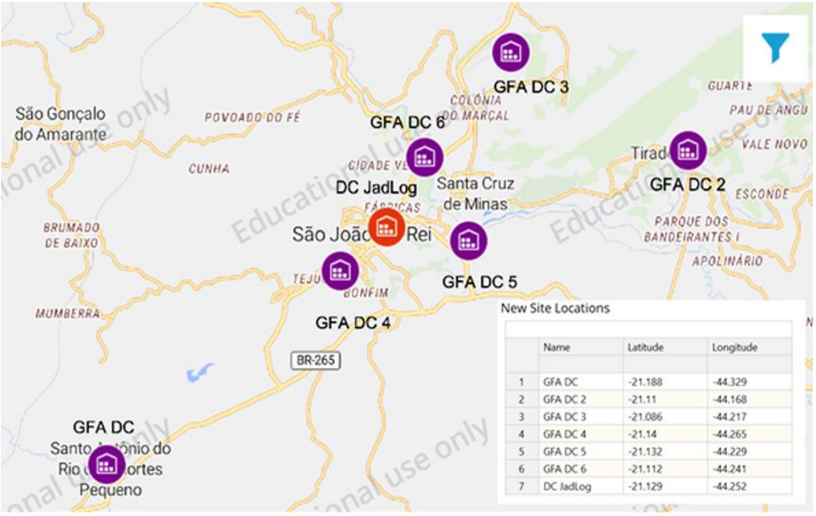

Figure 3: Locations to DLs (2 km).

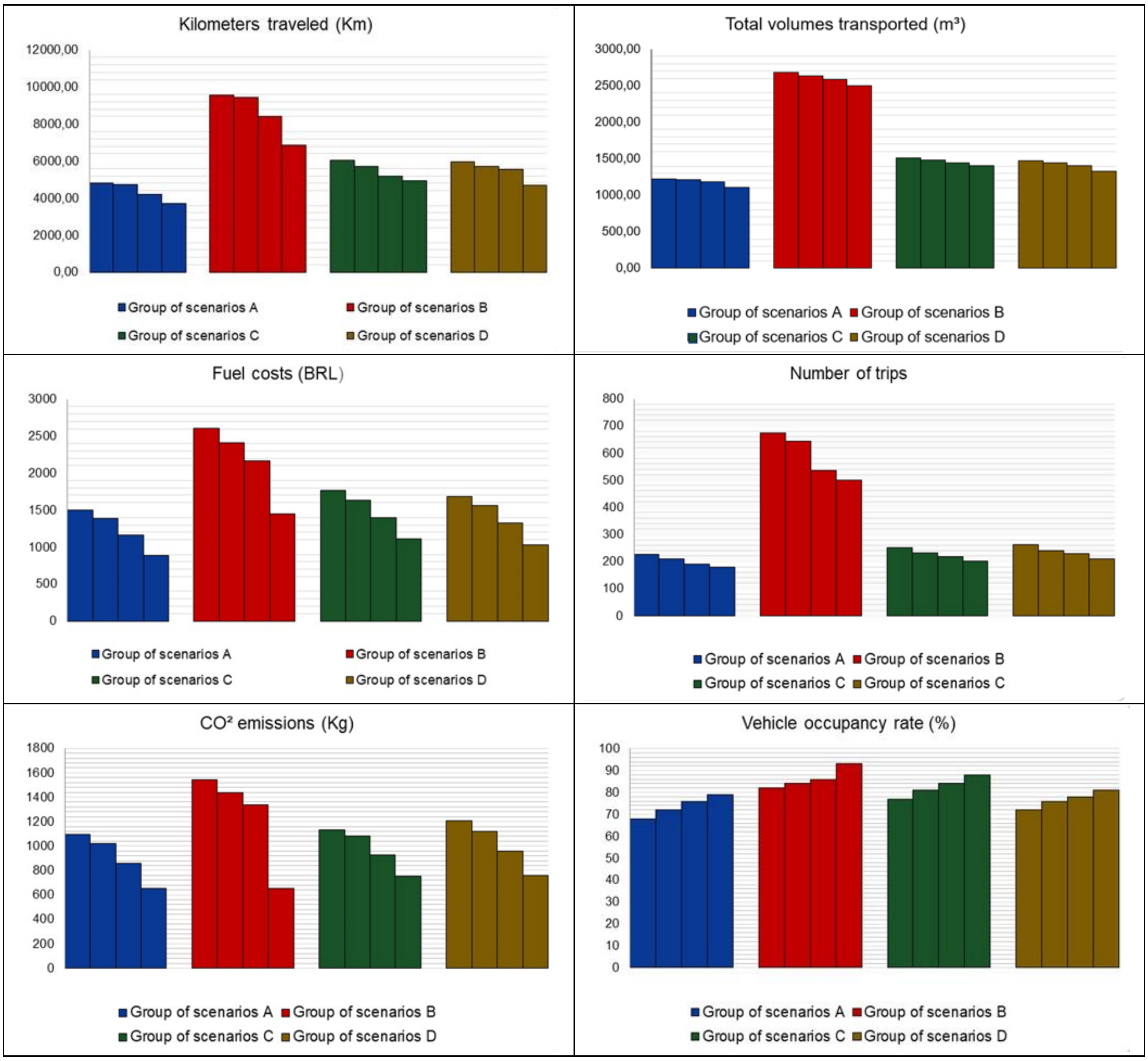

Figure 4: Scenarios comparison.

It can be observed that the scenarios simulating the use of DLs show gains for all related variables compared to scenarios without the use of DLs. This is particularly the case in the pandemic scenarios, where there is an increase in demand for supplies and a greater use of DLs. For the scenarios in group A (without pandemic), the use of DLs shows a reduction of up to 23 % in kilometres travelled, 10 % in volume transported due to the reduction in re-deliveries, 41 % in fuel costs, 21 % in number of trips, 41 % in CO_2 emissions and an improvement in vehicle utilisation from 68 % to 79 % compared to scenario A. These gains can be increased with greater use of DLs by customers, as observed in the groups of scenarios B, C and D.

To compare the benefits of using DLs in each group of scenarios in terms of items and volumes transported, CO_2 emissions, average cost per kilometre and transport productivity (Fig. 5).

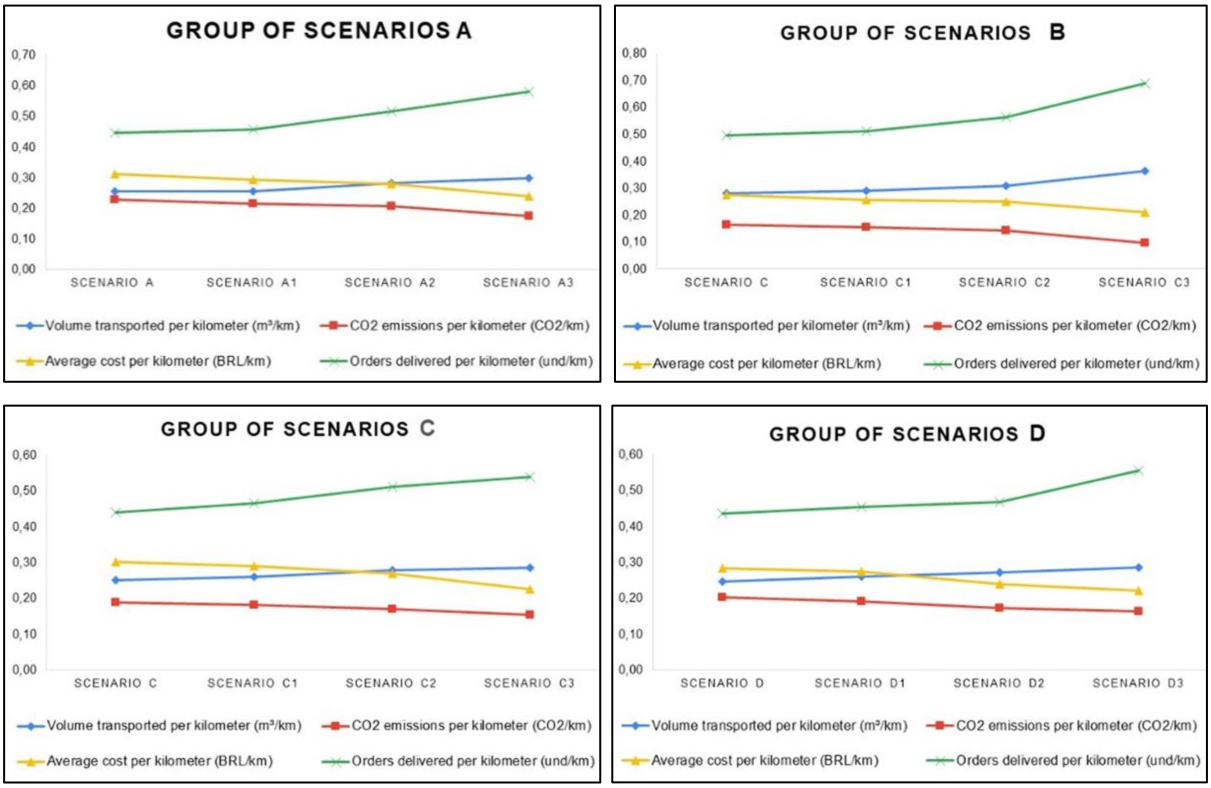

Figure 5: Indicator analysis.

We can see that the use of DLs resulted in gains in all simulated scenarios. These results highlight that DL deliveries bring benefits to carriers in terms of emissions, operations and improvement of the delivery process. Similar results were obtained in [7, 9, 28]. These changes will have a direct impact on vehicle flows on urban roads, improving urban mobility and reducing greenhouse gas emissions, thereby improving air quality indicators.

5. CONCLUSION

This article analyses the impact of pandemic last-mile e-commerce deliveries using Hybrid Simulation Models (HSMs). The model is comprehensive and has been implemented in Anylogistix®. Given the complexity of the system studied, the model was effective in generating coherent solutions that allowed us to represent different situations under different scenarios. The data for this study was collected during periods before and during the pandemic. This situation provides an ideal opportunity to analyse and investigate the use of DLs as initiatives to mitigate the impact on last-mile e-commerce deliveries.

The initial analysis simulated 4 scenarios and 3 real-world scenarios using data from one carrier, while 1 scenario considered 20 % growth projections relative to 2019, and a further 12 scenarios were simulated including the use of delivery lockers (DLs). The results showed that delivery demand increased significantly (in some cases doubling) due to the COVID-19 pandemic, resulting in increased delivery orders, kilometres driven, volumes transported, fuel costs, number of trips and CO_2 emissions. However, the significant increase in demand improved vehicle utilisation and consequently the company's logistics operations to meet demand.

The use of DL during the pandemic led to better results for all variables analysed in the simulation. When simulating scenarios with DL use, we observed that the greater the DL use, the greater the reduction in kilometres travelled, fuel costs, number of trips and CO_2 emissions. DL use also led to gains of up to 20 % in terms of volumes transported, orders, emissions and per kilometre. This results in full utilisation of freight capacity through better load consolidation and carrier direction, which could ultimately reduce the number of vehicles needed to make deliveries. The efficiency of this system can be further improved by encouraging more customers to use DL. Incentives for the use of DL need to be implemented, e.g. by reducing shipping/delivery costs. With regard to the pandemic, the use of DLs could reduce the negative effects of increased circulation of delivery vehicles in urban areas.

This article contributes to the scientific knowledge on the use of HSMs as a decision support tool applied to urban logistics. It is noteworthy that the framework presented here can be generalised to other cities and regions, since the agents studied follow the same rules as those modelled here, and since the GIS region can be easily changed, along with the input parameters that support the model. The main scientific contribution is the evaluation of an analytical model to assess e-commerce deliveries, highlighting the impact generated by the COVID-19 pandemic on transport companies through HSMs.

Our model was somewhat limited and future studies could consider delivery times to assess whether increased order numbers would have an impact on carriers in terms of overtime costs, for example. DL allocations could also be better explored, along with occupations. Despite these limitations, this study provides valuable insights, not only for current freight planning and policy making, but also for future studies on other new forms of transport services or other future pandemic events.

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REFERENCES

[1] Sawik, B.; Serrano-Hernandez, A.; Muro, A.; Faulin, J. (2022). Multi-criteria simulation optimization analysis of usage of automated parcel lockers: a practical approach, *Mathematics*, Vol. 10, No. 23, Paper 4423, 17 pages, doi:10.3390/math10234423

[2] De la Torre, R.; Corlu, C. G.; Faulin, J.; Onggo, B. S.; Juan, A. A. (2021). Simulation, optimization, and machine learning in sustainable transportation systems: models and applications, *Sustainability*, Vol. 13, No. 3, Paper 1551, 21 pages, doi:10.3390/su13031551

[3] Statista. Annual Retail E-commerce Sales Growth Worldwide from 2017 to 2023, from *https://www.statista.com/statistics/288487/forecast-of-global-b2c-e-commerce-growth/*, accessed on 19-03-2021

[4] G1 Economia. Com pandemia, comércio eletrônico tem salto em 2020 e dobra participação no varejo brasileiro, from *https://g1.globo.com/economia/noticia/2021/02/26/com-pandemia-comercio-eletronico-tem-salto-em-2020-e-dobra-participacao-no-varejo-brasileiro.ghtml*, accessed on 19-03-2021

[5] Fabius, V.; Kohli, S.; Timelin, B.; Veranen, S. M. How COVID-19 is changing consumer behavior – now and forever, from *https://www.mckinsey.com/industries/retail/our-insights/how-covid-19-is-changing-consumer-behavior-now-and-forever*, accessed on 22-08-2020

[6] Arora, N.; Charm, T.; Grimmelt, A.; Ortega, M.; Robinson, K.; Sexauer, C.; Staack, Y.; Whitehead, S.; Yamakawa, N. A global view of how consumer behavior is changing amid COVID-19, from *https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Marketing%20and%20Sales/Our%20Insights/A%20global%20view%20of%20how%20consumer%20behavior%20is%20changing%20amid%20COVID%2019/20200707/covid-19-global-consumer-sentiment-20200707.pdf*, accessed on 19-03-2021

[7] Alves, R.; Lima, R. S.; de Oliveira, L. K.; de Pinho, A. F. (2022). Conceptual framework for evaluating e-commerce deliveries using agent-based modelling and sensitivity analysis, *Sustainability*, Vol. 14, No. 23, Paper 15505, 18 pages, doi:10.3390/su142315505

[8] Rai, H. B.; Touami, S.; Dablanc, L. (2022). Autonomous e-commerce delivery in ordinary and exceptional circumstances: the French case, *Research in Transportation Business & Management*, Vol. 45, Part A, Paper 100774, 11 pages, doi:10.1016/j.rtbm.2021.100774

[9] Milewski, D.; Milewska, B. (2021). The energy efficiency of the last-mile in the e-commerce distribution in the context the COVID-19 pandemic, *Energies*, Vol. 14, No. 23, Paper 7863, 13 pages, doi:10.3390/en14237863

[10] Silva, K.; da Silva Lima, R.; Alves, R.; Yushimito, W. F.; Holguín-Veras, J. (2020). Freight and service parking needs in historical centers: a case study in São João Del Rei, Brazil, *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2674, No. 11, 352-366, doi:10.1177/0361198120943888

[11] Abudureheman, A.; Nilupaer, A. (2021). Optimization model design of cross-border e-commerce transportation path under the background of prevention and control of COVID-19 pneumonia, *Soft Computing*, Vol. 25, No. 18, 12007-12015, **Retracted** on 27-12-2022, doi:10.1007/s00500-021-05685-6

[12] Sakai, T.; Hara, Y.; Seshadri, R.; Alho, A. R.; Hasnine, M. S.; Jing, P.; Chua, Z.; Ben-Akiva, M. (2022). Household-based e-commerce demand modeling for an agent-based urban transportation simulation platform, *Transportation Planning and Technology*, Vol. 45, No. 2, 179-201, doi:10.1080/03081060.2022.2084397

[13] Bae, K.-H.; Mustafee, N.; Lazarova-Molnar, S.; Zheng, L. (2022). Hybrid modeling of collaborative freight transportation planning using agent-based simulation, auction-based mechanisms, and optimization, *Simulation*, Vol. 98, No. 9, 753-771, doi:10.1177/00375497221075614

[14] Ivanov, D. (2021). *Supply Chain Simulation and Optimization with any Logistix*, 5th edition, Berlin School of Economics and Law, Berlin

[15] Barbieri, J. P.; Pinho, A. F.; Montevechi, J. A. B. (2023). Autonomous entities: a hybrid model and its effects, *International Journal of Simulation Modelling*, Vol. 22, No. 2, 187-198, doi:10.2507/IJSIMM22-2-628

[16] Gutierrez-Franco, E.; Mejia-Argueta, C.; Rabelo, L. (2021). Data-driven methodology to support long-lasting logistics and decision making for urban last-mile operations, *Sustainability*, Vol. 13, No. 11, Paper 6230, 33 pages, doi:10.3390/su13116230

[17] Suwatcharachaitiwong, S.; Lin, C.-C.; Huang, W.; Hung, L.-P. (2020). On the medication distribution system for home health care through convenience stores, lockers, and home delivery, *Health Informatics Journal*, Vol. 26, No. 4, 3163-3183, doi:10.1177/1460458220936395

[18] Gonzalez-Varona, J. M.; Villafanez, F.; Acebes, F.; Redondo, A.; Poza, D. (2020). Reusing newspaper kiosks for last-mile delivery in urban areas, *Sustainability*, Vol. 12, No. 22, Paper 9770, 27 pages, doi:10.3390/su12229770

[19] Cardenas, I. D.; Dewulf, W.; Vanelslander, T.; Smet, C.; Beckers, J. (2017). The e-commerce parcel delivery market and the implications of home B2C deliveries vs. pick-up points, *International Journal of Transport Economics*, Vol. 44, No. 2, 235-256, doi:10.19272/201706702004

[20] Melkonyan, A.; Gruchmann, T.; Lohmar, F.; Kamath, V.; Spinler, S. (2020). Sustainability assessment of last-mile logistics and distribution strategies: the case of local food networks,

International Journal of Production Economics, Vol. 228, Paper 107746, 17 pages, doi:10.1016/j.ijpe.2020.107746

[21] Masteguim, R.; Cunha, C. B. (2022). An optimization-based approach to evaluate the operational and environmental impacts of pick-up points on e-commerce urban last-mile distribution: a case study in São Paulo, Brazil, *Sustainability*, Vol. 14, No. 14, Paper 8521, 24 pages, doi:10.3390/su14148521

[22] Sargent, R. G. (2013). Verification and validation of simulation models, *Journal of Simulation*, Vol. 7, No. 1, 12-24, doi:10.1057/jos.2012.20

[23] Huang, Q. L.; Wang, W. J.; Liang, X. J.; Xu, L.; Niu, X. Y.; Yang, X. Y. (2022). Last-mile delivery optimization considering the demand of market distribution methods: a case studies using Adaptive Large Neighborhood Search algorithm, *Advances in Production Engineering & Management*, Vol. 17, No. 3, 350-366, doi:10.14743/apem2022.3.441

[24] Lopes, H. L.; Lima, R. S.; Leal, F. (2020). Simulation project for logistics of Brazilian soybean exportation, *International Journal of Simulation Modelling*, Vol. 19, No. 4, 571-582, doi:10.2507/IJSIMM19-4-529

[25] Friend, J. D.; da Silva Lima, R. (2011). Impact of transportation policies on competitiveness of Brazilian and U.S. soybeans: from field to port, *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2238, No. 1, 61-67, doi:10.3141/2238-08

[26] Mapa, S. M. S.; da Silva Lima, R. (2014). Combining geographic information systems for transportation and mixed integer linear programming in location-allocation problems, *Journal of Software Engineering and Applications*, Vol. 7, No. 10, 844-858, doi:10.4236/jsea.2014.710076

[27] Enomoto, L. M.; da Silva Lima, R. (2007). Análise da distribuição física e roteirização em um atacadista (Analysis of physical distribution and routing in a wholesaler), *Producao*, Vol. 17, No. 1, 94-108, doi:10.1590/S0103-65132007000100007

[28] Banks, J.; Carson, J. S.; Nelson, B. L.; Nicol, D. M. (2009). *Discrete-Event System Simulation*, 5th edition, Pearson, New York

[29] Wang, X.; Kim, W.; Holguín-Veras, J.; Schmid, J. (2021). Adoption of delivery services in light of the COVID pandemic: who and how long?, *Transportation Research Part A: Policy and Practice*, Vol. 154, 270-286, doi:10.1016/j.tra.2021.10.012