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Microsimulation-Based Collaboration Model for Urban Freight Transport

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ABSTRACT The different stakeholders involved in urban freight transport, their behaviours, and interactions are attracting the attention of researchers and practitioners in logistics and freight transport, pushed by the need to develop methods and models for assessing ex ante actions/measures to improve the logistics process performance. Besides, the large amounts of data currently available open up new opportunities, as well as the possibility of using them to review past operations and provide suggestions and guidelines for future decision-making. In this context, to improve city sustainability and liveability, the cooperation and coordination among transport and logistics operators have been some of the measures for optimizing freight operations, with a subsequent reduction in vehicles and traffic impacts. Therefore, opportunities arise to point out the stakeholders' decentralised collaboration and the dynamic information driving urban logistics operations. In this context, this paper presents a microsimulation model framework to support the operational decision-making of an urban supply chain that makes the most of such cooperation and coordination and appropriately responds to the dynamic changes of demand and supply. The model was first tested using data collected in the urban area of Medellin, Colombia and we obtained satisfactory results that show the benefits of implementing such modelling framework to support decision making policies.

INDEX TERMS Micro-simulation, collaboration, cooperation, urban freight transport, city logistics, cooperation, agent-based.

I. INTRODUCTION

Urban Freight Transport (UFT) is an important field in city logistics because of the impacts it generates, such as traffic congestion due to freight loading or unloading on the streets and pollutant emissions [1]. Additionally, some city logistics measures promoted by local public administrations seek to improve traffic flow at historic and business centres [2]. For this reason, logistics operators should review their operations to comply with such regulations [3], [4].

According to Russo and Comi [5] and Marcucci *et al.*,[6], cooperation and coordination among operators are some of the most common measures to improve the sustainability and liveability of cities and reduce operating costs. In addition, such measures can exploit Information and Communications Technologies (ICTs) and Intelligent Transportation System (ITS) applications [7]. These tools may both improve the effectiveness (in terms of high service levels) and efficiency (in terms of cost reduction) of logistics flows and reduce negative externalities while enhancing the enforcement efficiency and broadening the scope of enforcement.

The evolution of information technology and telematics over the past years has opened up opportunities for urban freight operators to optimise their costs [8], [9]. Therefore, the first objective of this paper is to identify, from the extensive literature on freight delivering collaboration and information management process, the main criteria for classifying them. This identification will focus on their collaborative mechanism, collaboration basis, modelling tool, objective, and system size, aspects that could explicitly support the definition of delivery strategies within the context of collaborative operations (Section 2).

Since policy making involves making choices regarding a system in order to change its outcomes in a desired way, the selection of a set of measures to be implemented should be based on a planning-scenario implementation process able

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to simulate the main effects of an exogenously specified scenario (i.e., ex-ante assessment - "*what if*" approach). In this way, the obtainable effects can be evaluated prior to implementation and their results verified afterwards. Thus, the desirability to have methods and models for *ex-ante* assessment—which utilize the needs and delivery behaviours of the different stakeholders—gives rise to the second objective of this paper: to develop a modelling framework that can be used in the *ex-ante* assessment of innovative delivery scenarios to estimate impacts and system performance, and, hence, compare future scenarios based on a set of given target values (Section 3).

Such a modelling framework should also identify the dynamics of demand because, as reported by Comi [10], the rapid growth of urban freight transportation due to changes in the supply chain (e.g., just-in-time, home deliveries, and e-shopping) has resulted in an ever-increasing number of deliveries and light goods vehicles in urban areas. In addition, it has led to a fluctuation of transport demand, thus generating major impacts on urban sustainability and liveability [11]–[13].

Surprisingly, this modelling task has received little attention, and there would seem to be no modelling frameworks that combine dynamic changes on the demand and supply sides and with more than three different types of changes. The traditional approach to simulate this type of problems has been based on the adaptation of static models [14]. However, advances in computing capacity and developments in the ICT field, such as the Global Positioning System (GPS) or the Geographic Information System (GIS), have encouraged research into UFT in dynamic decision-making environments [15]–[17].

As a result of the evaluation of different types of city logistics measures, collaborative measures are expected to produce significant benefits, particularly for retailers and transport and logistics operators [3], [4], [18], [19]. Such benefits are thus assessed by means of a microsimulation of a real test case, as will be shown in Section 4 and discussed in Section 5. The demand and the supply are dynamically simulated in order to ensure that the changes that may occur during/after each pick-up and delivery operation are considered. Therefore, based on the results, the third objective of the paper is to investigate the changes of delivery system performances based on collaboration in information management of delivery operations and to evaluate the performances and advantages of the proposed modelling framework.

The remainder of this paper is structured as follows. Section 2 presents a basic literature review on collaborative measures in UFT and describes the problem dynamic information management. Section 3 provides the conceptual framework of the proposed model. Section 4 details the application of this model in a logistic network in Medellín, Colombia where an Urban Consolidation Centre (UCC) is also introduced. Section 5 discusses the main results. Section 6 reviews the main findings and outlines the further development of this research.

II. LITERATURE REVIEW

A. COLLABORATIVE MEASURES IN URBAN FREIGHT TRANSPORT

As mentioned above, among a large number of initiatives implemented to optimise UFT operations, collaborative measures are considered by stakeholders to be one of the best performing. Collaboration, defined as an initiative for independent companies to join forces in terms of information exchange, planning, execution of objectives, and even strategic alliances [20], [21] has proven to be a valid strategy for every stakeholder to gain in competitiveness. It uses information sharing to create knowledge about the market and business operations [22] and allows companies to deal with highly competitive environments [23]. In the field of UFT, several studies have presented some of these initiatives with different stakeholders and types of collaboration.

In accordance with the objectives of this paper, we classified the main studies into collaborative measures based on the following major criteria (as reported in Table 1): collaborative mechanism (e.g., information sharing for negotiation, transportation agreement, inventory management, or use of an urban consolidation centre), collaboration basis (e.g., quantity to deliver or reliability), modelling tool (e.g., simulation or optimisation), objective/scope of collaboration (e.g., reduce internal or external costs), and system sizing (e.g., city or set of enterprises).

From the analysis of such criteria, it is observed that many of them do not explicitly consider the dynamism of demand and supply: they are not used (or cannot be used) to forecast the effects of collaboration in a real context. These models were developed to simulate some aspects of the UFT and do not start from demand. Hence, it is difficult to establish a link between these models (developed mainly for stakeholder integration) and the demand and supply models (developed for freight mobility) and to analyse the complexity of UFT without considering all the components that make up an urban system. Therefore, studies should investigate the unified structure in which freight transport demand and supply and collaborative information sharing interact (as they do in practical situations). In fact, collaboration and UFT are usually modelled separately. Few models explicitly represent the interplay between goods movements and information flow and its effect on the transportation system. Ignoring these interactions may be appropriate when commodity flows take place on their own dedicated system. However, they clearly cannot be ignored in many urban real situations for instance traffic congestion is an effect caused by both markets and which decision-makers presumably take into consideration before making a UFT decision.

Consequently, collaboration among the stakeholders in UFT processes allows them to communicate and react to different changes that occur in the dynamic operational context [35], [36]. The importance of this strategy lies in the fact that it helps to achieve operational efficiency through value creation in the UFT process considering local regulations [37], maintain or reduce distribution costs, and

TABLE 1. **Collaborative measures in urban freight transport.**

	Collaborative mechanism	Collaboration basis	Modelling tool	Objective/Scope	System size
Aschauer and Starkl [24]	Information-sharing for negotiation	Quantity to deliver	Simulation	Reduce external cost	City
Bahinipati and Deshmukh [25]	Information-sharing for negotiation	Quantity to deliver	Optimisation	Reduce internal cost	Set of enterprises
Hall and Saygin [26]	Inventory management	Reliability	Simulation	Reduce internal and external costs	Set of enterprises
Vornhusen et al.,[27]	Transportation agreement	Quantity to deliver	Optimisation	Reduce internal cost	Set of enterprises
Scavarda et al., [28]	Information-sharing for negotiation	Reliability	Optimisation	Reduce internal and external costs	Set of enterprises
Arango-Serna et al., [29]	Inventory management	Quantity to deliver	Optimisation	Reduce internal cost	Set of enterprises
Akeb et al., [30]	Urban consolidation centre	Quantity to deliver	Simulation	Reduce internal cost.	City
Perboli and Rosano [31]	Transportation agreement.	Quantity to deliver	Simulation	Reduce internal cost	Set of enterprises
Anand et.al.,[32]	Urban consolidation centre	Quantity to deliver	Simulation	Reduce internal and external costs	Set of enterprises
Firdausiyah et al., [33]	Urban consolidation centre	Quantity to deliver	Simulation	Reduce internal and external costs	Set of enterprises
Stinson et al.,[34]	Information-sharing for negotiation	Quantity to deliver	Simulation	Reduce external cost	City

respond to many of the changes that affect the process. Trust and adequate coordination mechanisms are important to support collaborative processes among stakeholders. In addition, they make it possible to evaluate their economic, social, and environmental benefits, as well as the barriers to their implementation, such as the lack of strategic information exchange between stakeholders [38]. Therefore, this suggests again the need to have modelling tools that explicitly simulate the interactions between stakeholders; nevertheless, currently there are some strategies that improve collaborative processes, including the use of information technologies [39], [40], and collaborative delivery systems [41]–[43].

B. DYNAMIC INFORMATION MANAGEMENT IN URBAN FREIGHT TRANSPORT

UFT, as the last mile link in the supply chain, exhibits behaviours that change over time. Some of the dynamic factors (e.g. travel times, new customers, time windows) are produced by interactions between customers - suppliers, or by information flows between actors. Moreover, the dynamic conditions of each actor involved in the supply chain, as well as the way they share information for the benefit of all, must be modelled. Akyuz and Gursoy [35] consider that sharing information and reducing the asymmetry between supply-chain partners are key for a successful real-time information-based collaboration. Important information shared among stakeholders includes data on demand, inventory, and product traceability [44].

The types of dynamic information and the tools that have been developed to simulate it are examined below. In addition, the modelling frameworks that have been designed to manage information are discussed. Finally, the benefits resulting from collaboration and dynamic information sharing are pointed out.

1) DYNAMIC INFORMATION IN URBAN FREIGHT TRANSPORT

The constant changes in the operational conditions in UFT must be modelled to properly represent and analyse the daily process of urban freight pick-up and delivery. Communicating these changes should be associated with information management and collaborative processes in order to improve the performance of logistics systems. One of the main mechanisms that facilitates such collaboration is proper information management system and its related technologies [35], [45]. Some of the changes that must be shared as dynamic information and which arise in the operational context of UFT processes, include:

i) customer demand for both new orders and cancellation of existing ones [46]–[48];
ii) customers' location, which may change and impact the allocation of the facility that will serve a certain customer [49];
iii) movement of vehicles in the city and their interaction with traffic, difficulty in finding parking lots, limited delivery times, and temporary restrictions on access to urban areas [50];
iv) number of products and vehicles in the distribution network, and levels and types of networks [51];
v) accessibility to customers located in city centres with changing conditions [52];
vi) increased travel times due to traffic congestion, possible accidents, and so on [53], [54]; and
vii) variations in freight operations times (e.g. loading and unloading) at customers' locations [55], [56] due to the number of vehicles waiting in line to be served or simply because of delays in vehicles servicing.

In studies into UFT, these changes (usually one or two) have been analysed. For example, [56]–[59] only identified changes in the number of known customers and the arrival of new orders. Reference [60] considered, besides the arrival of new orders, the variation in travel times. In addition, Kuo *et al.* [55] included the variation in service (delivery and travel) times.

There are relatively few studies that model more than two dynamic variables. For instance, [61] analysed, as dynamic variables, the lists of travel times between customers, estimated travel costs, current number of products being transported, and current location of vehicles. The use of multiple dynamic variables in a model can better represent an urban real-life scenario and the management of operational logistics decisions [62].

2) MICROSIMULATION FOR THE INFORMATION MANAGEMENT

Microsimulation can be used to model data communications among different stakeholders. Despite its great potential for the analysis and solution of dynamic problems, this tool has been rarely used in the logistics processes in UFT [63]. Microsimulation models can detail the process elements at a the microlevel [64] by representing the behaviours of each microunit of analysis, the micro-changes in the dynamic variables of the environment, and the different road connections between each customer, supplier, and UCC, along with the travel times associated with them. Moreover, microsimulation may be employed to model the interactions between the various stakeholders in UFT collaborative processes and even more in dynamic environments. However, no studies in the literature have yet reported the use of this tool in the design of models. Its application focuses on evaluating matters such as the development of demand models, the parking of cargo vehicles, the environmental impacts of UFT, the use of GIS and modelling processes, and the integration between freight movement and passengers.

Microsimulation can be useful for information management, as it serves to communicate the different changes on-line in order to update the entire system and respond to them effectively and efficiently. By means of microsimulation, the different individual behaviours of each stakeholder and the urban context can be represented. Every small change in each entity behaviour (i.e., micro-change) can be notified in real time to assess the possibility of responding to them in the best possible manner. For instance, customers communicate their demand requests and changes in service times, suppliers do the same with product supply and service times, and external authorities or entities inform about changes in travel times on the different road connections between these stakeholders.

3) COLLABORATION FOR DYNAMIC INFORMATION MANAGEMENT

Collaboration in information management is currently an important issue due to the large volumes of data generated by each stakeholder in the distribution network [65]–[67]. Furthermore, the current collaborative initiatives are insufficient or designed considering centralised processes for the analysis of events and decision making that will affect every stakeholder in the system. The use of decentralised strategies with information sharing has been infrequent. Therefore, decentralised collaboration for information management in UFT (which takes into account the different information each stakeholder manages and the behaviours to react to it) can contribute to the literature into supply chain management, logistics, decision support, and UFT.

Additionally, the multiple dynamic variables that represent the communication of information regarding changes coming from the stakeholders and the urban context, as well as their effect on the performance and achievement of objectives, must be analysed. These operational changes are diverse and constitute multiple dynamic variables. According to the literature, these changes are associated with customers' orders (demand) or times for providing the distribution service (supply). Based on this, we classified them into changes in demand and changes in time (supply), as shown in Table 2. When there are changes in demand, the initial routes must be assessed and modified to serve the new request. When changes in time occur, vehicle routes and the time they have to visit the remaining customers are affected; hence, routes must be recalculated.

TABLE 2. Dynamic variables in urban freight transport.

Variable	Type of variable
New order request Order cancellation request Quantity modification request Time window modification request	Demand variables
Travel time Service time at customer's location	Supply variables *(changes in time)*

Changes in these variables involve any stakeholder, who has the autonomy to notify the new information and update the state of the system; therefore, the process of managing information related to the operational context is considered decentralised. However, the entire freight distribution process must find the best response to every change.

Even though microsimulation is a tool with great potential to analyse and solve dynamic problems, it has been little used in logistics processes associated with UFT [63]. In this paper, we use microsimulation to integrate the collaborative and decentralised management of external information (large volumes of data generated by customers and the urban context) with multiple communication channels collaboratively shared among the different stakeholders, which generates operational changes to which the distribution model must respond. Furthermore, we use autonomous information from each actor involved in the pick-up and delivery operations in freight distribution, as well as the urban context, to design a collaborative model that employs information sharing to react to every single change in the operational context. Some studies in the literature have employed agent-based modelling to represent the behaviours of the stakeholders. Nevertheless, our model uses agent-based microsimulation to collaborate for individual and collective dynamic information management. Therefore, the development of a collaboration model based on microsimulation for the management of dynamic information in UFT is a contribution to this field of knowledge.

III. PROPOSED FRAMEWORK FOR DYNAMIC INFORMATION MANAGEMENT

This section describes the proposed modelling framework. The purpose here is to identify the main components of UFT, aiming to link the choices of customers (i.e., receivers and retailers) and suppliers (i.e., wholesalers, distributors, and restockers) in a dynamic environment. First, we provide some definitions and notations, and then, we detail the structure of the proposed modelling framework.

A. DEFINITION AND NOTATION

Freight transport in urban and metropolitan areas includes both pick-up and delivery in retail, parcel, and courier services; waste transport; transport of equipment for the construction industry; and a broad range of other types of transport services. In this study, freight distribution within an urban/metropolitan area is based on delivery tours that depart from an UCC assuming a pull-type movement [68]. The following two stakeholders (among others) are directly or indirectly involved in UFT (last mile distribution):

- Retailers, who aim to optimise their restocking process, integrate freight receiving operations into their selling activity, optimise their part of reverse logistics to reduce estate costs, and minimise (or eliminate) inventory cost.
- Transport and logistics operators (transport enterprises), who seek to optimise their operations (e.g., loading, routing, and scheduling), the travel time in terms of last mile delivery as well as at-customer deliveries, and their part of reverse logistics.

The geographical area, which contains the freight distribution system to be analysed, may be expressed by means of a graph, $G = (N, L)$, where N is the set of internal and external nodes; and L, the set of pairs of nodes belonging to N, called 'links' or 'arcs'. Certain variables perceived by users (e.g., travel times and monetary cost) can be associated with each of these entities (i.e., links and nodes). These variables are referred to as level-of-service or performance attributes that change throughout the day due to, for instance, different levels of traffic congestion.

A freight distribution plan is defined based on the choices made by receivers (customers) and transport and logistics operators. In addition, it depends on the performance of the road network where delivery vehicles, along with their constraints (e.g., maximum load), move.

Consequently, as mentioned above, the considered UFT flows result from customers' (retailers) needs. The characteristics of the restocking process (i.e., freight flows from suppliers to customers) are strictly related to the type of retail businesses to be restocked in terms of delivery size, delivery frequency, freight vehicle type, and operations times, among other factors. For example, delivery size and freight vehicle dimension tend to increase with the size of retail businesses, while the delivery frequency tends to decrease, with a major influence on the total distance travelled by freight vehicles. Therefore, restockers' choices regarding delivery (such as tours to be performed and vehicle paths) affect the restocking characteristics and the total distance travelled by freight vehicles.

Furthermore, the service offered by suppliers may depend on the accessibility of their areas and those where customers are located. Thus, if accessibility changes (for instance, due to management measures and traffic congestion), the suppliers' operation process may also change. Then, if the characteristics of customers and/or the accessibility of their area changes, the UFT characteristics may do so as well.

B. PROPOSED MICROSIMULATION FRAMEWORK

As stated above, the proposed modelling framework was specifically developed to analyse UFT and consider the possible relationships between receivers, suppliers, vehicle needs, and road network status, which hereinafter will be referred to as 'stakeholders.

This modelling framework simulates a freight distribution system and focuses on interactions between suppliers (e.g., restockers and wholesalers) and receivers (e.g., customers and retailers), taking into account that the receivers' requests (demand), as well as the operation characteristics, can change over time due to, for instance, road congestion. Hence, this modelling framework combines data coming from different datasets: road network data (which serves to obtain the supply features), customers' characteristics (socio-economic data, requirements in terms of deliveries, and location), and suppliers' restocking characteristics (socio-economic data, vehicle fleet, features of the service offered, and location). In addition, the simulation outputs (i.e., initial and final vehicle routes, minimum number of vehicles required, cost of routes, service level to new customer requests, and time variation in routes) are also presented.

In particular, the proposed microsimulation model (Fig. 1) aims to dynamically simulate the changes that may occur during UFT operations (i.e., pick-up and delivery at customers' location) due to customers' requests and the road network status (i.e., performance of the network, such as travel times and delivery times which are random variables). Thus, current choices could be simulated and future choices forecast based on certain network attributes that can be modified by implementing the schedule distribution. The model has two layers, one layer for *data initialisation* and a second level for *microsimulation* of decentralised collaboration for the management of dynamic information. The first layer consolidates information from different sources of the operational context such as city road network and the static data (initial customers' demand and location) from customer and supplier. The second layer is used to microsimulate the dynamic context in the UFT operation by creating the *O-D matrix*,

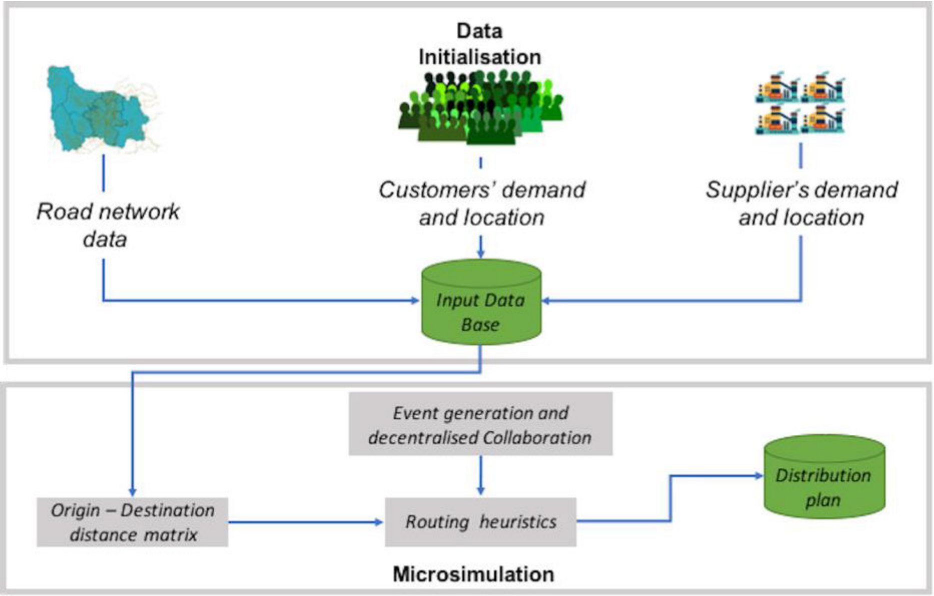


FIGURE 1. Architecture of the proposed microsimulation model.

the configuration of the different changes in the variables by *the event generation and decentralised collaboration*, the response to these changes by using metaheuristics for the *routing* process and finally stablishing the *distribution plan* of each vehicle.

Fig. 1 presents the proposed microsimulation model. The decentralized collaboration process of the management information emulates the sharing information in real-time, based on the generation of dynamic variables that depend on the behaviour of each involved actor. The roles and choice behaviours of the stakeholders (i.e., receivers and senders) and their interaction, as well as the context configuration (e.g., road network status forecast through event generation), help to identify the UFT environment and how information is managed in a decentralised manner.

Subsequently, the microsimulation process defines the micro-changes (i.e., changes in each variable coming from the different stakeholders, such as new order and travel time between arcs) in customers' requests, suppliers' services, and the road network, as well as the time of the day when they occur. If a micro-change takes place before the last vehicle leaves to the UCC, the routing process is updated in order to consider the majority of these micro-changes with the same number of vehicles.

The input database (Fig. 2) includes information on the following three identified environments:

- Customers (retailers): number and location, demand in terms of quantities, type of products required, time windows, and average loading and unloading times required to serve them.
- Suppliers (restockers): number and location, product offerings, loading service times, and load capacity of vehicle fleet.
- Road network: time-dependent travel times.

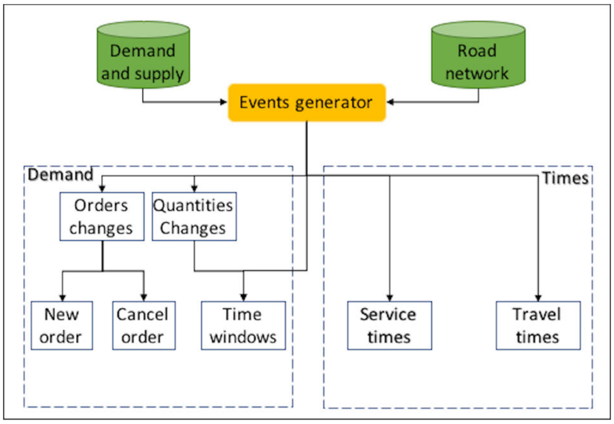


FIGURE 2. Dynamic information modules of the event generator.

Events are generated through the two-module generator, as shown in Fig. 2, which represents the dynamic information of the UFT. The first module simulates the events associated with the demand considering three actions:

1) changes in the orders requested by customers (new orders or cancellations),
2) changes in ordered quantities, and
3) changes in time windows for receiving services by suppliers

The second module of the event simulation deals with times:

1) service times at suppliers for loading the vehicles and at customers for providing services and
2) travel times on road network.

We used the agent-based microsimulation platform JAS-mine® [69] for the collaborative decentralization of the information management process in the UFT. In order

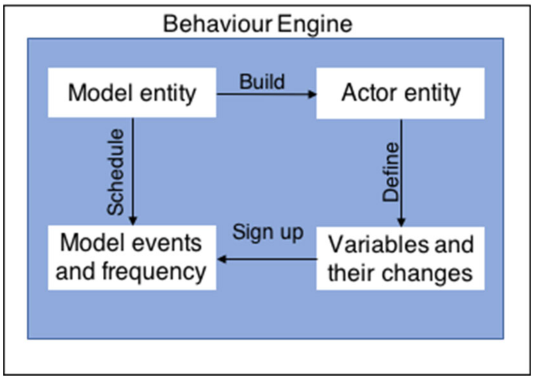


FIGURE 3. **Microsimulation behaviour engine.**

to implement the model in JAS-mine®, it was necessary to set up two entities: Model and Actor entities (Fig. 3).

The Model entity generates the list of scheduled events following the discrete simulation paradigm and creates the list of Actor entities (i.e. customers, suppliers, arcs from road network and vehicles). The events (micro-changes) can be programmed and executed only once ''Schedule Once'' or repeatedly ''Schedule Repeat'' considering the starting time of each event, the order of events, and the time interval between them.

The Actor entities represent, based on data, the actors of the model (customers, suppliers, vehicles, and arcs) and their different behaviours. These entities have historical data that determine the probability of occurrence of the multiple independent micro-changes and impact the execution of the daily operations of goods distribution.

To define the decentralised collaboration process for information management, it is necessary to three features to the model, 1) actors' behaviours, 2) event identification and communications and 3) operation time control. These features allow us to open multiple information channels for the UFT actors, in order to share the different micro-changes related to the operational context and generate massive management of the logistics information that is constantly updated and communicated. Fig. 4 represents the flow of microsimulation of the decentralised collaboration process for management information.

1) Actor behaviour: The roles, behaviours, and interactions among the actors are defined to present different micro-changes in the input variables at some point over the operation horizon. These changes can occur on customers (referring to orders and service times), suppliers (service times), arcs (travel times between nodes), the UCC (route generation), and vehicles (route execution).
2) Event identifications and communications: Micro-changes are only known at the moment they occur. Therefore, they can be treated as online responses, and the generated output can be information about the change in terms of six variables: new orders with quantity and type of requested products, quantity change, cancelled orders, time window, service time, and travel time. These micro-changes can occur in a single actor or in multiple actors at the same time. This process is finally responsible for informing the UCC and the vehicles about variations to which the model must react.
3) Operation time control: Microsimulation behaviour engine allows us to keep the same time scale for all the actors and determine the moments at which communication processes are carried out. This time control also keeps track of events and the start and end of distribution operations according to the time windows of the UCC.

IV. APPLICATION TO A REAL TEST CASE

A. *STUDY AREA AND MODELLING SET UP*

The microsimulation of the decentralised collaboration process for the management of dynamic information for UFT uses a logistics network structure for the distribution channel with a UCC as an intermediary between suppliers and customers, which frequently used in the retail secto (Rushton *et al.*, (2011); Sadjady (2011); Antún (2013). The network is composed of suppliers that manufacture different products and, additionally, a logistics operator or Urban Consolidation Centre (UCC) that consolidate the orders that customers place to suppliers and their final shipments to meet demand. Therefore, the actors included in this network are suppliers, the logistics operator (UCC), vehicles, and customers.

There are three different types of initial data from multiple suppliers, multiple customers, and Medellín road network. Each supplier produces a specific product and each customer requests a set of products in an order. Each segment of the road network connecting two actors exhibits properties such as length, travel time, and time-dependent changing probability. We used Open Street Maps for the segment distances, and the travel speed of the vehicles was set at 30 km/h, according to Área-Metropolitana (2018), which may change according to the time of day in the simulation.

The model makes queries to generate the matrix of distances between the actors in the process. The model uses this matrix to define the initial distribution plan through Greedy Randomized Search Procedure (*GRASP*) heuristic, which enables us to establish the number of vehicles that are needed. Once the initial routes are established, the microsimulation begins with the decentralised event generation process, and, each time an event occurs, the actor communicates the event to all the other actors to respond to the different changes through a Solomon's routing insertion heuristic [74] combined with a 2-opt enhancement operator.

To perform the microsimulation, the following information is required:

- Individual demand data of each customer: geographic location, quantity and type of required products, time windows, and vehicle service times.

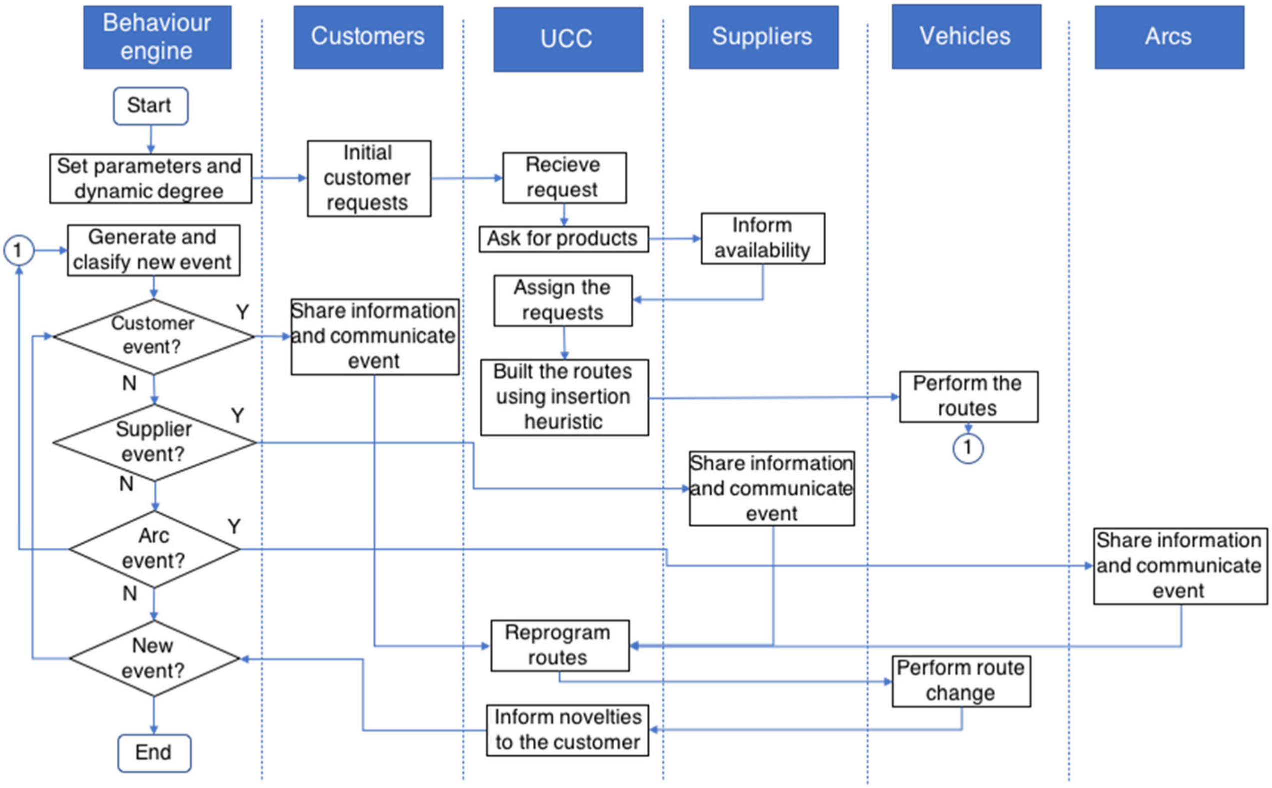


FIGURE 4. Microsimulation of the decentralised collaboration process for information management.

- Individual supply data of each supplier: geographical location, quantity and type of product manufactured, and loading time.
- Logistic operator data: geographical location, daily operating time, consolidated origin–destination distance of the routes used in the freight pick-up and delivery, and transportation cost per kilometre travelled.

To test the model, we used the data of 100 initial customers that must be visited in one day of operation in Medellín, Colombia. Additionally, there can be new orders of other 100 customers in the database. These customers place orders to 7 different suppliers. The UCC plays a fundamental role in the implementation of the decentralised collaboration process, coordinating the reception of information from all the actors on the different events that occur during the operation and the transmission of specific information to the agents involved. Fig. 5 shows the georeferencing of customers, suppliers, and the UCC. The road network is used to generate the connection between these actors. The dataset of the case study was taken from [75].

We analysed the results of 20 microsimulations of the decentralised collaboration process for information management among the actors in the UFT. Every actor presented behaviours in response to each micro-change with an independent probability distribution. The arrival time of the new orders throughout the simulation followed a normal distribution with a mean of 120 minutes (i.e., *t/4*, where *t* is 600 minutes, the duration of the operation day) and a standard deviation of 50 minutes. The travel times exhibited an empirical time-dependent distribution. The operation time of a day was divided into 5 segments with a higher probability of travel time at peak hours. Each link had the same probability for its travel time in the same segment of the day. The model entity evaluated the changes in new orders and travel times every minute of the simulation.

We assumed that the other events had a uniform distribution for each customer and followed a Poisson distribution with a lambda equal to 0.15 events per minute, which generated a low level of dynamism with an average of 5 events per simulation of this type of event. These micro-changes are part of the behaviour of each actor entity.

For the arrival of new orders, we established an average of 13 new orders per simulation; and, for travel time changes, an average of 12 changes per simulation. The probability of each event could be adjusted to set different dynamism degrees. The parameters and variables of the simulation are shown in Table 3.

B. RESULTS AND DISCUSSION

We simulated the model using the Java® JAS-mine platform. It allowed us to program insertion heuristics to react to changes in the simulation. The algorithms were run on a computer with 4Gb of RAM and a 2.4-Ghz Intel Core2 duo i5 processor. Table 4 summarizes the results with the maximum and

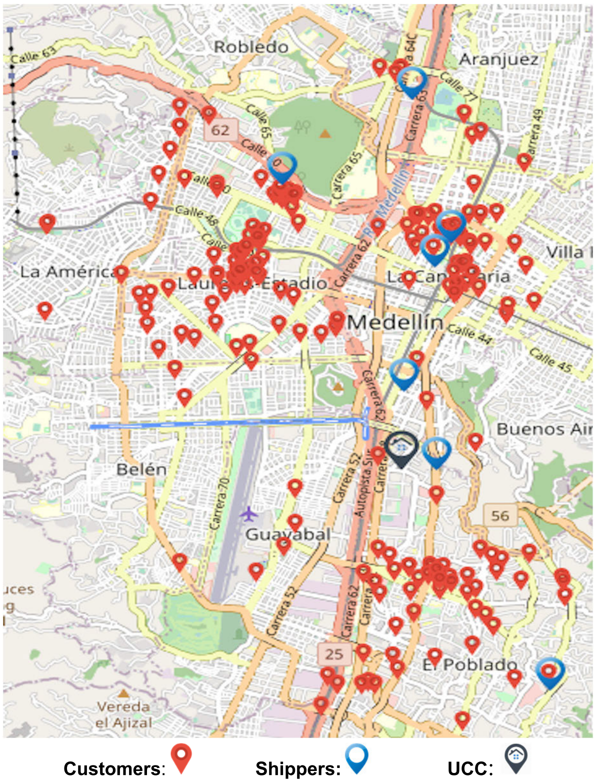


FIGURE 5. Geolocation of actors.

TABLE 3. Simulation parameters.

Parameter	Value				
Initial customer	100				
Vehicle capacity	200 unit				
Daily operation hours	7:00 a.m. – 5: 00 p.m.				
Service time per	10 minutes				
New order probability	Z ~ N (150, 70) minutes				
Cancel order probability	~ U (0.02667)				
Probability of quantity change in an order	~ U (0.03333)				
Time window change probability	~ U (0.03000)				
Service time change probability	~ U (0.09475)				
Travel time change probability per day	0.05	0.017	0.085	0.0017	0.05
Slice of the day	7:00–8:30	8:30–11:00	11:00–2:00	2:00–3:30	3:30–5:00
Travel speed	30 km/h time-dependent				
Frequency of changes evaluation	1 minute				

the minimum number of events as well as the average values of the 20 runs.

Due to the randomness in the model, there were some variations in the total number of changes in all the simulation runs (maximum number of events=54; minimum number of events=30). These changes were distributed differently in each model variable. The most frequent events are new orders and travel time changes, followed by service time changes. These events affect the percentage of accepted events and the operational costs. An important finding is that the average load factor presented low levels, with an average of 43.08% among the six vehicles used to make the distribution. The results show that a greater number of events produces lower service levels.

A comparison between the initial distribution plan and the simulation runs that implemented the maximum and minimum number of events shows that the number of cancellation requests affects the total cost of the routes because some initially planned customers were not visited. It can also be seen that, with the use of the decentralised collaboration process for information management, new requests can be fulfilled, which was not possible at the initial stage. Likewise, an increase in the average load factor of the vehicles was identified due to the acceptance of new orders by the vehicles located at the UCC before the request was received. Changes in travel and service times revealed that it was necessary to have historical information about such behaviour for a better characterization in the microsimulation.

Fig. 6a presents the initial operation time and the accumulated travel times between customers in each route. When the line is parallel to the x-axis, the vehicles do not move because they are waiting or unloading. Similarly, Fig. 6b details the performance of the vehicles when they are unloading a customer's order or waiting for operation, and, in this case, when the lines have zero slope is because the vehicles are moving.

Figs. 6a and 6b show the vehicles leaving the UCC at various times over the simulation because the different time windows produced long initial waiting times, in some cases up to 200 minutes. This time is used to react to new orders if they had enough freight. The use of safety stock in every vehicle could help to increase the percentage of event acceptance by reacting to more new order events and customer quantity changes.

Fig.7 represents how vehicles visit customers during the day. It compares the number of visited customers and those to be visited. The latter varies when a new or cancellation request occurs, and its fluctuations can be perceived when changes appear in these variables. Similarly, it shows the total number of customers visited during the day of operation, and the simulation minute when the last customer was visited. In this specific figure, the vehicles visited 105 customers at the end of the day.

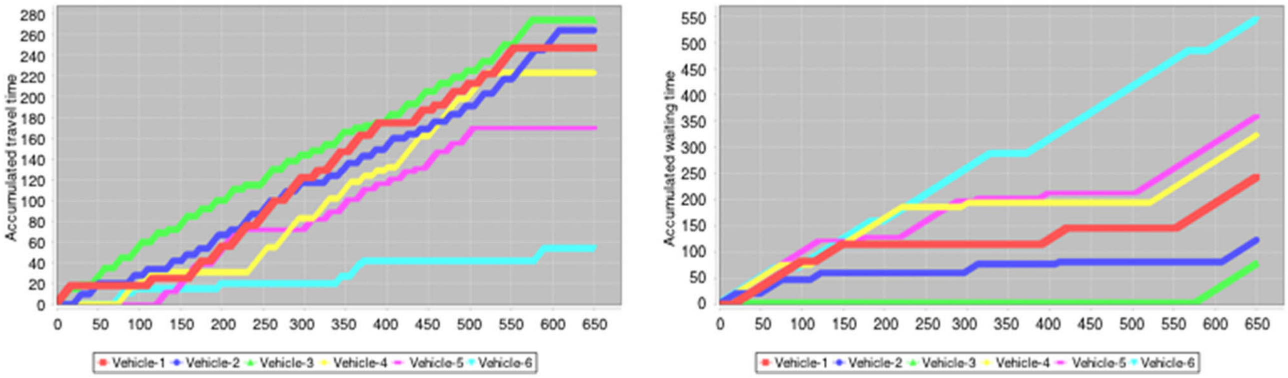
C. RELATIONSHIP OF VARIABLES WITH THE MODEL OBJECTIVES

The number of variables considered in the microsimulation model generated different impacts on the distribution cost and the percentage of events at the end of the day. For this reason, it was necessary to find the relationships between the different types of variables and the two objectives of the model.

In this section, we use a graphic and correlation analysis of these relationships based on the simulation results. Fig. 8 (a) is a chart of the relationship between the total

TABLE 4. Summary of simulation results.

Run number	Run with the maximum number of events		Run with the minimum number of events		Average of the 20 runs
	Static	*Microsimulation*	*Static*	*Microsimulation*	*Microsimulation*
Total number of requests	54		30		41
New accepted requests	0	35	0	22	29
New rejected requests	54	19	22	8	13
Cancellations request	5	5	1	1	2
New customers' requests	18	18	8	8	13
New customers accepted	0	4	0	5	5
New customers rejected	18	14	8	3	7.5
Requests of quantity changes	7	7	5	5	3.5
Accepted requests of quantity changes	0	4	0	0	0
Rejected requests of quantity changes	4	2	5	4	3
Time window changes	3	3	1	1	2
Accepted time window changes	0	0	0	0	0
Rejected time window changes	3	3	1	1	2.35
Travel time changes	9	9	8	8	11.1
Processed travel time changes	0	9	0	8	11.1
Service time changes	13	13	8	8	9.6
Processed service time changes	0	13	0	8	9.6
Average of service time changes (minutes)	2.48	2.48	1.89	1,89	0,33
Average of travel time changes (minutes)	1.89	1.89	10.75	10.75	5.61
Total costs of initial routes	\$362.57	\$362.57	\$362.57	\$362.57	\$362.57
Total costs of final routes	\$362.57	\$349.448	\$362.57	\$368.93	\$374.69
Average load factor	40.73%	41.00%	41.52	43,50%	43.08%
Service level	--------	63.64%	--------	73.30%	68.10%



(a)

(b)

FIGURE 6. Accumulated time per vehicle. (a) Travel time. (b) Waiting time.

number of events and the service level achieved in each simulation.

It is not possible to establish a linear relationship between them because some peaks in the graphs do not match. It may be because this relationship depends on the type of event, or the impact of each variable on the objective is different. For this reason, it was simulation. It is not possible to establish a linear relationship between them because some peaks in the graphs do not match. It may be because this relationship depends on the type of event, or the impact of each variable on the objective is different. For this reason, it was essential to connect each variable with the service level since no model so far had integrated this number of variables into the performance of the distribution processes.

Fig. 8(b) does not show a clear relationship between the total number of events and the total distribution cost. This is because, when the number of events is the highest, the total distribution cost is the lowest; but, when the distribution cost is the highest, the number of events is not the lowest. Instead, it shows that, when the number of events is the lowest,

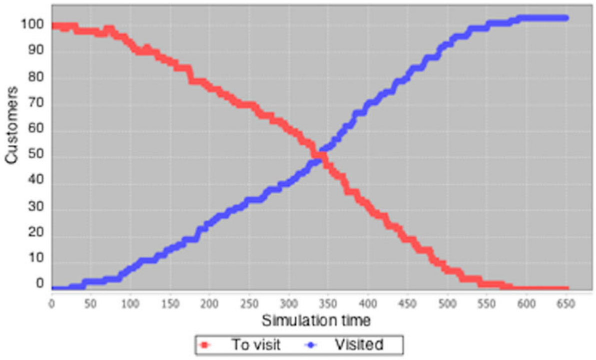
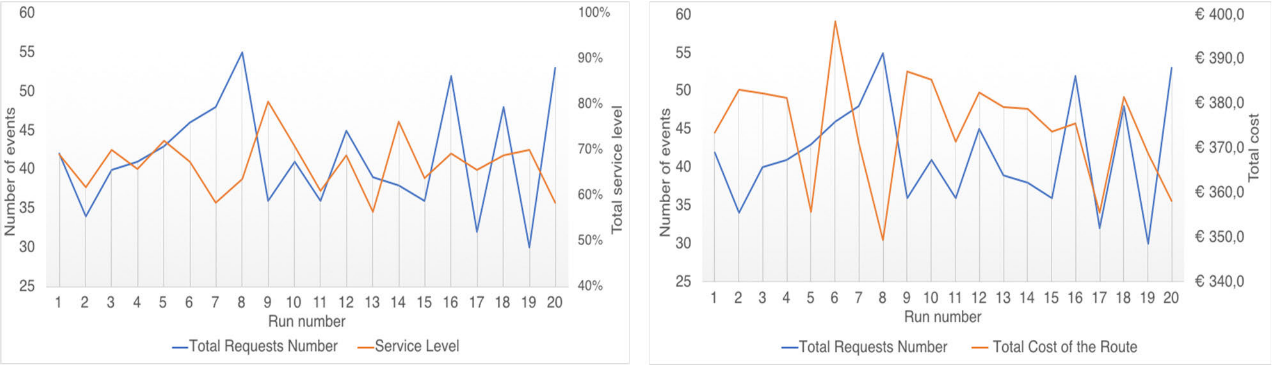


FIGURE 7. Visited vs non-visited customers.



(a) (b)

FIGURE 8. Relationship between total number of events and (a) Percentage of events acceptance. (b) Total cost.

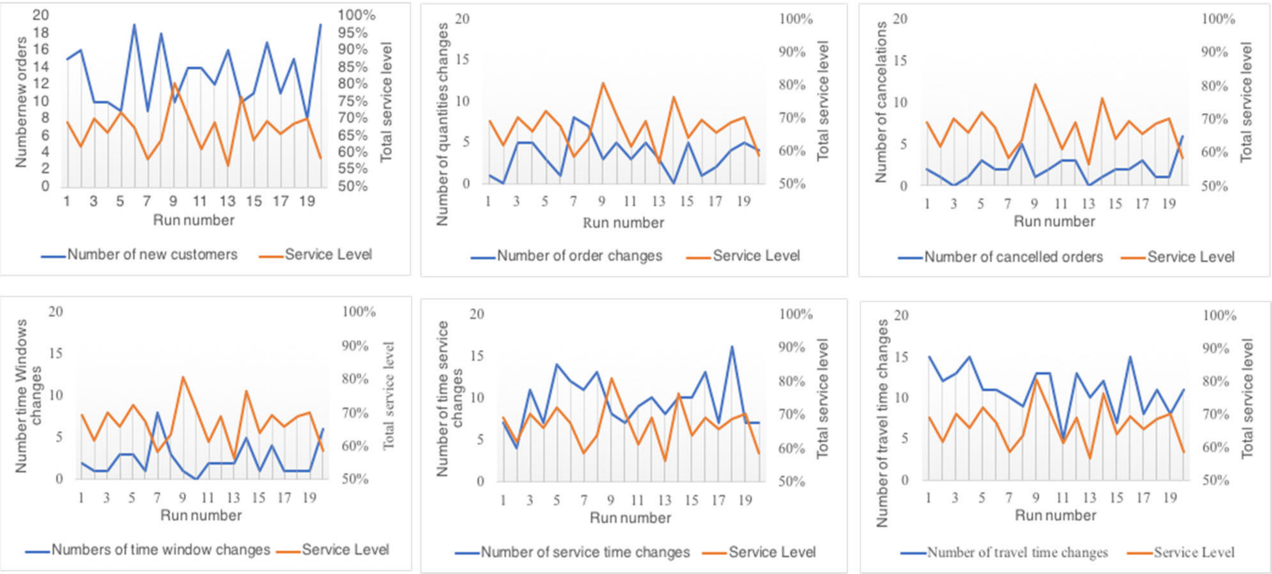


FIGURE 9. Relationship between service level and types of events.

the cost is similar to the average among all the runs. As this relationship does not exhibit a clear trend, it is critical to identify the behaviour of the different types of variables with respect to the total distribution cost and percentage of event acceptance. The same occurs in Fig. 8(b) with the number of events and the service level. Figs. 9 and 10 relate the six variables and the two objectives of the model.

Figs. 9 and 10 plot the number of changes that occurred in each variable considered in this study versus total distribution costs and service level, respectively, in order to identify any linear relationship between them. As can be seen, there is no linear relationship between the variables and the response indicators. One reason for this may be that the relationships between the variables are not linear, especially considering that each change can impact the process performance.

Table 5 shows the correlation between the different pairs of dependent and independent variables. According to the Pearson correlation coefficient, it can be deduced that for almost all variables there is no linear correlation except for a negative correlation between the cancellation request and the total cost of the route of final routes. This is because a cancellation reduces the travel distance for a vehicle and impact directly the cost of the route.

TABLE 5. Pearson correlation coefficient.

	Sl	Tcr	Cr	Nc	Qc	Tw	St	Tt
Sl	1							
Tcr	0,28	1						
Cr	-0,29	-0,66	1					
Nc	-0,40	0,04	0,41	1				
Qc	-0,26	-0,27	0,21	-0,27	1			
Tw	-0,31	-0,35	0,35	-0,01	0,21	1		
St	0,17	-0,08	0,08	0,06	0,20	0,16	1	
Tt	0,41	0,41	-0,25	0,07	-0,23	0,06	-0,03	1

Sl=Service level; Tcr=Total cost of final route, Cr=Cancellation request; Nc= New customers; Qc=Quantity changes; Tw=Time windows; St=Service level; Tt=Travel time.

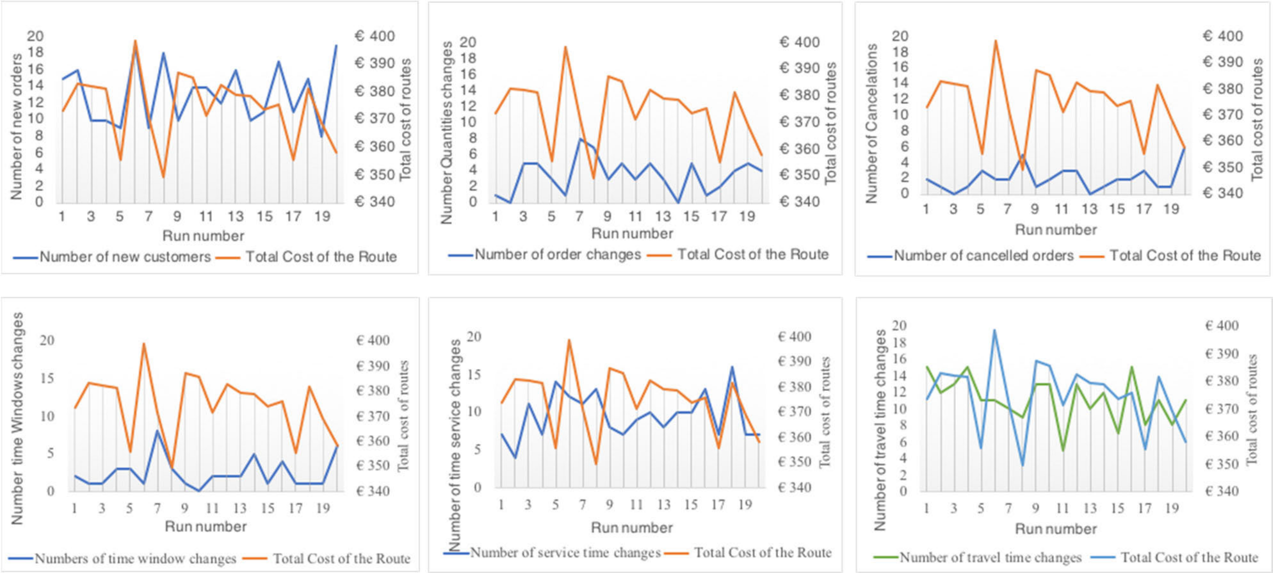


FIGURE 10. Relationship between total distribution cost level and types of events.

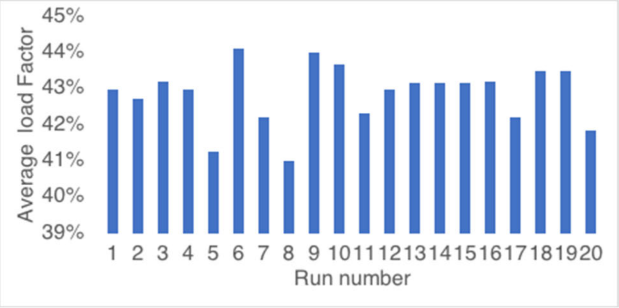


FIGURE 11. Mean of the load factor for all the used vehicles.

The average load factor is an important indicator for the UFT as a measurement of the efficiency of the use of resources (vehicles) in the distribution process. Hence, the microsimulation of the decentralised collaboration process for the information management also calculated the average load factor of the six vehicles that visit the different customers in each run: 43% of the vehicle's capacity, as it can be observed in Fig. 11. This low efficiency in resource management may, as stated above, allow us to use vehicle safety inventory to respond to some new and change of quantities request, thereby increasing the service level to different customer requests.

The proposed microsimulation-based collaborative model can assess reactions to a broad range of changes in demand and road network. The model involves the autonomous information management for all the actors and their on-line communications of the dynamic changes. This characteristic allows the model to support decision making on the UFT and adequately react to changes. Using a UCC can reduce the number of routes and vehicles performing the deliveries and increase the vehicles' load factor. The results from the model support the design of policies to react to demand and road network changes as well as the use of the vehicle fleet in order to reduce the cost of the distribution process and increasing the service level.

One of the main benefits regarding the obtained results is that the modelling framework can support policy makers in defining new scenarios for improving city sustainability and liveability. In fact, as test case showed, it adapts very well to public policies such as, delivery hours, road restrictions, UCC support, in particular with those associated with vehicle capacity and load levels, peak-hours issues, access restrictions to certain areas and roads in the city, loading and unloading times. It allows to obtain quick and timely responses on the modifications occurring after policy implementations from logistics operators.

With this modelling framework, it is possible to achieve greater collaboration among the different actors and improve the global goal associated with urban logistics processes. It could assess and lead public policies for UFT supported by intelligent systems easier to implement operationally.

Additionally, by the microsimulation model used to support demand and supply management processes, it is easier to predict the origin-destination matrixes, to estimate the use of the roads and to assess management public policies with the impacts produced by the UFT.

V. CONCLUSION

With the microsimulation model of decentralised collaboration for information management in the urban distribution of goods, it was possible to represent the autonomy of each actor but also its collaboration by sharing its own information with the supply chain stakeholders in order to improve the flexibility and timely reaction to different changes in the operational context. Furthermore, we modelled six different variables for the allocation and routing logistic operations: arrival of new customers, cancellation of orders, changes in the quantity of product to the initial orders, time window changes, travel times, and service times. This model is a contribution to the state of the art of city logistics because no study in the literature has involved these many variables representative of the operational logistic processes; some articles have addressed two or three variables, thus falling short of representing dynamic changes in UFT.

With the model developed here, the communication of the information of each actor in the process could be simulated to react in an efficient way to different changes in the operational context. The model can represent the dynamism in the pick-up and delivery of freight transport processes in urban environments and find feasible solutions to these changes. The application of this model to the case study shows that can react to an average of 68% of the new events, this is a satisfactory result that show the benefits of implementing such modelling framework to support decision making policies.

A future research field is the implementation of tools (such as evolutionary heuristics or local search) to optimize or improve the model's responses to the various changes that occur in real life. In this sense, multivariable decision-making to react to on-line dynamic changes should be investigated.

Similarly, the decentralised collaborative process for information management would allow to keep updated information on changes in the urban context. Other future investigation line could be focused on modelling tools that lets integrate, this collaboration with the coordination of the resources of all the actors to react efficiently to these changes while combining cost minimization and service level maximization objectives, such as multi-agent systems. An additional line of research is the integration of the microsimulation of the decentralised collaboration process with vehicle traffic microsimulation to analyse, in depth, the changes in the mobility that it produces and that, at the same time, affect the urban distribution of goods.

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