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Analysis, design and reconstruction of a VRP model in a collapsed distribution network using simulation and optimization

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A R T I C L E I N F O

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A B S T R A C T

One of the main characteristics of real transportation problems is not only the complexity of designing their models but also the characterization of the elements that make up the supply chain. A more detailed study will certainly provide more information about the system. However, the use of regular networks for the development of models can remove key characteristics needed for correct decision making, so we propose the characterization of transport models through the conceptualization of complex networks.

The methodology proposes a mechanism for the reconstruction of the network when the distribution network is under attack, and any of its nodes or arcs stop operating; making it very hard to find a solution to the vehicle routing problem. In this way by reconstructing the route and the cost matrix it is possible to obtain feasible routes.

The purpose of this research is to show how the proposed methodology can be applied.

1. Introduction

The main purpose of a vehicle routing problem (VRP) is to design least cost routes assigned to the vehicles that distribute product to a group of customers; with the characteristic that each route starts and finishes at the same departure point. This type of problem is treated as a classic problem of combinatorial optimization and due to its complexity, is cataloged in the literature as a NP-Hard problem as mentioned in (Braekers etal., 2016; Cordeau et al., 2007; Mohammed et al., 2017; Parragh et al., 2008a, 2008b; Policroniades, G., 2013). These types of models can be solved by heuristic, metaheuristic, or exact techniques (Policroniades, G. et al., 2018). However, because of limited time to find solutions, the preferred method is usually the metaheuristic techniques due to the quality of their solutions and runtime in comparison with exact techniques that provide optimal solutions but taking longer times (Cordeau et al., 2007). The application of these models for solving a distribution network problem considers the customers as the nodes of the network; the arcs are represented by the travel paths, while a cost representing travel time or distance is assigned to each of these arcs.

The VRP as mentioned in (Policroniades, G. et al., 2018), has been mainly concerned with solving problems of combinatorial optimization routing, seeking to optimize the resources used in a general way to obtain a solution. This principle can go so far as to undermine transportation models, by eliminating relationships and significant real variables to make efficient models that do not take long to execute while mostly considering time deterministic models; however, reality is not always like this and fortuitus events that cannot be controlled by decision makers usually occur, an example of this can be found in (Dalla Chiara & Pellicelli, 2016). In many cases, within the systems or in their environments there are factors that are usually omitted when performing a modeling, due to increased complexity both computational and systemically. The metrics provided by complex networks are a tool that makes it possible to analyze the system and identify possible critical points in the distribution network, as they enable us to identify and characterize the classification of a distribution network. These metrics include clustering coefficients, centrality analysis, grade distribution and vulnerability analysis among others. In (Oyola et al., 2016), is mentioned that stochastic VRP models have been solved by different techniques; like exact methods, metaheuristics, hybrid techniques; among other; however, the preferred method of solution is the application of metaheuristics.

Two of the factors that usually generate uncertainty in deterministic VRP transport models, as mentioned (Berhan et al., 2014), are usually those related to stochastic time arches and stochastic nodes. In transport models, where in real systems these types of restrictions may arise, deterministic model solutions may no longer be feasible. However, an

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aspect not considered by the classification developed by (Berhan et al., 2014) and (Braekers et al., 2016), and that has been recently explored in two articles identified from the year 2021, is the case of arch blocking.

In the first of them, developed by (Nadizadeh & Sabzevari Zadeh, 2021, 2021), It is proposed to exchange the blocked arch that belongs to the best-known solution, for some other arch or sequence of arches that belong to the distribution network and that allow joining the nodes that belong to the eliminated arch, always seeking to minimize the cost of the new route obtained. The second proposal elaborated by (Li et al., 2021), uses an ACO algorithm to generate arcs and nodes that do not belong to the original network in order to generate alternate routes that allow the interchange of blocked arcs. However, the research proposal shown in this paper integrates the following characteristics, not included in the previously mentioned works.

1. *Each company has a method for generating alternate routes*: It is important to mention that, as it is a cargo vehicle, it will have restricted access to certain roads. The random generation of routes without a prior review could lead to traffic problems in legal terms. Faced with this fact, the algorithm and the proposed methodology give the companies freedom to create alternative routes, to maintain the vigilance and feasibility of the new alternative routes. The proposed solution algorithm is briefly described in section 3.2.4.
2. Blocking of some key nodes for distribution: In real cases, the partial closure of a distribution warehouse may occur; a factor that the previously mentioned authors do not consider; and to which the proposed methodology provides a feasible solution.

The solution method proposed by the methodology consists of the use of simulation - optimization with a process-based approach. In (Policroniades, G. et al., 2018) is mentioned that this type of approach is usually the most used to solve the VRP models through simulation - optimization.

2. The proposed Methodology, Description, and background

The methodology consists of nine stages, including a verification and validation process of information as exposed in the Fig. 1. The validation process is performed to validate both, the conceptual model, and the simulation model. This is a cyclical process with the main purpose of achieving an improvement within the distribution system. The following methodology is based on (Banks, 2010; Hamdy A. Taha, 2016; Prawda, J., 1991).

In general terms, the methodology begins by identifying the problem as a VRP using company indicators. Subsequently, a systemic analysis stage is executed, using the operation research methodology (Hamdy A. Taha, 2016). Once the systemic analysis is finished, the conceptual model is constructed (Banks, 2010), and the distribution network analyzed by metrics of complex networks (Estrada, 2015; Rokach & Maimon, 2005). With these stages, we proceed to implement the simulation process and generate the scenarios to improve the topology of the network. Once this stage is completed, we proceed to simulation–optimization stage (Carson & Maria, 1997), the results are presented, and the solution is implemented. The process must be under constant supervision and if possible, when failures are detected, the methodology must be performed again.

The proposed methodology consists of different methodological and technical approaches; as shown in Fig. 2. From left to right, it can be identified the methods and techniques:

- Complex Networks: This approach is based on the topological analysis of the distribution network, mainly aimed at identifying the vulnerability and efficiency of the network in the face of possible attacks that could generate blockages on the routes, or temporary elimination of nodes in the network, together with an analysis of metrics that enables us to quantify the coefficients of centrality,

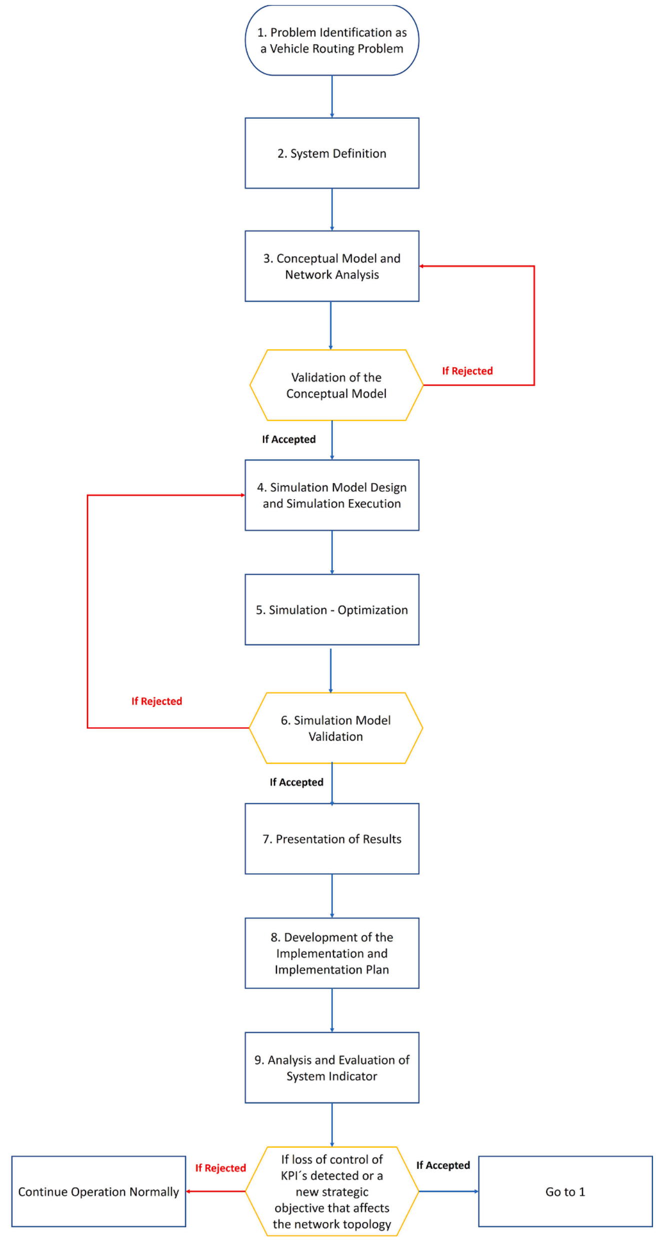

Fig. 1. Proposed methodology, based on (Policroniades, G. et al., 2018).

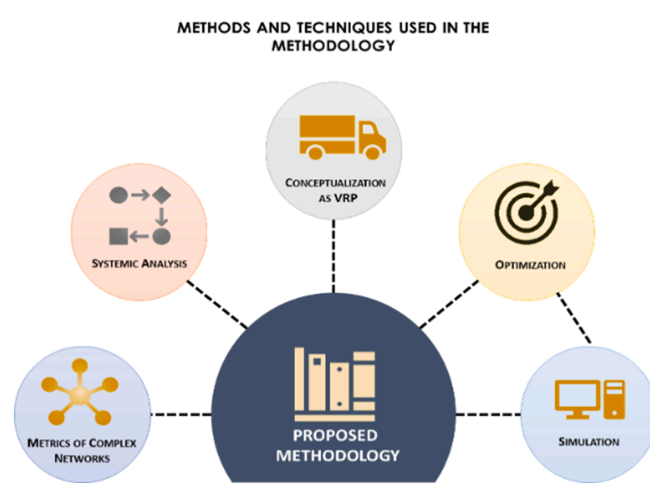

Fig. 2. Proposed methodology.

clustering, assortativity, among others (Casasnovas, 2012; Estrada, 2015; Lei et al., 2012). In (Lei et al., 2012), the advantages of performing a topological analysis of distribution networks are mentioned.

- General systems theory: This approach allows a systemic analysis to identify the limitations, relationships, variables, and functions that exist within the system. During this process, it is possible to identify internal or external elements of the system that can affect the distribution of the product throughout the network (Prawda, J., 1991; Von Bertalanffy, L., 1976).
- Vehicle Routing Problem: The core part of this methodology is to solve vehicle routing problems, for which, the specific characteristics and limitations must be identified that enable the classification of the type of vehicle routing detected in the company.
- Simulation – Optimization: This selected solution technique enables the integration of environmental or fortuitus factors that cannot be integrated into deterministic models. Some of these factors may be vehicle breakdowns, stochastic customers, stochastic demands, changes of routes due to unexpected closures, etc. (Berhan et al., 2014; Bertsimas, 1992; Huang et al., 2018). The concept of optimization is linked to the VRP to find the best route that minimizes the predetermined cost function (Baggag et al., 2016; Juan et al., 2013).

As for the methodology, similar papers that use the topological analysis of companies in the automotive industry include (Lei et al., 2012). However, when the purpose is to implement a combination of the VRP with a complex network approach as applied to a manufacturing sector, it is important to note that the linearity of the process does not allow the existence of bifurcations in the paths, as found in (Aleta et al., 2016; Gallotti et al., 2016). According to this, the use of the metrics of a complex network are proposed for the analysis of the distribution network of a company in this sector, emphasizing the vulnerability and efficiency metrics of the network against possible failures in nodes and arcs. These concepts, as mentioned in (Holme et al., 2002) can be measured through attacks directed at certain arcs or nodes. One of the reasons why this type of study should be done, as the author proposes, it is to protect the most important nodes of the network to improve the robustness of the network. These nodes can be central depots or regional warehouses as well as important customers.

A VRP, as identified in (Cordeau et al., 2007), is a complete network which indicates that all the elements or nodes of the network are connected to each other by arcs. This means an assortativity coefficient equal to 1 (Shergin et al., 2021). When analyzing a company's distribution network with regards to its customers, we can observe that this may consist of a set of different complete networks. The way to identifying them lies in finding the central or regional warehouses that make it up. Each of them has a specific portfolio of interconnected customers that are served by a fleet of vehicles that form a complete network. However, what happens in the case of one or two regional warehouses and one central depot? As the example illustrated by the following Fig. 3:

In Fig. 3, there is more vulnerability in the VRP 1 network because there are only two different ways of getting from the central depot to one of the other two warehouses.

Another possible scenario that can affect the product distribution would be having a warehouse closed for a certain cause. When this happens, as mentioned by (Cartledge & Nelson, 2011), the arcs belonging to the failed node are disabled within the network until after the contingency, causing a drastic loss of connectivity within the network.

The distribution network of each one of the companies that make up the automotive sector's distribution chain has a specific structure, depending on the consolidation mode: Milk-Run, Consolidation at the Transfer Point, or Supplier Consolidation as mentioned in. Each of these modes may vary from company to company, depending on the type of agreement with their customers and its facilities. However, these distribution networks because of the volume of product they handle and the high globalization and search for emerging markets in the same sector, are vulnerable before possible supplier failures, changes of routes, partial closure of warehouses, elimination and capture of new customers among other factors (Braese, Niklas, 2005).

One important aspect of the proposed methodology that is worth mentioning, consists of the development and improvement of the distribution networks, to avoid areas or regions vulnerable to failures. This can be achieved by developing scenarios that explore the different metrics that characterize the network, with the objective of increasing or decreasing its density in certain specific regions. Increasing the density of the network increases its strength to deal with possible attacks. Under these characteristics, it is necessary to analyze the following aspects:

1. There is some other warehouse that can provide the necessary products, if so, then an arc of connection can be added between the disconnected nodes and the new distribution warehouse. This will result in the customers always being connected to a supply source.
2. In the event of removing a customer from the network, verifying if deleted connections do not affect the connectivity of a neighboring node, if so, this node must be reconnected to the remaining nodes.

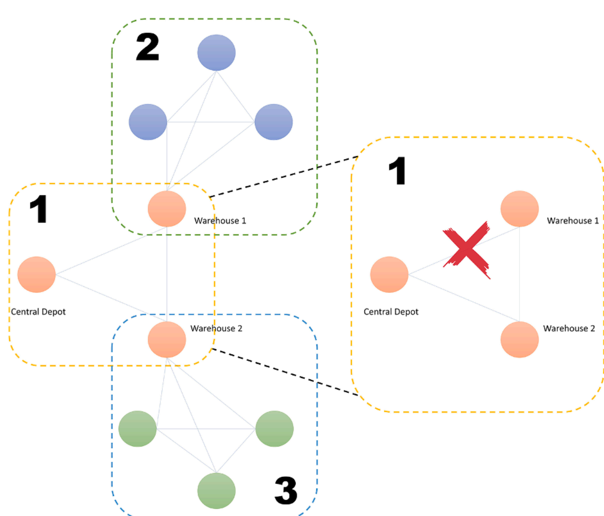

Fig. 3. Example of the elimination of an arc in the distribution network.

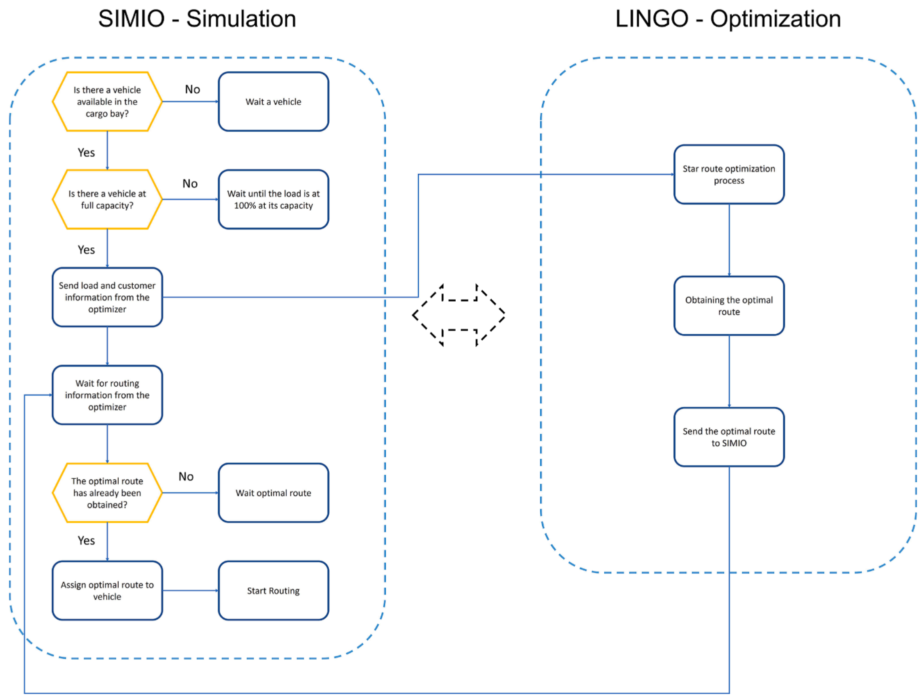

Fig. 4. Diagram of the Simulation – Optimization process.

This analysis will make it possible to discover and study unexplored connections that may represent a topological and operational improvement of a distribution network.

Another important aspect of the methodology is the Simulation - Optimization process, which is done through the LINGO optimizer, through the process shown in Fig. 4.

The optimization process is carried out with the support of the LINGO software, one of the main reasons for defining this process is that the Optquest optimizer provided by the SIMIO software bases its optimization on certain system indicators as can be seen in the user manual of the same software. Generally, when a Simulation - Optimization process is solved, what is sought is the best value of the system's input variables, (Carson & Maria, 1997); however, in a process such as VRP, where demand and customers are stochastic, they force them to find the best route based on the demand satisfied by each of the vehicles. That is, each time the simulation is run the solution will be different, this will depend on the definition of the statistical distributions of demand and the arrival times of each one of these. In this regard, the solution obtained by the SIMIO Opquest will not offer a suitable solution unless the routing process and simulation are deterministic, that is, that the demands do not change over time.

Another important aspect, for which the use of the LINGO software is selected, is due to the size of the problem, which is made up of a total of 8 nodes. If the bibliography of the VRP is analyzed, such as the one mentioned in (Braekers et al., 2016; Mohammed et al., 2017; Policroniades, G. et al., 2018), exact algorithms are recommended for problems with a small number of nodes (Cordeau et al., 2007). On the other hand, as the complexity of routing models grows, the authors usually recommend heuristic, metaheuristic models that allow searches to be made and offer good solutions in reasonable times for correct decision-making (Laporte, 2009).

The optimization process, as mentioned, is envisioned by means of a joint process between the SIMIO simulation and the LINGO optimizer. To achieve this goal the Excel, Write, Excel Read operators are used, which allow the export and import of the state variable data to an Excel file, these operators are integrated in SIMIO. Once the values of the state

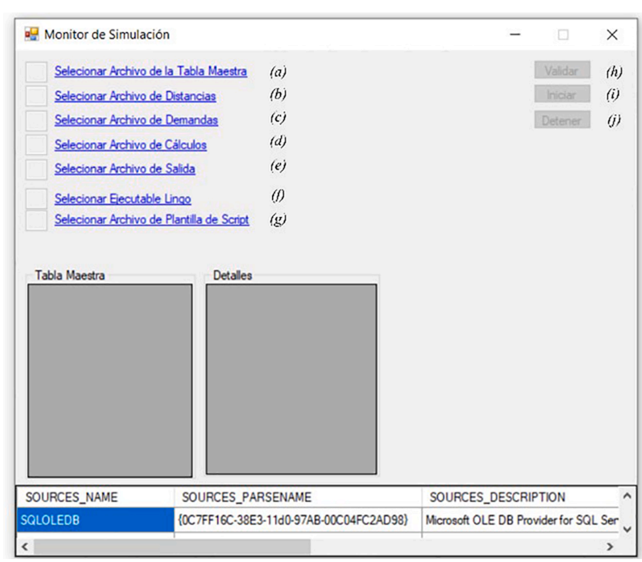

Fig. 5. Monitor image, used to link SIMIO and LINGO.

variables are inscribed in the Excel file, the LINGO program starts to obtain the optimal solution to the problem.

An important aspect to mention is the use of the Excel file which as can be seen, is shared by both the LINGO program and the SIMIO simulator. Requiring the development of a tool that manages the file resource, to ensure that there are no collisions between the two programs when writing or reading the desired file. This program is called MONITOR, (Fig. 5) which controls access to excel files shared by LINGO and SIMIO, pointing at LINGO that it should wait its turn to start the optimization process, likewise, it happens when LINGO is using the file and SIMIO wants to access it.

The optimization monitor is made up of a total of 10 elements, which are shown in Table 3.

The missing items run the monitor once the previous files have been loaded into the system. It is important to indicate that one of the reasons for the existence of so many Excel files is to avoid the concept of competition for the use of one file and not to saturate the optimization process.

2.1. Description and sequence of the proposed methodology

The process of application and development of the methodology will depend to a large extent on the company under study, not all steps must be performed strictly and are at the discretion of the modeler, the designated team and the company's senior management. The proposed methodology is described in (Policroniades, G. et al., 2018) in a very general manner.

Stage 1. Definition of the Problem, as a VRP

During this first stage, it should be verified that the company's problem is attributable to a VRP analyzing the behavior of logistics KPIs (Kasilingam, 1998). If the problem is attributable to the company's distribution system, then the company's transportation model should be defined, and an economic proposal that justifies the development of the project and therefore the application of the methodology should be made. To carry out these studies it is necessary to carry out a Project Charter; identifying the areas involved, the commitment dates, the expected and current objectives, the economic impacts and the impacts or improvements for the client. The economic analysis of the project should include all the items in a general way, considering the possible unit costs to be incurred; in the same way, the investment recovery time should be indicated. In (Pizdek,T. & Keller,P., 2009), the process for defining a Project Charter is mentioned; similarly, a review of the literature related to financial analysis or economic engineering is recommended.

An important aspect to mention; it is the existence of some objective of improvement of the distribution network of the company. In this case, the analysis of the logistics KPIs may be omitted, and the definition of the Project Charter and financial analysis of the project may be defined.

Stage 2. System Definition

It is important to point out that Stage 2 is developed under the following two subdivisions; the first one applies to the original network of the Distribution System, where variables, limitations of the resources and relationships prevailing in the System are identified (Mota et al., 2017).

During this process, some new elements may be attached to the system, such as regional/local warehouses that need to be disaggregated to identify their relationship with the other existing elements in the system. The disaggregation of the system is carried out by the black box method (Acosta Flores, 2002). The analysis of the distribution network environment should be considered in the same way, identifying all those internal or external factors that may collapse the arcs or nodes of the system.

Another important aspect of this stage lies in the statistical adjustment of the data found during the analysis (Mota et al., 2017).

Stage 3. Conceptual Model and Network Analysis

During this stage, two different processes are developed; first the conceptual model of the system must be developed; both of the current state, as well as the proposed state. Secondly, the topological analysis of the distribution network is performed if it is within the company's organizational objectives. This analysis consists of the application of complex network metrics, such as: centrality measures, asortality coefficient, cluster analysis; among other metrics that allow identifying and improving the network topology (Barabási, Albert-László, 2016; Estrada, 2015; Rokach & Maimon, 2005), while rebuilding the VRP, applying the reconstruction algorithm shown in section 3.1.4. Fig. 8 shows the general scheme of stage III. In (Mazzuco et al., 2018), it is mentioned that the conceptual model should correspond to a description of the real system, involving the most relevant variables, relationships and processes of the system. The same author briefly describes the general steps for the development of a conceptual model of a Simulation - Optimization.

Stage 4. Simulation Model Design and Simulation Execution

Stage 4 is mainly divided into three sections; the first one, the design of the simulation model (Banks, 2010; Mota et al., 2017).

The second one, the development of scenarios for the improvement of the distribution network topology. During this process, you should focus on building different topologies of the original network, which will be defined as "Topological Scenarios". To each of these scenarios, the VRP network reconstruction algorithm, mentioned in section 3.4.1, should be applied; to include the possible collapse scenarios of arcs and nodes of the distribution system identified in Stage 2 during the environment analysis process. For each of these scenarios, a topological analysis should be performed, and the best network configuration will be selected.

The third one, the improvement of the simulation based on the improvement of processes; For this section it is possible to apply lean manufacturing principles (Allen, Theodore, 2019; de Bucourt et al., 2011).

Stage 5. Simulation - Optimization

During this stage, depending on the type of algorithm selected for the optimization process, the link between the optimization algorithm and the simulation program must be established. The authors (Carson & Maria, 1997), identify a set of different techniques that can be used during a Simulation – Optimization. On the other hand, there are different similar simulation–optimization applications applied to routing problems; how are the papers made by (Barceló et al., 2007; Fan et al., 2009; Sopha et al., 2016), in which different ways are identified to make a link between the optimization program and the simulator.

Other works related to the Simulation – Optimization process of transport problems, are those of (Calvet et al., 2016; Shetty et al., 2020). However, regardless of the models and approaches used, the solution process is usually very similar. On the one hand, the simulator controls the processes of loading, unloading, manufacturing of the entities or products that are loaded in the vehicles; and on the other hand, there is an optimizing algorithm that provides the best possible route for the vehicle to take.

Stage 6. Validation and Verification of the simulation model

During stage 6, the validation of the Simulation - Optimization model is carried out through the selection of the simulation method. The validation method will depend on the test instances, which can be obtained from the literature or by means of real system instances. To identify the best validation method of the Simulation – Optimization model, it is recommended to review (Huerta Barrientos, 2014).

Stage 7. Results presentation

During this stage, the results of the Simulation - Optimization are presented to the company's top management. The presentation of the simulation results should contain certain minimum elements; as mentioned in (Banks, 2010, 1998).

Stage 8. Development of the implementation, and implementation plan

The implementation process should consist of an implementation plan, with a specific schedule and the person responsible for these activities, always approved by the company's top management (Pizdek,T. & Keller,P., 2009).

Stage 9. Analysis and Evaluation of System Indicator

During these last stages of the methodology, the statistical control of the key indicators of the distribution process must be maintained in case any of the indicators is out of control, it must be evaluated whether the application of the methodology is warranted again (Pizdek,T. & Keller, P., 2009).

3. Case of Study, Description and application

The study case is focused on a company within the automotive sector, whose supplies its product directly to an automotive assembler, automotive workshops, and automotive agencies.

Table 1
Monitor components, shown in Fig. 5.

Element	*Description*
a)	Select the file from the master table: The main objective of the master table is to indicate to the system which of the LINGO models should be executed; for example, if an arc in the system is blocked, then model (1) must be executed, otherwise, an alternate model (2).
b) And c)	In this case, it is the distance and demand data, used by the LINGO optimizer.
d)	Select calculation file: In this file the prioritization process is carried out for each of the elements of the system.
e)	Select output file: In this file, LINGO's solution will appear, with the respective priorities of the elements; in the same way, from this file the SIMIO simulator will read the data to make the assignments of the vehicle trips.
f) And g)	These sections correspond to the location of the LINGO executable file, and the script of the model to be solved.
h)	Validate that the files have been uploaded correctly
i)	Starts the process of Simulation – Optimization; controlling access to files shared between LINGO and SIMIO
j)	Stops the monitoring process and the optimization process

Table 2
Constraints considered for the design of the problem of Company X.

Characteristic	*Description*
1	Real demand is divided by a factor of 1000 or 100 in order not to exceed the number of entities that circulate around the system in each time for the SIMIO simulator. The demand values for this model are found in the following source: (INEGI, 2019).
2	The maximum number of vehicles used in the system is 4 units, two for each of the warehouses.
3	For the simulation process, the time windows of clients and warehouses are not considered.
4	The maximum load capacity of the vehicles, both in the central warehouse and in warehouse 2, is 5 entities, in such a way that each entity is equivalent to one product Pallet. A product pallet in turn can integrate a set of product type entities.
5	For modeling, only the following node and arc collapse events are considered: Vehicle failure, Failure in system warehouse 2, Presence of shock in an arc.In this way, possible collapse scenarios within a network are covered, which may affect the distribution of the product.
6	The product under study, only corresponds to a single type; selected due to its high sales volume. This product is shared with different vehicle platforms of different brands and clients.
7	The production process of a seat belt can be roughly classified into the following three different stages:1. Manufacture of the rope for retractors2. Preparation of the retractor3. Seat belt assembly

The company, which we will call Company X oversees the design, development, and distribution of seat belts. Among its main clients the following can be mentioned: *General Motors, Volkswagen, Nissan, Ford, Mitsubishi, Chrysler, Toyota, Mercedes Benz, BMW,* among others.Table 1

3.1. Description of the problem

The problem of Company X will be addressed as a small case, due to the following aspect, showed in Table 2.

Mentioned the above, the case will be presented.

Company X has a portfolio of 8 customers, which are cataloged into two regions according to their percentage of sales and distance from the central depot. However, despite the regions, customers are served from one single warehouse. Fig. 6 shows the structure of Company X's distribution network.

These customers' consumption behavior is determined by different statistical distributions depending on each customer, we also know the statistical distribution of the orders' interarrival time. These customers can be classified into three types: the first being assembly plants, the second, automotive agencies and the third, service workshops.

The production process of a safety belt goes through two manufacturing cells prior to the assembly of the safety belt. These cells correspond to the elaboration of the rope for the retractor, the elaboration of the retractor, and the assembly of the final belt. For the purposes of the example, two production lines for seat belts were agreed giving a total of 6 manufacturing cells. Each of the manufacturing cells has a bill of materials, as well as a cycle time, which will be addressed in more detail in Stage 4 of the simulation model.

It has: a warehouse with a maximum capacity for 250 seat belts, a fleet of two vehicles with capacity for 4 packaged products, considering that each packaged product contains 4 belts, a sales department with a person responsible for this job.

As we have already mentioned, three types of customers depend on the central depot: Automotive Agencies, Service Workshops and Assembly Plants. Each of these groups of customers has its own characteristics. For example, orders from the assembly plants usually present a uniform distribution behavior, while orders from automotive workshop and automotive agencies usually present a stochastic behavior. But everything will depend on the statistical fit.

The problem can be classified as is shown in Table 3.

As for its routing system, each warehouse in the system would control its own fleet of vehicles, in which case, optimization must be performed for each one of them separately. Also, it is important to mention the following characteristics of the routing problem, shown in Table 4.

3.2. Application of the methodology

In this section, it will be possible to appreciate the application of the methodology, depending on the decisions and the development of the problem. It is important to point out that only a summary and representative image of each of the stages will be shown, with the purpose of showing the sequence up to Stage 6.

3.2.1. Stage 1 Problem Identification as a VRP

In the example of Company X , the main objective of generating the scenarios is to decrease the vulnerability of the distribution network and avoid possible collapses of arcs and main nodes as shown in Table 4. Added to this, the following objectives, and characteristics of the VRP are detected, shown in the Table 5.Table 6.

Once the VRP model has been identified, we can start the next stage of the process, when the systemic analysis is developed.

One of the reasons why the VRP model used to solve the routing problem of Company X is visualized as a CVRP model, apart from being based on the use of student version software, is based on the characteristics of the real system constraints mentioned above; on the other side, it is necessary to mention that the simulation software allows to simulate and control complex aspects that can increase the computational complexity of a VRP model (Mazzuco et al., 2018), acquiring in the simulation model that complexity, some of the VRP restrictions that can be simulated in the simulation software, as long as in the real system the possibility is present, are:

- Time Window Restrictions
- Assignment of vehicles to loading bays
- Product loading problems
- Stochastic demands
- Stochastic customers

In the case of time windows, for example, it is possible to elaborate a small process in the simulation by which, if the order cannot be delivered within the established time period, it will proceed to assign it to another time opening or another working day. This will always depend on the characteristics of the real system, allowing it to be controlled by the simulator, and not having to depend on the optimizer.

The reduction of the constraints of a VRP model, to be controlled by the simulator, will always depend largely on the skill of the modeler and the characteristics of the constraints of the real system.

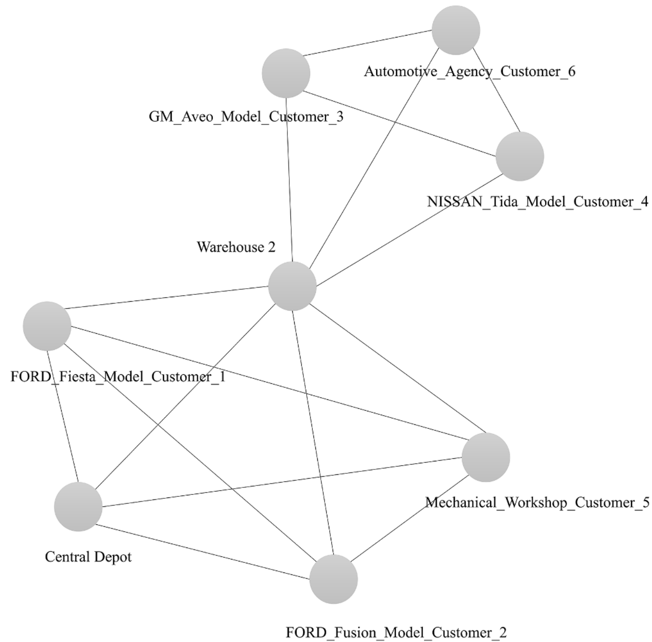

Fig. 6. Company X distribution network, obtained through software R.

Table 3
Constraints considered for the design of the problem of Company X.

Characteristic	*Description*
1	Shortage of Raw Material: Over the last 7 months the company has suffered from a shortage in the delivery of its raw material and, despite talks with its suppliers, the problem could go on indefinitely owing to the lack of components for its manufacture and legal regulations meaning that the product needs yet another check when delivered to customers. The company has tried to find new suppliers, but this is the only supplier of that type of product.
2	The person in charge of the logistics area performs the programming of the vehicles based on the concept of the shortest route. This process is carried out after the vehicle is loaded, which must be 100% of its capacity.
3	Demand and Arrival of Orders: Because customer demands and order arrivals are stochastic, the company does not have a method for identifying the best routing sequence, which means, once the vehicle is loaded, the delivery of the product is random, sometimes generating a longer travel distance than expected.
4	Lack of Suppliers: Faced with the suppliers ́ growing failure in delivery times, the company considers a strategy of installing one or two regional warehouses that could deal with possible shortages in its production area. Also considering the proximity to its customers and source of supply, to reduce the distances traveled through the entire system.

In the case of the problem of Company X , it is possible to reduce the complexity of the model, due to the following considerations:

In the real system, the calculation of the vehicle route is performed by the following process in Fig. 7.

As it can be seen in Table 7 the method used to design the routing process for Company X is far from being an optimal process, however, it does allow a sequence of trips to be obtained.

Faced with this scenario, it was decided to develop a Simulation-Optimization model that would provide Company X with greater robustness in the design of its distribution network, like the company's ability to add new customers in the future, and thus ensure the reduction of distribution costs in the event of possible collapse of arches and nodes that it may face.

Thus, it can be said that the objective of the application of the methodology is a strategic aspect for cost reduction, to improve its routing process, and to face possible events that may violate its

Table 4
Characteristics of the routing problem.

Characteristic	*Description*
1	The vehicles wait until they are filled before starting the journey to the corresponding customers. The vehicles have a maximum capacity of 15 pallets.
2	Demand that exceeds the capacities of the vehicles can be divided up and sent in several vehicles.
3	Every vehicle has a schedule for the driver's working day. During rest periods, the vehicle returns to the corresponding warehouse to await a new trip.
4	Each vehicle has a failure time, meaning the time taken up by a vehicle's breakdowns and repair time, when the vehicle is moved to a service node, once the repair is completed the vehicle takes up its activities again.
5	From this information, the main objective of the company and the research to be carried out can be defined in the following two points: • Identifying the best configuration of the distribution network that reduces its vulnerability to possible failures in the warehouse 2. • Using Simulation - Optimization, we intend to find a vehicle routing sequence that minimizes the distance traveled in the product delivery process.

Table 5
Objectives and characteristics detected in Company X.

Characteristic / Objective	*Description*
1	Find the best network configuration to lower vulnerability to possible failures of the Warehouse 2, and the arc between the central warehouse and the client 1.
2	Use simulation - optimization to obtain a routing sequence for the vehicles that minimizes the distance traveled during the delivery process.
3	In the current state, the company uses the shortest route concept to develop the delivery process, which must be improved.
4	The VRP model identified for the example under study has the following characteristics: A routing problem with limited vehicle capacity (Capacitated Vehicle Routing Problem -CVRP), Stochastic Customers, Stochastic Customer Demand, An inventory problem.

Table 6
Considerations for reducing the complexity of the VRP model.

Characteristic	*Description*
1	There is no time window restriction by any customer.
2	Route calculation by means of the optimizer is not performed until the vehicle is completely full and ready to start a distribution process in the loading bay of either of the two warehouses. In this case, it is known to which customers the delivery will be made; thus, ensuring that the VRP model follows a deterministic route.
3	Collapse events, when they occur in the system, force a new route calculation at the time they occur.
4	To manage and control possible chaos with respect to fortuitous demands and fortuitous customers, proceed as indicated in point 2.
5	Although the company has two warehouses, each one is independent in its operation, except for warehouse 2, which belongs to the distribution network of the central warehouse. With this consideration, there are two complete networks with the same VRP in the distribution system. The number of nodes in the central warehouse may vary when warehouse 2 is closed; however, the routing constraints are the same. In this case, the simulator manages that the demands of warehouse 2 are sent and supplied by the central warehouse.

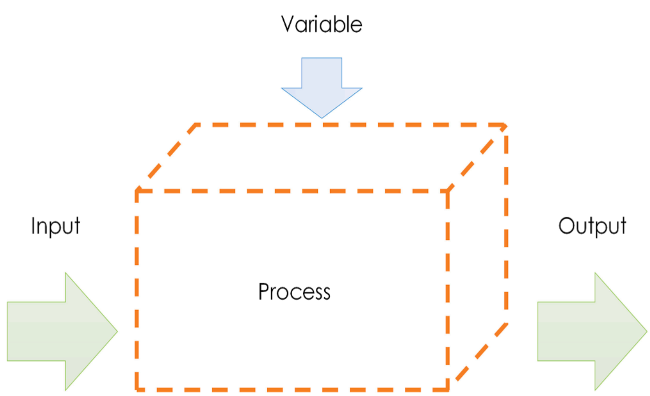

Fig. 7. The black box concept, design based on (Acosta Flores, 2002; Hamdy A. Taha, 2016).

Table 7
Algorithm for route design for Company X , provided by the company.

Step	*Process*
1	Identify the corresponding customers to the loads located inside the vehicle.
2	For each customer i, identify through Google Maps, the distance in Km, from the warehouse to each customer.
3	Select from the routes identified in the step 2, the route with the lowest cost or distance. And identify the customer with the lowest value with i^*.
4	Assign as the first trip of the vehicle, the route selected in step 3, to the customer i^*.
5	Position yourself at the customer i^* and remove (*) badge.
6	From the customer location of step 5, calculate the distance to the remaining customers.
7	Select the customer with the shortest route and assign the badge (*).
8	Repeat steps 5 to 7 as many times as there are customers.

distribution network; for this reason, we proceed with the feasibility of the company's application.

3.2.2. Stage 2 System Definition

The systemic analysis is obtained through the construction of a model that synthesizes the most relevant aspects of the real system; however, this abstraction may prevail in the type of model to be built. Some of these models, as mentioned in (Berhan et al., 2014) can be classified into two main strands: the first, deterministic models, and the second, stochastic models. The operations research models to which the proposed methodology is intended to provide a solution are stochastic models. These models, as mentioned by the same author, are ruled by probabilistic or stochastic characteristics, mainly focused on characterizing aspects of the system that can cause blockage of arcs, blockage of nodes (customers or warehouses), as well as certain demand behaviors that can lead to the vulnerability of a company's distribution system.

The proposed systemic analysis is based on the concept of a black box, where, as shown in Fig. 7, the different elements that are combined to produce a given good or service can be identified.

The way in which this systemic analysis operates consists of disaggregating the system into different levels of details in order to obtain the desired level of detail for the construction of the model, in case it is solved, Figs. 8, 9, 10 and 11 can be identified, referring to the different levels of disaggregation for the case shown.

Fig. 8 shows the systemic analysis of Company X at the first level, identifying the company as an entity that receives raw material, transforms it by means of some process and then starts the distribution process after obtaining the finished product.

Correspondingly as an example, Figs. 9 and 10 show the systemic analysis of Company X at the second and third levels. In Fig. 11, a new element to the systemic analysis can be identified.

In Fig. 11, a new element to the systemic analysis can be identified, which is proposed in the methodology; this aspect involves the analysis of the possible effects of the environment on the distribution network; more specifically, in those aspects that could trigger some node closure or arc blockage. This aspect involves the analysis of the possible effects of the environment on the distribution network; more specifically, in those aspects that could trigger the closure of nodes or blockage of arcs.

The systemic analysis, and the level of detail will depend on each system under study, however, it should be kept in mind that the objective is to identify the variables, their relationships and the settings of the statistical distributions that characterize their behavior. Each company, by means of a vulnerability analysis and a study of the strengths and weaknesses of its distribution system, will be able to identify the critical factors that can generate blocking of nodes and arcs within their respective distribution system. The aforementioned was outlined in Fig. 11.

In the case of Company X , as can be seen below, it is subject to the following possible collapses within its distribution network, based on Fig. 15, shown in the Table 8.

It is important to point out that step 2 is developed under the following two parts: the first one applies to the original network of the Distribution System, where variables, constraints of the resources and relationships prevailing in the system are identified.

One of the main objectives of this stage, as previously mentioned, is to identify the key variables and relationships between the elements of the system. This is achieved, as shown below, by means of data fitting of the identified variables. Another important aspect of this stage lies in the statistical adjustment of the data found during the analysis.

Fig. 12 is given as an example of this section, where the customer's demands can be identified, and their respective distribution can be determined from the corresponding adjustment obtained through MINITAB 17 software. In Table 9, some of the elements shown in the adjustment graphs are represented, with their respective translation. Fig. 13.Fig. 14.

As an example, we show three data adjustment obtained through the MINITAB 17.

It is important to mention that we are using integer values as they represent demand values.

Fig. 15 below gives an example of how a set of variables supports the definition of a function that is part of the inventory process.

3.2.3. Stage 3 Conceptual Model and Network Analysis

Once the analyses of the scenarios and the original network have been obtained, we proceed to select that scenario whose characteristics meet the objective of the scenario selection defined during Stage 4, these

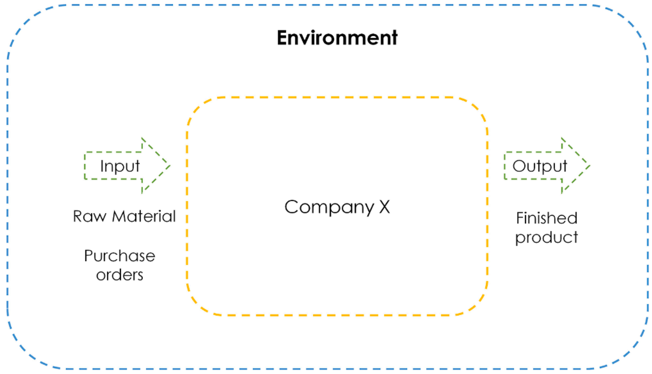

Fig. 8. Representation of the first level analysis of Company X.

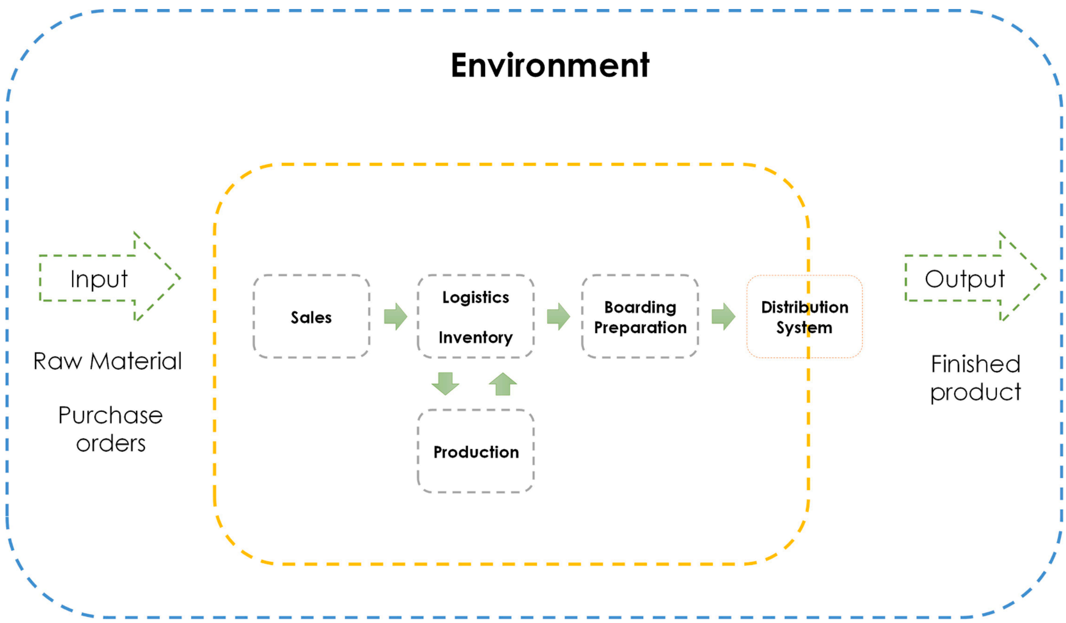

Fig. 9. Representation of the second level analysis of Company X.

scenarios must be based on the mathematical formulation for the creation of alternative routes, and on the search for the reduction of the vulnerability of the network.

Depending on the characteristics of the selected scenario, if there is any new element in the network, the second section of Stage 2 will be developed. Through a systemic analysis of the selected scenario, its conceptual model is developed.

One of the objectives of this stage, as mentioned in section 2, is precisely the development of the conceptual model, it should be remembered that there will be at least two conceptual models, that of the current state of the system, and that of the proposed state. The conceptual map of the proposed state should be elaborated from the best-case scenario selected after the topological analysis, or to meet the company's objective. Fig. 16 shows the conceptual map of the current state of the central warehouse. The concept maps, as deliverables of stage III, will be part of the deliverables of this stage, and will allow the development of the simulation model.

Another very important aspect of this stage, if it is considered in the company's objectives, is the topological analysis of the different scenarios generated during Stage 4. For this stage, the network for each of the scenarios is constructed.Table 10

Using R software, the distribution network of Company X is obtained for the different scenarios in Table11, shown in Fig. 17

Fig. 18 shows that by eliminating or blocking the node equivalent to Warehouse 2, 65% of the network connectivity is lost, since the nodes that depend on this warehouse are completely disconnected from the distribution network. One of the most significant metrics that will be used to improve the network is the concept of network density, which has a value of 55%, indicating that only 55% of the possible connections within the distribution network are being used. As this value increases, the network tends to become a complete network, indicating that all nodes are connected to each other.

In Stage 4, when generating the possible scenarios for improving the distribution network, the two scenarios generated to eliminate the infeasibility of the VRP in the face of the possible collapse scenarios detected are shown in Table 11.

As can be seen in Fig. 19, the vulnerability of the network in scenario 2 is greater than in scenario 1, however, this scenario forces the Central Warehouse to have the operational capacity to be able to support the clients of warehouse 2 when it fails for a certain period, as previously mentioned. This observation can be seen in Fig. 17, however, in Fig. 19, in scenario 2, it can be seen, that if warehouse 2 fails and the path to the customer (Region 2 Automotive Repair Shop) is blocked, then communication may fail. For this reason, the vulnerability graph of scenario 2 shows a behavior in which the network is mostly threatened.

All this is due to the density metric of the two networks; in the case of

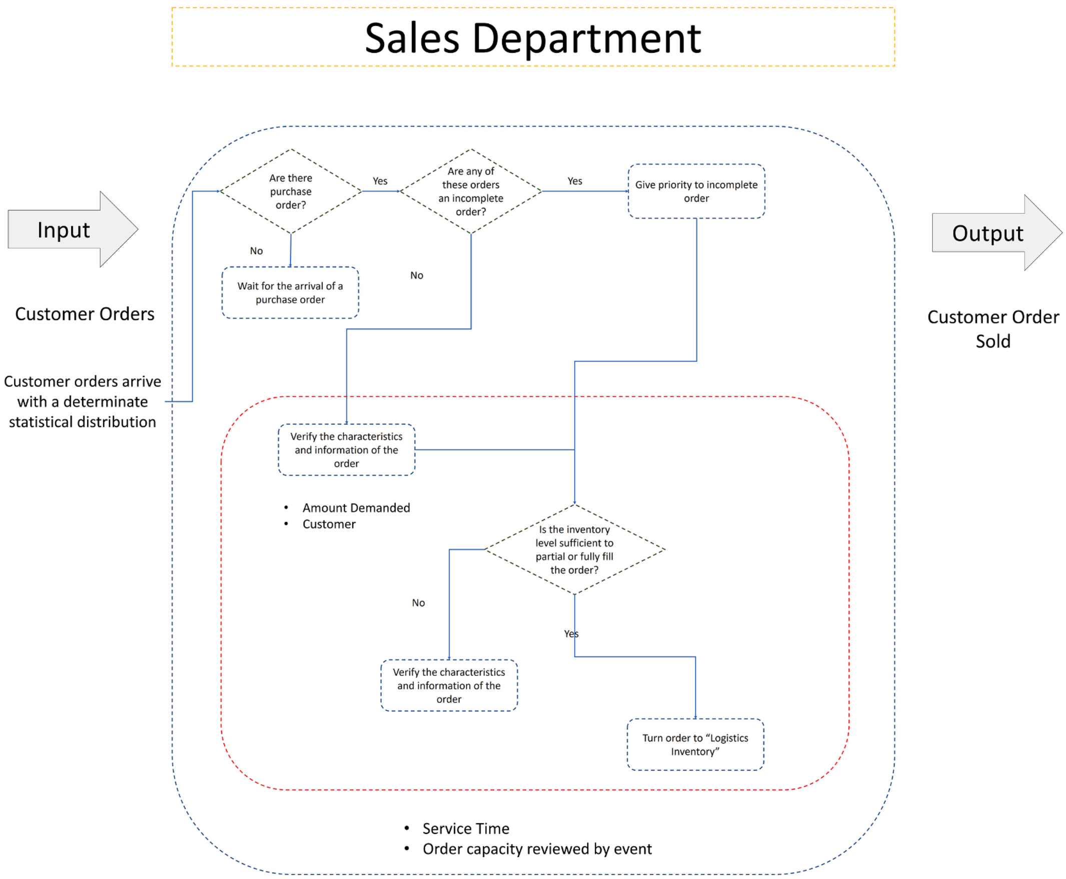

Fig. 10. Third level analysis of the sales department of Company X.

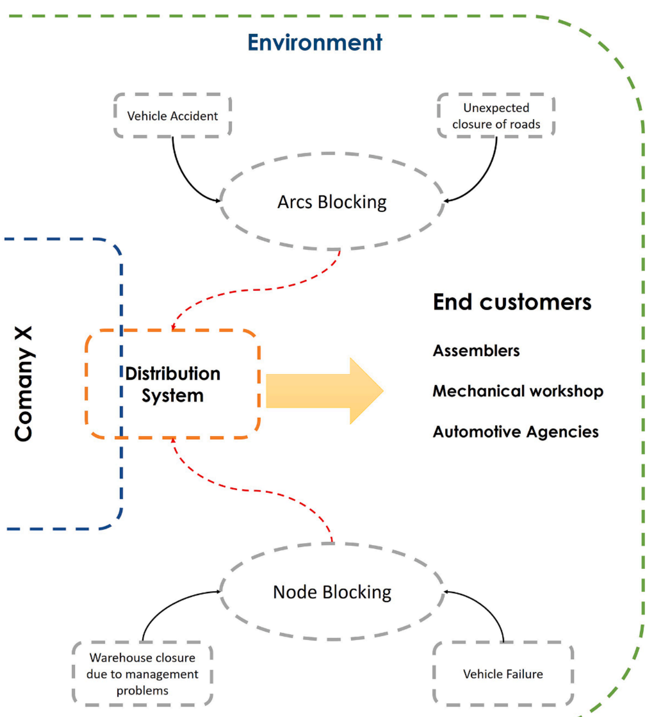

Fig. 11. Representation of the second level analysis of the environment and Company X.

scenario 1, it has a density of 88% and scenario 2, 66%, therefore, it can be said that the number of connections within the network is greater, since in this scenario the By-Pass is integrated into the system and the connection of all customers of warehouse 2 to the central warehouse. Thus, although the centrality analysis is not shown, it can be said that as there are more connections within the network, the nodes will be closer to each other, i.e., there are more possible ways to get from one node to another within the network.

The deliverables of this stage will be the two or more conceptual models of the current state and the proposed state for the elaboration of the Simulation Model. In this way, scenario 1 is selected for the construction of the Simulation Model.

3.2.4. Stage 4 Simulation Model Design and Simulation Execution

Before presenting the simulation, it is important to mention that the following possible collapse scenarios are identified within the distribution network, which could put the integrity of the network at risk:

These collapse events come from Stage 2, specifically from the analysis of the system environment shown in Fig. 11. Observe how some events can occur simultaneously.

In this way, 6 different possible models are identified and constructed that will be related to each of the previously mentioned collapse events. When one of these events occurs, a flag indicates to the system which optimization model should be executed so that the vehicle always circulates on the best possible route. This route will be obtained through the LINGO optimizer and due to the number of nodes, it will always be equivalent to the optimal route under the indicated nodes. The simulation process will be carried out as mentioned above:

One of the key stages of the methodology is Stage 4; in which, apart from being defined the scenarios for the improvement of the topology of the distribution network, the simulation models of the current state and

Table 8
Definition of node and arc collapse.

Concept	
Arch collapse	A blockage of the arch (Central Warehouse - Client 1) has been identified; due to the presence of frequent accidents on this roadway.
Node collapse	To specify the collapse of a node within the distribution system, it is necessary to indicate, as mentioned in this research, that the collapse is considered only in the main nodes of the distribution system; thus, the collapse present in this work is the blockage of warehouse 2, due to inventory revisions.
Simultaneous collapse of Nodes and Arcs	This event occurs when the two previous events occur at the same time.

Table 9
Translation of some parameters located in the adjustment graphics obtained by MINITAB 17.

Customer	*Distribution*	*Parameters*
FORD_Fiesta_Model_Customer_1	Gamma Distribution	$\alpha = 3$ $\beta = 7$
FORD_Fusion_Model_Customer_2	Gamma Distribution	$\alpha = 2$ $\beta = 4$
GM_Aveo_Model_Customer_3	Gamma Distribution	$\alpha = 2$ $\beta = 7$
NISSAN_Tida_Model_Customer_4	Gamma Distribution	$\alpha = 1$ $\beta = 6$
Mechanical_Workshop_Customer_5	Normal Distribution	$\mu = 2.2$ $\sigma = 2.7$
Automotive_Agency_Customer_6	Normal Distribution	$\mu = 3.6$ $\sigma = 4.3$

the desired state of the system are also developed.

Referring to the stage of creating the scenarios of Table 10, these should meet the objective of reducing the vulnerability of the network and the search for alternative routes to possible arc blockages. The objective, as mentioned, should seek a balance between the density of the network, the activities that each of the warehouses must carry out for the proposed new network and provide solutions to possible arc blockages. In case of the example in this article, only a single case of improvement is generated largely due to the limitations of the software mentioned in the first section. However, in the absence of such restrictions, it will be possible to generate scenarios with a greater amount of complexity. The objective of the case shown in this article, states the function of making known the different stages of the methodology and showing roughly the scope of it.

The development of the methodology is only carried out to Stage 4 as the Simulation–Optimization process for the proposed network and the current network is still pending. The software used to run the simulation and the subsequent simulation–optimization process was SIMIO - Simulation version 10.181; on a PC with an Intel core i7, 8th Generation processor.

Simulation model of the current state

The current simulation model of Company X is built after Stage 2 and 3 of the methodology, where the systematic analysis of the distribution network must be carried out and its conceptual model. With these two elements, it is then possible to develop the simulation model.

Table 12 shows the assumptions considered for the development of the simulation model; The information shown in this Table comes from stage I of the methodology.Table 13.

When executing the simulation model, it is possible to obtain the following results shown in Fig. 20.

An important aspect that stands out in the Fig. 20, is the number of orders received in store 2; however, when the warehouse closes due to inventory review, customer orders are no longer received.With these results, it is necessary to improve the production area of the company, to eliminate the bottleneck generated in that section of the model. To improve the production area, the manufacturing cells are leveled, and the process is improved through the application of lean manufacturing concepts.

Simulation of the proposed state

The proposed state simulation model should consider the presence of each of the system's collapse events, as well as process improvement of the system. The latter, from Fig. 20, is defined as the increase in production capacity from 2 manufacturing cells to 4 which doubles the production capacity.

In this proposed state, shown in Fig. 21, only the event of closing store 2 is presented; which causes an increase in the number of orders received in the central depot; and therefore, an increase in the distance traveled by their vehicles.

The occurrence of the events in Figure 22 is based on the definition of the system in stage 2; where the statistical behavior of the system

Daily Demand Adjustment of the FORD Fiesta Model platform - Client 2

Distribution	AD	P	LRT P
Normal	1.775	<0.005	
Box-Cox Transformation	1.081	0.007	
Lognormal	0.967	0.014	
3-Parameter Lognormal	0.965	*	0.434
Exponential	4.433	<0.003	
2-Parameter Exponential	1.825	<0.010	0.000
Weibull	1.080	<0.010	
3-Parameter Weibull	1.008	0.013	0.078
Smallest Extreme Value	2.454	<0.010	
Largest Extreme Value	1.167	<0.010	
Gamma	**0.974**	**0.017**	
3-Parameter Gamma	0.931	*	0.335
Logistic	1.708	<0.005	
Loglogistic	0.978	0.006	
3-Parameter Loglogistic	0.977	*	0.960

Fig. 12. Example of the parameters of the statistical distributions for the demand data obtained by the MINITAB 17 software when fitting the data.

Fit test of the time between arrivals of customer demands

Goodness of Fit Test

Distribution	AD	P
Normal	7.829	<0.65
3-Parameter Lognormal	0.439	*
2-Parameter Exponential	**2.091**	**<0.010**
3-Parameter Weibull	0.357	0.470
3-Parameter Gamma	0.524	*
Logistic	4.861	<0.52
3-Parameter Loglogistic	0.901	*
Johnson Transformation	0.227	0.810

Fig. 13. Time between arrivals of customer demands.

Daily Demand Adjustment of Mechanical Workshop - Client 5

Distribution	AD	P
Normal	**1.722**	**<0.005**
3-Parameter Lognormal	0.288	*
2-Parameter Exponential	1.271	0.038
3-Parameter Weibull	0.404	0.380
Smallest Extreme Value	3.429	<0.010
Largest Extreme Value	0.518	0.194
3-Parameter Gamma	0.446	*
Logistic	1.039	<0.005
3-Parameter Loglogistic	0.294	*
Johnson Transformation	0.280	0.624

Fig. 14. Example of "Mechanical Workshop" customer demand behavior.

variables is determined. In this case, the statistics of the events 2, 3 and 6 were obtained from (INEGI, 2019) and (Moreno et al., 2017).

In this section, the Simulation - Optimization model has not been executed yet.

Construction of the alternate route

The proposed algorithm for the reconstruction of the route will be briefly described.

When the second of these events occurs within the system, the VRP cost matrix will show a null value in the column and row belonging to the collapsed arch. In this scenario, the solution becomes infeasible. If this happens, the VRP must be rebuilt, appending new routes as shown in Fig. 22, until the VRP network is complete again, in a few words, generates a fictitious node to which a name or ID is assigned, through which a new route will pass only as a route identifier.

In Fig. 22 it can be seen how this new route defined by node F1, has two sections with a and b distance respectively. If both sections are joined together, a real distance of the alternate route will be obtained, which we will designate with the nomenclature of $C_{F1} = c = a + b$. The value of C_{F1} will be appended in the row and column where the empty value is present due to the blocked arc. If there are several alternatives for the alternate route, then the minimum route between the start and end node must be selected.

Once the alternate route has been identified, the two scenarios shown in section 3, Table 10, are generated and the corresponding process continues. It is important to point out that the first objective in the creation of scenarios should always be to achieve a complete cost matrix in the VRP only if there are events with that characteristic. Otherwise, the objective of the scenarios may be different.

3.2.5. Stage 5 simulation and the optimization model

The Simulation-Optimization process is explained in section 2 of this work; therefore, we will proceed to the analysis of the validation of the Simulation - Optimization in Stage 6.

3.2.6. Stage 6 Validation of the Simulation - Optimization Model

The simulation model validation is performed by comparing the distance traveled by the vehicle within the Simulation – Optimization of the proposed model, with respect to the distance to be traveled offered by the company's current algorithm. The test instances are shown in the Fig. 23.Fig. 24.

For the results of the validations and comparisons, all the instances shown in the Fig. 4 were executed.

It is important to appreciate that when the collapse event number 2 occurs in the system, the only solution obtained is that of the optimization simulation model. The current algorithm used by the Company X is not capable of offering a solution and leaves the decision of the route to the driver of the unit; therefore, the information of the route is lost.

As can be seen in Fig. 25, despite the collapse event that occurred in

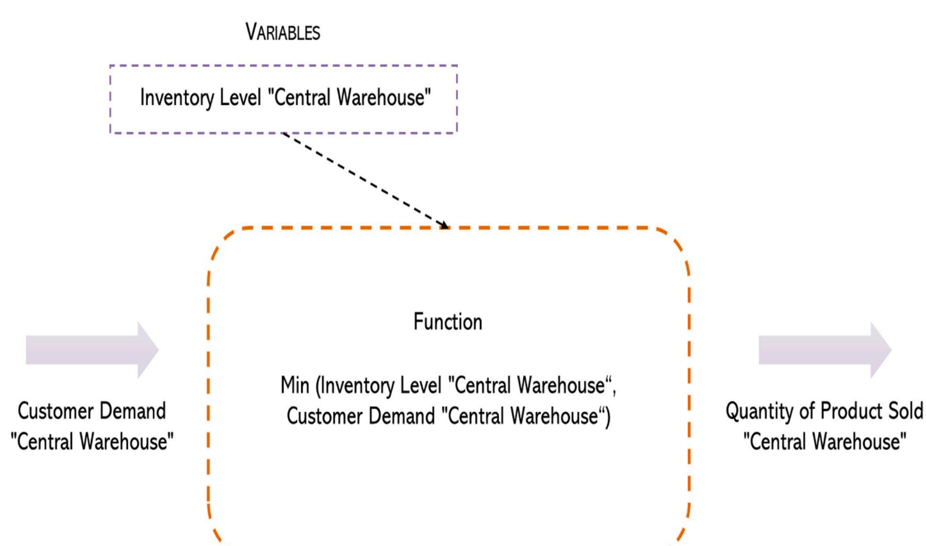

Fig. 15. Example of the relationship between the variables and the calculation of a function.

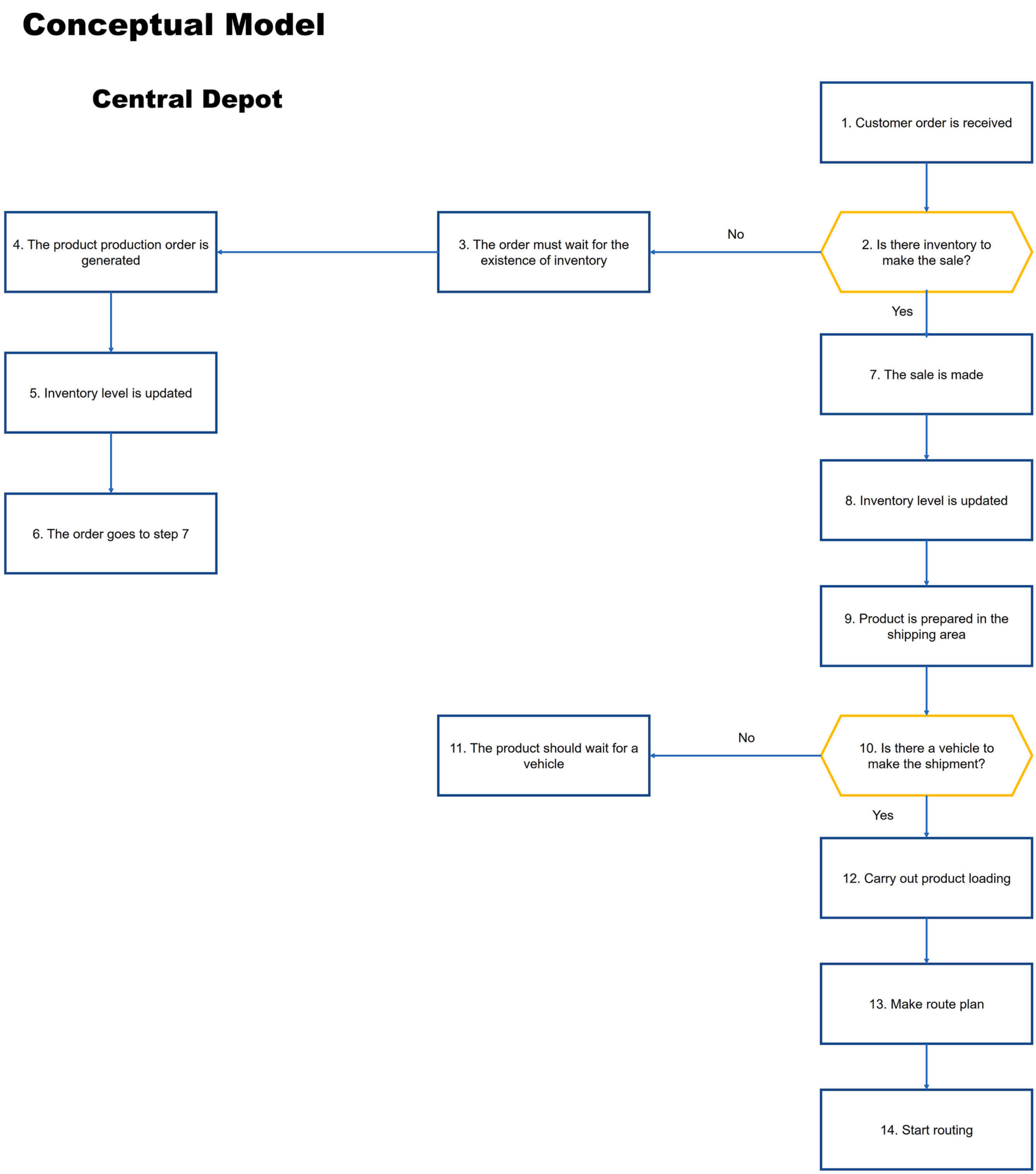

Fig. 16. Conceptual Model for the Central Depot.

Table 10
Description of scenarios generated to reduce the vulnerability of the network.

Scenario	*Description*
Scenario 1	An alternative route is attached between the central warehouse and customer 1, as well as connecting all customers in warehouse 2 to the central depot.
Scenario 2	An alternate route is attached between the central depot and customer 1, as well as connecting a randomly selected customer from warehouse 2 to the central depot.

Table 11
System Collapse Events.

Collapse Events	*System Collapse Events*
1	Traditional settings where none of these events occurs for the central depot
2	Blocking of a main route between the central depot and one of the clients.
3	Blocking of the main route between the central warehouse and one of the clients, and blocking of warehouse 2
4	Only the closure of warehouse 2 is presented due to the inventory review
5	Traditional settings where none of these events occurs for the warehouse 2
6	Failure of vehicles belonging to warehouse 2

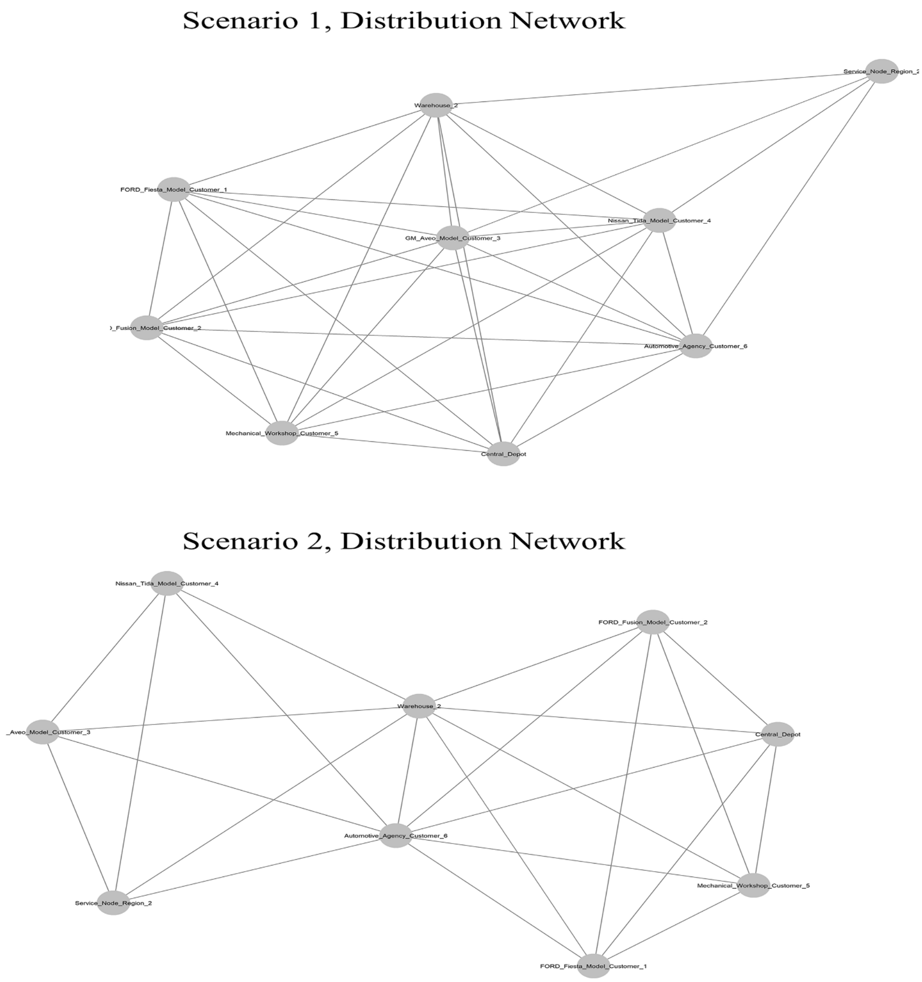

Fig. 17. Distribution networks for each of the proposed scenarios in Table 11, obtained by R.

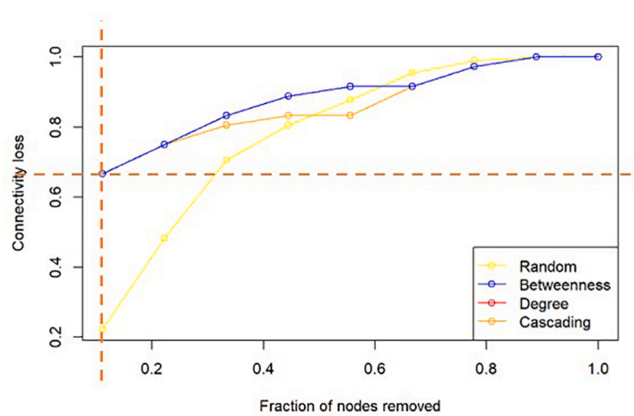

Fig. 18. Vulnerability analysis of the distribution network of Company X , in its current state.

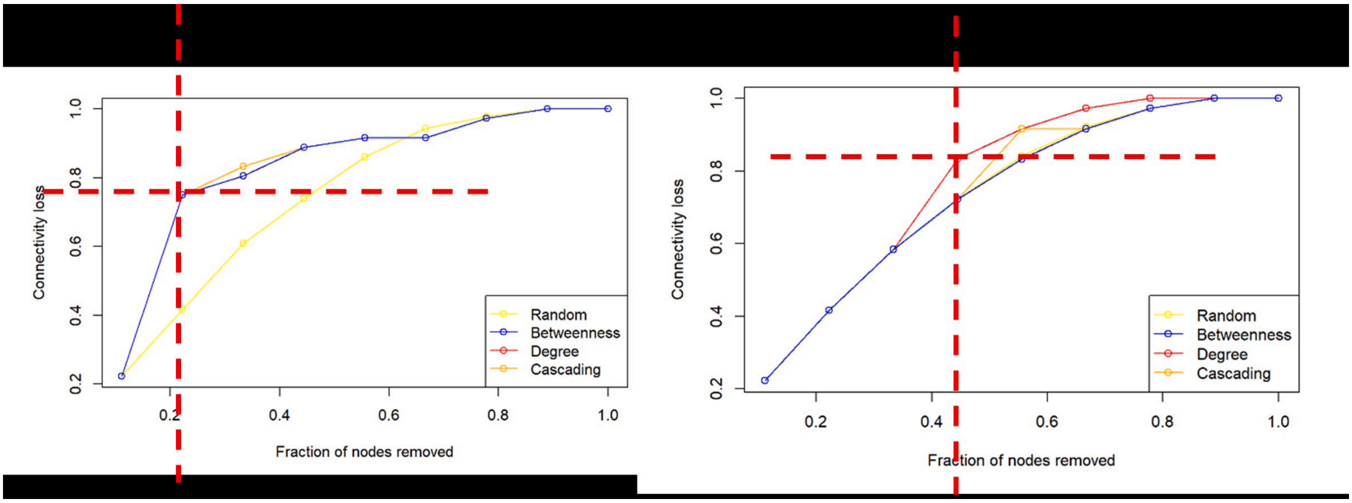

Fig. 19. Comparison of the vulnerability analysis of Scenario 1 and Scenario 2.

Table 12
Aspects considered for the simulation.

Aspects / Specific Area of Company X	*Consideration*
General Aspects	An important aspect to mention, not shown in Stage 2 of system analysis, is the existence of the following departments within the company: Order reception area, Finished Product Warehouse, Production department, Boarding area of finished product. Another important aspect of the current model lies in the lack of the optimization process, since the person in charge of the logistics area, sends the services based on the shortest route criterion considering the vehicle load. The vehicles leave the central warehouse or warehouse 2, until they meet 100% of their capacity.
Production Area	The production area, as shown in figure 30, is made up of a set of 2-line manufacturing cells each of which is defined by a certain cycle time depending on the activity carried out. The cycle times of each manufacturing cell of the current state production area are the following: Preparation of the spring of Retractors: 1.3 min, Preparation of the Retractor: 2.5 min, Buckle Assembly: 1.9 min, Seat Belt Assembly: 4.6 min.Each production line is simulated through the concept of Workstation
Inventory Area	The inventory area has a maximum capacity of 250 seat belts with a 30-seat belt reorder point, Upon reaching this minimum point the production order is made, for the amount of (Maximum Capacity - Remaining Capacity) at the time of placing the order.

the system, the optimization simulation model was always able to offer a feasible solution for each of them. However, the current algorithm used by the company was no longer useful when any of the events occurred in the system, leaving the routing to the decision of the driver.

For the results shown below, the demands are considered constant, and there are no collapse events in the system.

In Fig. 26, it can be seen how the behavior of the data of the Simulation - Optimization model shows a better consistency than the current algorithm used by Company X

In Fig. 27, when comparing the standard deviations, the observed in Fig. 26 is demonstrated, which indicates that they belong to different samples and that the Simulation -Optimization model obtains better performance than the current algorithm used by Company X.

Table 13
Occurrence of collapse events during simulation.

Event Number	*Observations*
1	During the simulation time, the event where the central warehouse operated in a normal way, without presenting collapse of nodes or arches, occurred a total of three times during the 5 days elapsed.
2	The event where the collapse of the arch between the central warehouse and customer number 1 occurs, was presented a total of 2 times. This is derived from the statistics of the presence of crashes in the roads of the state of México, according to (INEGI, 2019). Now, the rehabilitation of the arch was considered within a period of 2 h, as a constant value.
3	This event depends on two collapse events occurring at the same time; the first of them is collapse number 2, whose statistics are already known. For event 3 to be activated, while event 2 occurs, event 4 occurs. Event 4 remains active for three constant days, during which the inventory review is performed; its occurrence is once every two months.
4	As mentioned in event 3, event 4 occurs once every two months; and it lasts for three days.
5	The event indicates that warehouse 2 is operating normally.
6	Vehicle breakdown occurs with a Weibull distribution; according to the data shown by (Moreno et al., 2017). Once the vehicle enters the repair shop, it can go back to its distribution process where it left off.

As a conclusion, it can be said that the proposed Simulation - Optimization model always offers a feasible solution to the problem, regardless of the type of collapse event that may occur in the distribution network. On the other hand, the algorithm used by the company ceases to be useful when collapse events occur. This proposal is presented as an alternative for decision makers in the face of stochastic scenarios that put the distribution of the product at risk.

4. Expected results and conclusions

The analysis of the metrics of a distribution network makes it possible to strengthen the general characteristics of the network, knowing the distribution and trend of its customers through analysis of grouping or grade coefficients. The aim is for the warehouses to be closer to those sets of customers with a higher level of sales or with special characteristics. On the other hand, it can also be said that the approach to these strategic customers can be strengthened if the number of

Simulation time equal to 5 days					
	Warehouse	Department		% of use / Concept	
Actual State	Central Depot	Receipt of Client Orders		Number of Orders Received 18.00	
		Orders Waiting Room		Utilization rate 0.66%	
		Inventory Quantity in PT Warehouse		Initial Quantity of Finished Product 100.00	
		Finished Product Warehouse		Utilization rate 2.3%	
		Production		Utilization rate 98%	
		Boarding Area		Utilization rate 1.10%	Total Quantity of Pallets 48; Distance Traveled (km) 557.5
		Vehicles	Vehicle 1	73.3%	327
			Vehicle 2	65.1%	230.5
	Warehouse 2	Receipt of Client Orders		Number of Orders Received 3	
		Inventory Quantity in PT Warehouse		Utilization rate 0.1229%	
		Boarding Area		Utilization rate 0.3955%	Total Quantity of Pallets 24; Distance Traveled (km)
		Vehicles	Vehicle 1	37.6%	54.5
			Vehicle 2	28.4%	21.3

Fig. 20. Current state simulation results.

Simulation time equal to 5 days					
	Warehouse	Department		% of use / Concept	
Proposed State	Central Depot	Receipt of Client Orders		Number of Orders Received 28	
		Orders Waiting Room		Utilization rate 0.404%	
		Inventory Quantity in PT Warehouse		Quantity of Finished Product 100	
		Finished Product Warehouse		Utilization rate 0.3813%	
		Production		Utilization rate 3.29%	
		Boarding Area		Utilization rate 1.68%	Total Quantity of Pallets 61; Distance Traveled (km)
		Vehicles	Vehicle 1	92.1%	856
			Vehicle 2	87.6%	711.5
	Warehouse 2	Receipt of Client Orders		Number of Orders Received 5	
		Inventory Quantity in PT Warehouse		Utilization rate 0.52%	
		Boarding Area		Utilization rate 32.4%	Total Quantity of Pallets 17; Distance Traveled (km)
		Vehicles	Vehicle 1	78.0%	127
			Vehicle 2	0.0%	45.7

Fig. 21. Results of the simulation of the proposed state.

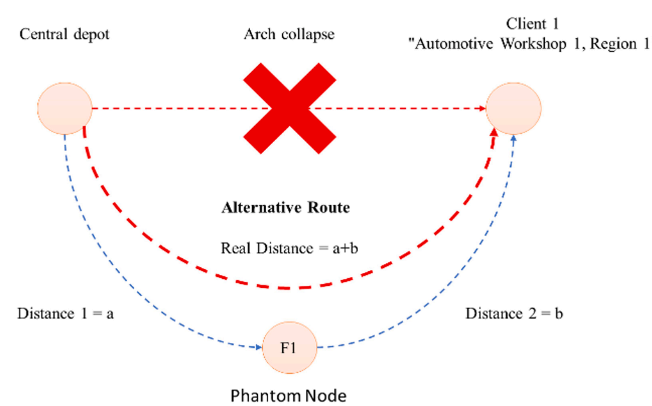

Fig. 22. Creating the alternate route.

existing arcs in the network is increased, which will have an impact on the reduction of the general vulnerability of the entire network. The afore mentioned characteristic, plus the design of strategies to have other providers as a back-up if a primary provider fails, will enable the network to deal with possible failures on both main nodes, and possible access routes.

However, it is also important to mention that the design of the attacks made for the analysis of the scenarios should be strategically directed involving only important points and seeking to make sure that the impact does not spread throughout the network.

Instance Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Node	Demand																	
Client 1	4	2	0	3	2	5	0	1	3	4	0	3	4	3	0	0	1	1
Client 2	0	4	0	0	8	2	0	5	4	0	0	0	4	1	0	6	4	4
Client 3	6	0	0	6	2	3	0	0	2	3	0	4	6	8	0	0	6	0
Warehouse 2	6	2	0	0	4	0	0	3	7	0	0	3	2	0	0	8	5	3
Client 4	0	4	9	7	0	4	6	2	0	2	5	0	0	2	5	0	0	0
Client 5	0	0	3	0	0	1	2	2	0	0	4	6	0	0	7	2	0	6
Client 6	0	4	4	0	0	1	8	3	0	7	7	0	0	2	4	0	0	2
Total demand	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16

Fig. 23. Test instances for validation.

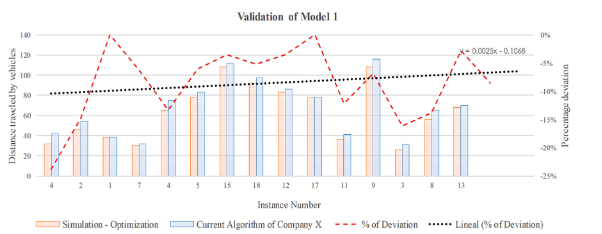

Fig. 24. Comparison of the performance of the simulation process, with respect to the optimal algorithm; comparing model 1.

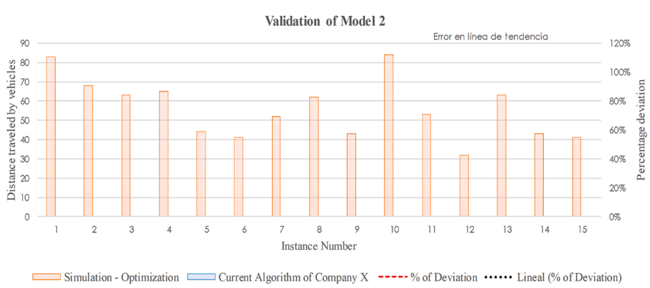

Fig. 25. Results obtained from model 2.

Another advantage of the application of the methodology is finding a route sequence that minimizes transport costs within the entire distribution network using the concept of Simulation - Optimization. This also makes it possible to shorten the average distance traveled in the network and explore unexplored roads or routes to lower vulnerability by applying the concept of network assortativity.

The intermediation coefficient, which can be obtained globally or locally when used locally quantifies the frequency or the number of times a node acts as a bridge across the shortest path between two other nodes. This metric can help us to find the optimal place to locate local warehouses.

There are a wide variety of metrics that describe the topology of the network, and its strategic use for network analysis as they can help to improve the performance of vehicle routing problems.

Future work:

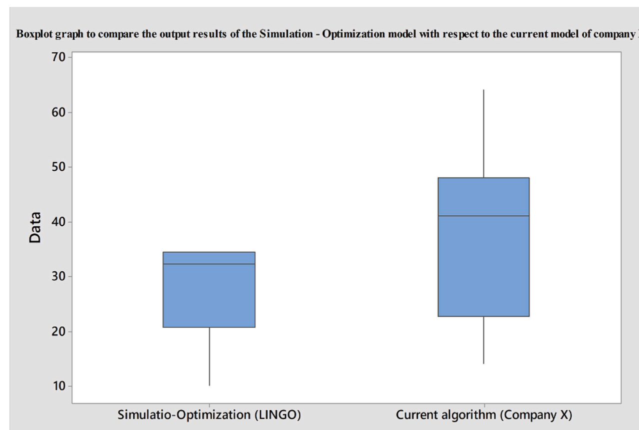

Fig. 26. Boxplot graph comparing the output results of the Simulation - Optimization model with the current model of Company X.

- To perform a more complete analysis of the company's distribution network, including a clustering analysis for the classification and assignment of customers to regional warehouses. Likewise, using this analysis to analyze the impact of the network's vulnerability on each of these subgroups that have been generated.
- Executing the optimization of the network to validate the improvement of the process.
- Including all the company's customers in the study.
- To publish the proposed algorithm.

Expected results:

- The methodology is expected to improve the performance of the any company's distribution network; combining two aspects: Topological and Operational.
- It will also enable us to integrate elements of the environment that could influence the performance of vehicle routing, as in the case of Company X , with vehicle failures.
- Simulation-Optimization will enable us to find routing schedules that improve how the vehicles are assigned to the established routes to lower the costs involved with distribution.

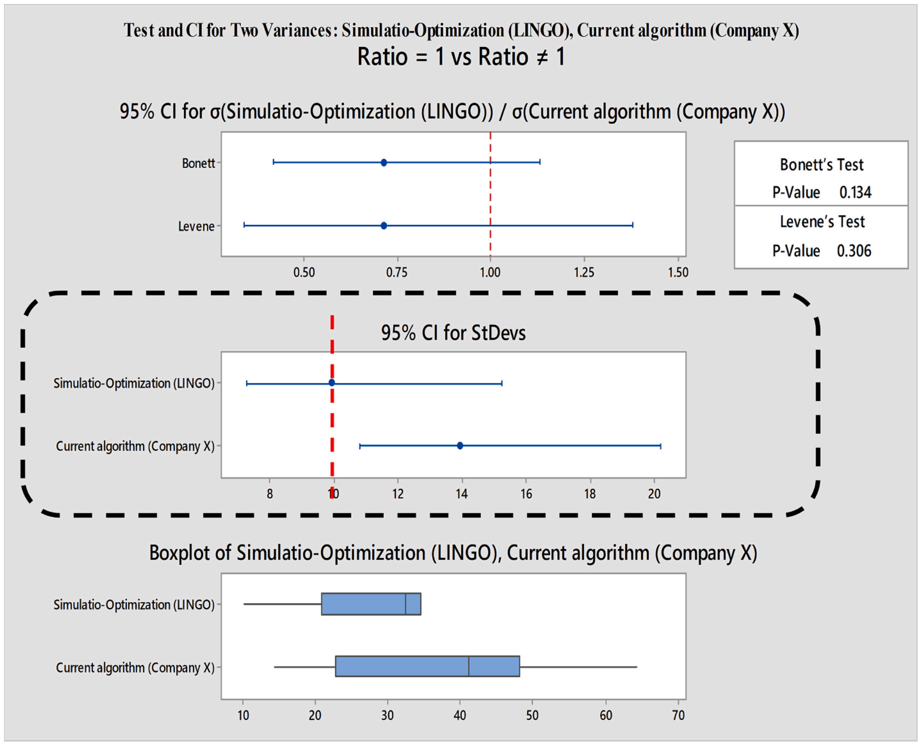

Fig. 27. Comparison of standard deviations between the Simulation - Optimization model and the algorithm of Company X.

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