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DESIGNING INTERNAL SUPPLY ROUTES: A CASE STUDY IN THE AUTOMOTIVE INDUSTRY

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ABSTRACT

In today's competitive market environment, logistics has a substantial impact on companies' performance. Improving the logistics efficiency is a main goal for many industries, especially, for those involved in car manufacturing. This work considers a real logistics problem in a car-assembly factory. The problem consists in optimizing the supply of components from the internal warehouse to the production lines, determining the best delivering routes. We describe the problem in detail, propose a mathematical programming model, and solve it with CPLEX. Afterward, to evaluate the impact of implementing the optimal routes in realistic scenarios, we apply Monte Carlo simulation and present a comparison between both solutions. The manufacturer`s Key Performance Indicators are considered for evaluating the obtained results. The study showed that the proposed solution outperformed the current one, pointing out that the optimized routes could deal with different levels of production in a more efficient and cost reductive manner.

INTRODUCTION

Improving logistics activities can lead to important cost reductions and improvements regarding customer satisfaction in different businesses sectors. In particular, car manufacturers logistics has always played a major role, thus companies are dedicating efforts and investments to improve their logistics activities. Most of the work that has been done focuses on external logistics, as the delivery of pieces, materials, and components along the supply chain

In this article, we focus on the internal logistics activities of a car-assembling factory, in particular, the optimizing of the internal warehouse's activities, as well as the delivery of the components to the different production lines. The main processes that take place in a warehouse are: reception; storage; retrieval; picking; and shipping (Longo 2011). The procedure of collecting products from the warehouses and delivering them to the different consuming points in a production line is known as warehouse shipping. Warehouse shipping falls in the category of routing problems. The Warehouse Shipping can be seen as an extension of the well-known Capacitated Vehicle Routing Problem (CVRP) (Laporte 2009; Juan et al. 2015), which is an NP-hard problem (Salomon 1987). The main goal of this work is to improve the current material flow from the internal warehouse towards the production lines, applying mathematical models and simulation methods to evaluate the impact before the actual implementation.

This research was carried out under an agreement with SEAT S.A., which provided us with the all necessary data and support. The SEAT (*Sociedad Española de Automóviles de Turismo*) is a Spanish company, a subsidiary of the Volkswagen Group. SEAT is present in more than 70 countries, with a volume of sales in 2016 of more than 410,000 units. From now on, we shall refer to SEAT S.A. as the car-assembling factory. Our study will focus on the internal logistics of one of its factories.

In this sense, the main research focus is to study and to model the actual warehouse shipping and routing at the internal warehouse at SEAT, and to develop a strategy that improves on the actual one regarding different Key Performance Indicators (KPIs) considered by the company. In the first place, we analyze in detail the warehouse shipping activities at SEAT by observing the actual practice, collecting data, and evaluating the actual solution. A linear mathematical model is proposed to solve this real-world warehouse-shipping problem. The model aims at calculating the best set of shipping routes, considering the car assembling factory environment and several constraints, as well as a realistic cost function. We consider a "one-product" demand since all products involved in this study are carried in standard and indistinguishable boxes. So, the model's demand is based on the number of requests made for these boxes (Stock Keeping Units or SKUs). We solve the mathematical problem through CPLEX. Afterward, to evaluate the practical implementation of the routes generated after the optimization phase, we design a Monte Carlo simulation method and study the performance of the optimized routes by analyzing many likely stochastic scenarios. Notice that this evaluation is very important for the company since they can both improve the actual situation and get better prepared for future scenarios, such as a launch of a new car model. The performance is measured through the company's KPIs which are the following ones: (i) the delayed demand in each period; (ii) the number of free spots in convoy at each period; (iii) the number of routes calculated; (iv) and the total distance traveled in a period.

The main contributions of this article are (i) to study a real internal logistic routing problem in the car-assembling factory, (ii) to design a mathematical model to optimize these supply routes, and (iii) to evaluate the performance of the obtained routes through a Monte Carlo simulation method, considering a realistic and stochastic environment. In this study, we considered real data as well as the KPI's proposed by the car manufacturing company, leading to interesting business insights for the SEAT Logistics department.

The remainder of this study is organized as follows. Section 2 defines the practical routing problem. Section 3 briefly discusses the methodology we applied. Section 4 presents the mathematical formulation and the simulation method. Section 5 refers to the experiments performed, and Section 6 presents the conclusions and describes the future work.

2 PROBLEM DEFINITION

This work deals with the warehouse shipping and routing at SEAT, which can be seen as a one-product capacitated vehicle routing problem with stochastic demand in an assembling car factory. Next, we describe the most important issues of the warehouse shipping and routing problem at an assembly factory.

The materials and components are requested from each consuming point at the production line to the Internal Logistics Warehouse. Afterward, these materials are supplied by a set of fixed routes using different vehicles. These vehicles are seen as a convoy type, and each route is assigned to a different convoy. A convoy is a small composition that is formed by three racks and a trolley (Figure 1). A convoy is loaded at the warehouse and travels towards the consuming points carrying the requested boxes. The consuming points or delivery points are located at the production line.

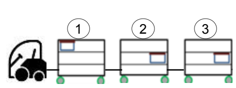


Figure 1: An example of convoy with three racks.

A consuming point requests different amounts of materials in different periods throughout the day. Along the day the demand is always served by the same route, i.e., once the routes are defined these routes run along all periods. The routes have two categories of operations: first, stop at each consuming point to deliver the products requested and, second, to observe the quantity available on that line and make a request order if necessary. Each route has only one convoy assigned. By definition, each convoy must complete the entire established trajectory, i.e., as mentioned, it stops at all consuming points assigned to this route.

It is noteworthy that there is a time limit to supply one material, i.e., a convoy must depart and returns to the initial point at the warehouse within a determined amount of time. Figure 2 shows an example of a route in a workshop. Therefore, the routing problem considers several constraints that extend the normal capacity constraints, as the multi-trips ones, the time constraints for each route and the stochastic demand constraints.

To illustrate the complexity of the real problem, we describe, as an example, the current scenario for a specific workshop with one production line at the car-assembling factory. Each day, an average number of 4,500 material orders is accomplished. The requested materials must be supplied during the day to 113 different consuming points, distributed along the workshop. Therefore, the routes have a direct impact on the picking and delivery logistics activities since the operators must follow these routes to pick and to deliver the materials. The picking activity has a huge interference in the management of a warehouse, being responsible for a great impact on its operational costs and throughput (Gagliardi et al. 2008).

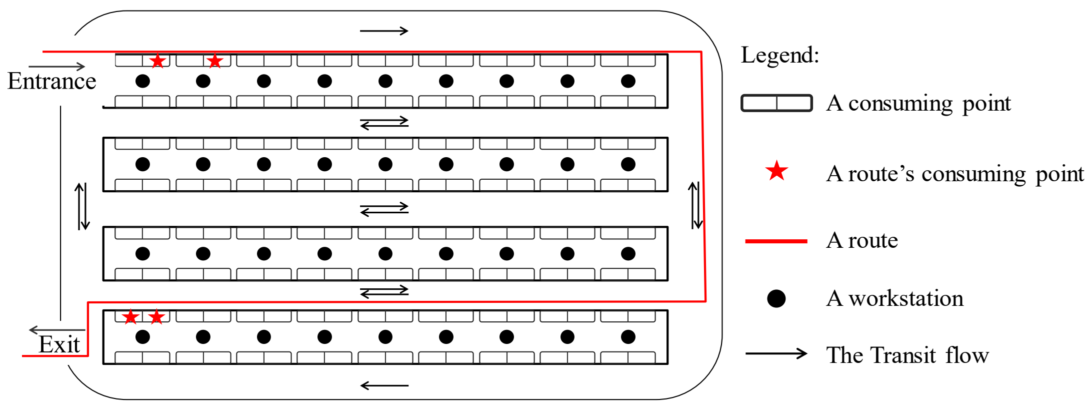


Figure 2: An example of a supply route in a workshop.

The routes' performance is evaluated according to the following KPIs: (i) the delayed demand in each period; (ii) the number of free spots in convoy at each period; (iii) the number of routes calculated; (iv) and the total distance traveled in a period.

These KPIs are aligned with others works from the literature, which already considered different variants of the Vehicle Routing Problem with Stochastic Demand (VRPSD). Juan et al. (2015) state that the classic goals applied to the VRPSD could be to minimize the total distance traveled and to minimize the number of vehicles employed. They also describe the main classes of constraints applied to that problem. These classes are: all routes must begin and finish at the same depot; the vehicles are capacitated, the capacity is the same for all of them; all the clients' demand must be satisfied, and each client should be supplied by a single vehicle. One example of the VRPSD problem application was done by Juan et al. (2013). The authors combined the Monte Carlo Simulation and parallel-computing in the search for solutions to the VRPSD. Earlier, Juan et al. (2011) combine the Monte Carlo simulation with the splitting techniques and the Clarke and Wright savings heuristic to find solutions to the Capacitated Vehicle Routing Problem (CVRP).

In our study, we are going to consider the Asymmetric Capacitated Vehicle Routing Problem (ACVRP), (Crainic and Laporte 1998), to obtain a mathematical model for the deterministic version and also the optimized routes. Afterward, as mentioned, we apply the Monte Carlo simulation to evaluate different scenarios based on the real data provided by the company.

3 THE OVERALL METHODOLOGY

In this section, we describe the overall methodology applied in this study. The methodology's purpose is to evaluate the performance of the supply routes from an internal warehouse to the production line in a car-assembling factory. The methodology is composed of several phases, as described in Figure 3. Each component of the overall methodology is described in detail.

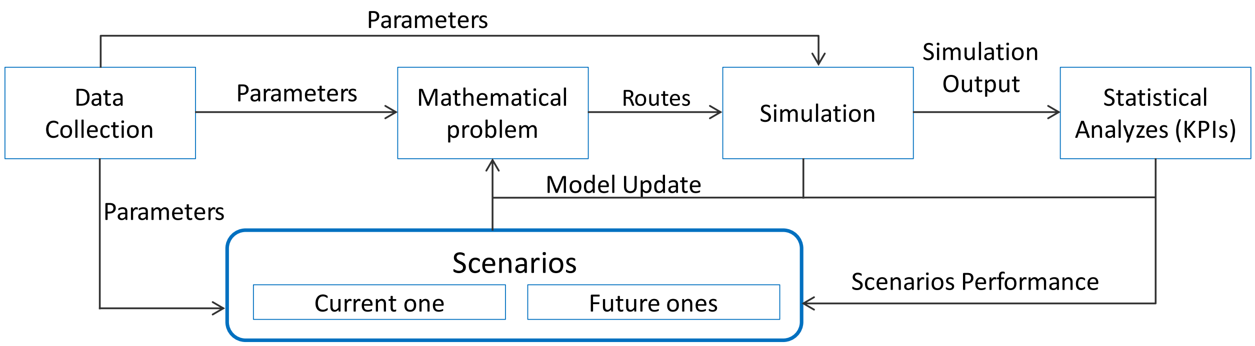


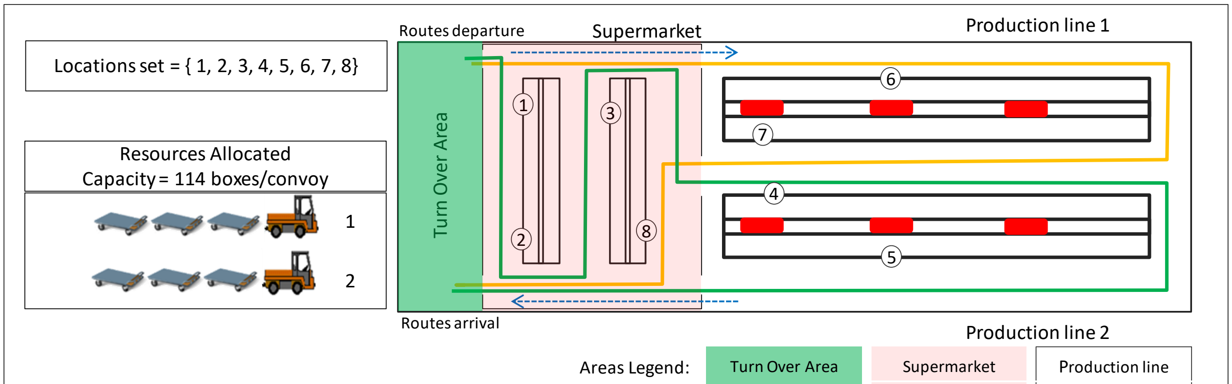
Figure 3: Methodology phases' interaction.

First, we start our study with the Data Collection process. The Data Collection is important to understand all aspects of the problem, such as to decide which data should be collected to be used as input data for the next procedures. In addition, in the data collection procedure, a statistical study and evaluation of the data are performed. Second, a linear integer mathematical problem is solved and it provides a set of optimized routes for the problem in its deterministic form. We present the mathematical model at sub-section 4.1. Third, we evaluate the performance of these routes through a Monte Carlo simulation. The simulation procedure is in charge of analyzing how the routes work when facing different stochastic scenarios (discussed at Sub-Section 4.2). Fourth, we evaluate the performance of these routes through several KPIs. These KPIs were defined based on strategic parameters set by the company (described at Section 2). The fifth step is to prepare different scenarios to be tested and eventually, depending on the conclusions provided by the KPI's output, repeat the process. This methodology was designed after observing the decision process currently implemented in the company.

4 THE SOLUTION METHOD

In this section, the Integer Linear Programming Model designed in this study is described. In this article, we applied the deterministic version of the realistic warehouse shipping and routing problem. That problem was modeled based on a car-assembly context, which is the object of our study. Then, we proposed a model according to the Asymmetric Capacitated Vehicle Routing Problem (ACVRP), which was presented by Crainic and Laporte (1998). A small example is illustrated to best introduce the problem. Next, describe a small example in detail. Following, we present our linear programming formulation in the sub-section 4.1 and, finally, the simulation model in the sub-section 4.2.

To better understand the warehouse shipping and routing problem at SEAT, we present an example of one of the factory's workshops (Figure 4). In this example, we consider two production lines composed of eight consuming points. The workshop has three areas: The Turn Over area; the Supermarket; and the Production Line, as named by the company. The Turn Over area corresponds to the beginning and the end of the supply routes. The Turn Over Area links the warehouse`s shipping area and the Supermarket. The consuming points are located in the Supermarket and the Production Line. In the Supermarket, some simple assembly operations are performed. Thus these points correspond to both consuming and supply points at the same time. In the example depicted, two supply routes were presented. The first one (yellow) is in charge of supplying the demand of the points 6, 7 and 8. On the other hand, the second route (green) is responsible for supplying the demands of the points 1, 2, 3, 4 and 5. The points 1, 2, 3 and 8 represent the consuming points inside the Supermarket, and the points 4, 5, 6 and 7 represent the consuming points inside the Production Line. The cars that are being produced are represented by red blocks. Each route begins its trajectory from the Turn Over area (blue top arrow). The route must pass through its respective demand points and finishes at the Turn Over area (blue bottom arrow). Also, the routes' path can be partially shared. The logistic operator must pass through the Supermarket, even though there is not a single consuming point to supply.



Possible Solution

Route	Locations	Material type	Resource
(yellow)	{ 6, 7, 8}	Boxes	1
(green)	{ 1, 2, 3, 4, 5}	Boxes	2

Demand Table

Route	Period 1	Period 2	Period 3
(yellow)	**Locations { 6, 7, 8}** Dem. { 100, 72, 2}	**Loc. { 6, 7, 8}** Dem. { 10, 22, 67}	**Loc. { 6, 7, 8}** Dem. { 12, 70, 66}
(green)	**Loc. { 1, 2, 3, 4, 5}** Dem. {2, 34, 3, 8, 9}	**Loc. { 1, 2, 3, 4, 5}** Dem. {0, 32, 3,8,99}	**Loc. { 1, 2, 3, 4, 5}** Dem. {2, 34, 3,8,9}

Figure 4: An example of the factory workshop.

In the Optimization procedure, the routes are obtained by solving an Integer Linear Mathematical Programming in a deterministic environment. Next, these routes are tested throughout the simulation in a stochastic scenario. The simulation will evaluate the routes' performance by testing them through three different scenarios. As an example, Figure 4 depicts the demand variation during three periods or scenarios. Then, we would like to evaluate the solution KPI's results after supplying all the requested demand.

In this study, we select three general scenarios to be evaluated based on the historical demand. These basic three scenarios are the following: (i) a hypothetical low level of demand rate; (ii) a real demand rate; and (iii) a hypothetical high level of demand rate. Then, we measure the solution performance through the defined KPI`s: (i) the delayed demand in each period; (ii) the number of free spots in convoy in each period; (iii) the number of routes calculated; (iv) and the total distance traveled in each period. Therefore, Figure 5 presents the interaction between the mathematical formulation and the simulation.

4.1 Mathematical Formulation

The Integer Linear Programming Model of the current problem is an extension of the Asymmetric Capacitated Vehicle Routing Problem (ACVRP). Table 1 and Table 2 present all the data and the parameters' description. In the following, we present the variables, the objective function (OF), and the constraints.

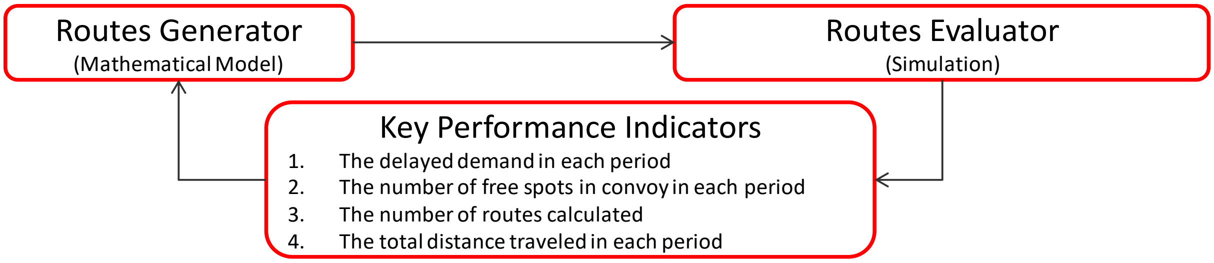


Figure 5: Routes procedures.

Table 1: Parameters' description.

Parameter	Description
$G = (N, A)$	**The set N of nodes and the set A of arcs of the graph G**. Each node $(n \in N)$ represents a consuming point. The arc a $= (i, j)$ represents the shortest way from the node i to the node $j \setminus (i, j) \in N$.
nc	**The maximum number of racks in convoy.**
m	**The maximum number of convoys.**
DE_i^{mat}	**The matrix that indicates the materials' demand of each consuming point $\forall$ $(i \in N)$.** That data is collect through a SAP file. This file has information about each request done, such as Material descriptions, units demanded, consuming point to be supplied and creation's time, and the deadline. In this study, we considered an average demand of two weeks. The average was calculated by taking into account all requests done by a consuming point in two weeks. This value was divided by the number of 30 minutes-working-periods that those two weeks has got. The working period takes into account neither the pauses nor the team meetings. That strategy is a good point of view because we considered the real period when the employees were working.
$material_i$	**The vector that indicates if the material goes to the consuming point i $\forall$ $(i \in N)$.**
CAP^{mat}	**The material rack's capacity.**
v	**The convoy's speed.** The convoy's speed considered is 7 km/h. This value was collected with employees who work with the current routes.
$tsup$	**The time required to supply a material at the consuming point.** The amount of time necessary to supply a box is 0.112 minute per box.
$tempt$	**The time required to collect an empty supply rack at the consuming point.** The values are the same of those to supply loaded boxes, which is 0.112 minute for an empty box.
T	**The maximum time a route can take.** A route must start its trajectory and comes back up to 30 minutes. This value was defined based on the amount of time a material can wait in the Turn Over area. The waiting time was set up to 60 minutes. To do so, we provide the possibility to deliver the requests within two 30 minutes periods.

Table 2: Objective function parameters.

Parameter	Description
d_{ij}	**The matrix that contains the length of the arc $(i, j) \in N$.** The total of consuming points is 113. It is infeasible to calculate the matrix d_{ij} without any support. Then, a C++ code was done to compute these distances. This code considers the aisle flow and distances to cover to achieve the point j from the start point i $\backslash(i, j) \in N$. The distance covered is a performance indicator. This is indicating in the model as $cost_{distance}$ that is a fixed cost.
$cost_{emp\_spot}$	**The empty material spot cost at the supply rack.** This parameter refers to the cost of leave a spot empty in convoy.
$cost_{route}$	**The fixed cost of introducing a route.** A solution with too many routes represents a bad solution in the practical view. The reasons are the incurred costs to maintain a route, such as employee's costs and resources' costs. Besides that, a workshop with too many convoys can incur in many other problems, obviously.

Variables:

- $x_{ij} = \begin{cases} 1, \text{if the arc } (i, j) \text{ represents a path.} \\ 0, \text{if the arc } (i, j) \text{ does not represent a path.} \end{cases}$
- $U_i = \{$ The load of the vehicle after visiting consuming point $(i \epsilon N) \setminus \{i \neq 0\}$.

Objective Function (OF): The OF aims at minimizing the sum of several costs associated with the real problem. The first cost is the one related to a convoy that is not fully loaded. Each empty spot (i.e., without a box) represents a lost opportunity to the company. The second cost component is related to the total distance of the routes, i.e., this is the most common cost function in routing problems. Finally, the last cost is the cost associated with the total number of routes.

$$Min \sum_{j \in N} \sum_{i \in N \setminus \{i \neq j\}} (cost_{distance} * d_{ij} * x_{ij}) + cost_{emp\_spot} (\sum_{j=2}^{N} x_{ij} CAP^{\text{mat}} - \sum_{i \in N \setminus \{0\}} \sum_{j \in N \setminus i \neq j} DE_i^{mat} x_{ij}) + cost_{route} * \sum_{j \in N} x_{j1} \tag{1}$$

Constraints:

The constraints (2) state that all the consuming points must be attended.

$$\sum_{i \in N \setminus i \neq j} x_{ij} = 1 \quad \forall j \in N \setminus \{0\} \tag{2}$$

The constraints (3) state that all vehicles must leave the consuming point after unloading.

$$\sum_{j \in N \setminus i \neq j} x_{ij} = 1 \quad \forall i \in N \setminus \{0\} \tag{3}$$

The constraints (4) ensure that the maximum number of convoys that departs from the depot is *m*.

$$\sum_{j=2}^{N} x_{ij} \leq m \tag{4}$$

The constraints (5) state, for each route, that the total time to complete the supply activities and complete the trajectory must be equal or lower than T. The total time is the sum of the supply time, the travel time and the empties boxes collection time.

$$\sum_{i \in N} \sum_{j \in N \setminus \{j \neq i\}} [(tsup + tempt) x_{ij} + \frac{d_{ij}}{v} (x_{ij})] \leq \sum_{j \in N} x_{1j} T \quad \forall i \in N, j \in N \setminus \{i \neq j\} \tag{5}$$

The constraints (6) and (7) are the sub-tour elimination constraints. These constraints impose both the connectivity of the solution and the vehicle capacity requirements.

$$U_j - U_i + CAP^{mat} x_{ij} \leq CAP^{mat} - DE_i^{mat} \quad \forall\, i \in N \wedge j \in N \setminus \{i \neq j\} \quad (6)$$
$$DE_i^{mat} \leq U_i \leq CAP^{mat} \quad \forall\, i \in N \setminus \{0\} \quad (7)$$

The constraint (8) states that variables U_i are integer and positive.

$$U_i \in \mathbb{Z}^+ \qquad \forall\, i \in N \setminus \{0\} \quad (8)$$

The constraints (9) state that variables x_{ij} are binaries.

$$x_{ij} = \{0, 1\} \qquad \forall\, (i,j) \in N \setminus \{i \neq j\} \quad (9)$$

This model is solved using AMPL and CPLEX version 12.7.0.

4.2 Simulation Method

The routes' performances are analyzed through the simulation. In this study, we aim at simulating distinct scenarios. These scenarios were calculated based on the average and the standard deviation (SD) of a two-weeks consuming points' demand (demand from Monday to Friday). Table 3 describes the seven scenarios tested. In the scenario 0 (Historical Data), the optimized routes were evaluated by applying the actual historical demand at each period. Scenarios 1 to 6 corresponds to the Monte Carlo simulation output. The demand of each consuming point is randomly generated based on variations of the historical data.

Table 3: Scenarios' description.

Item	Standard Deviation Description	Demand's Average
0	Historical data	Historical data
1	Low (↓5%)	Current Demand
2	High (↑5%)	
3	Low (↓5%)	Higher Demand (5%)
4	High (↑5%)	
5	Low (↓5%)	Lower Demand (5%)
6	High (↑5%)	

We highlight that we generated the demand for each one of the 113 consuming points for each considered time horizon. The demand was generated through the Monte Carlo method and based on the Normal distribution. The average and SD of this normal distribution were calculated from the two-week historical data, as previously mentioned. We chose the normal distribution because we assumed the probability of the demand varying equally from the average values, both up and down. The implementation of this procedure was done through a C++ code.

Then, for each proposed scenario, we evaluate a time horizon of ten days. Each day contains 45 periods of 30 minutes. These periods were established after removing all the kind of pauses in the production line. This information was described in Table 1. The variation of five percent in the demand`s average is due to the actual level of production and corresponds to the planning objectives. Moreover, the cumulative SD variation of 10% (the difference between the higher and lower SD) is because a higher variation would be an unreal overestimate factor, considering the analyzed historical data.

Then, we allocated each generated period's demand to its respective route. We repeated this procedure for each period. It is also considered that if a requested material is not attended at the correspondent period; it will be supplied at the following one, as explained in Table 1. In this sense, we simulate both sets of routes in each period and calculate its performance. We present the simulation scheme in Figure 6.

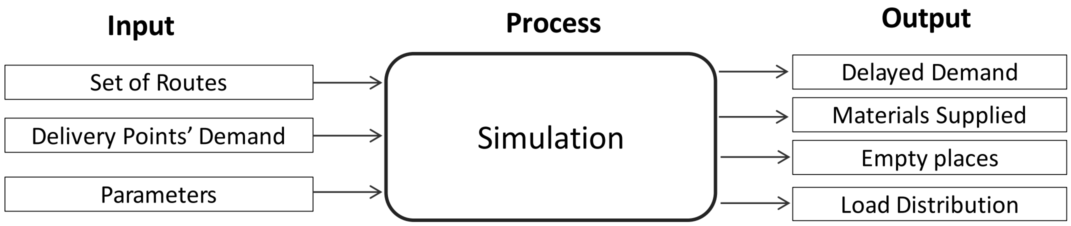


Figure 6: Simulation scheme.

Then, the expected simulation's outputs are (i) the delayed demand in each period, (ii) the materials supplied in each period, (iii) the total of empty places (spots) in all convoys in each period and, (iv) the cargo loaded distribution among the routes.

5 EXPERIMENTS

Section 5 presents the experiments held and the analysis of the obtained results. First, we present the current routes and the proposed ones. Next, we present the simulation's results for each scenario.

5.1 Routes Evaluated

We first evaluate the routes currently implemented at the company. The company designed these routes by aggregating several consuming points in a manually and historically manner. These aggregations are called Logistic groups. Afterward, we calculated the optimized set of routes by solving the mathematical model presented in the sub-section 4.1. We processed all the experiments described in this work in a machine equipped with Intel i7 processor, 2.70GHz, 16GB RAM and Linux 64 bits Ubuntu 11.0.4. The program languages C++ and AMPL were used. The mathematical model was solved through the compiler GNU GCC and the software CPLEX version 12.7.0. We present the current set of routes in Table 4.

Table 4: Routes comparison.

Item	Total of Routes	Distance Traveled (meters)	(OF) Cost
Current Routes	6	3,959.0	4,573.43
Proposed Routes	3	2,779.8	3,084.16

We defined a time processing limit of 3,600 seconds to the CPLEX. Then, we took the best solution provided as the optimized proposed routes. The OF cost of the obtained solution was 3,084.16, and its GAP was 19.5%. The GAP means the following equation:

$$(Upper\ Bound - Lower\ Bound)/Upper\ Bound.$$

5.2 Scenarios Results Through the Simulation

Here, we present the simulation's results related to each scenario described in Table 5 and Table 6.

On the calculation of the KPI, we would like to make some comments. First, on the one hand, we stated the route's trajectory completion time limit as 30 minutes at Table 1. On the other hand, we have up to 60 minutes to supply a material. The first KPI was calculated under this criterion. Second, the total number of empty places was calculated by summing all the empty spots in each convoy at each period. Moreover, if a route has not any material to supply in a period, then the total of empty spots will be zero for this period. It means the convoy does not need to departure.

Table 5: Simulation output - Scenarios 0, 1, 2, and 3. The letter A represents the proposed routes and the letter B the current ones. The items **I**, **II**, and **III** represent the Delay Demand Attended, the Attended demand, and the Sum of empty spots, respectively.

Item	Scenario 0		Scenario 1		Scenario 2		Scenario 3	
	A	B	A	B	A	B	A	B
I	0%	0%	0%	0%	0%	0%	0%	0%
II	100%	100%	100%	100%	100%	100%	100%	100%
III	98,266	198,043	139,248	310,529	139,248	310,530	138,347	309,628
OF cost	7,205	12,877	8,952	17,601	8,928	17,601	8,890	17,563

Table 6: Simulation output - Scenarios 4, 5, and 6. The letter A represents the proposed routes and the letter B the current ones.

Item	Scenario 4		Scenario 5		Scenario 6	
	A	B	A	B	A	B
Delay demand	0%	0%	0%	0%	0%	0%
Attended demand	100%	100%	100%	100%	100%	100%
The sum of empty spots	137,793	309,654	141,123	311,681	140,549	311,395
OF cost	8,867	17,564	9,007	17,650	8,983	17,638

We will now describe the main conclusions that can be obtained from the simulation experiment. It can be observed in Table 5 and Table 6 that both sets of routes were able to supply all demand in anytime. That is an important observation since the number of proposed routes is significantly inferior to the number of actual routes. The reduced number of routes leads to a cost reduction on equipment and personal. In addition, the total number of empty spots also reduced. The proposed routes presented nearly 45% less empty spots compared with the current routes. That output is another significant result because it represents a substantial improvement in the efficiency of the use of the resources. Regarding the cargo distribution among the routes, Table 7 illustrates the cargo distribution related to the worst-case scenario. This scenario represents both the higher demand and higher Standard Deviation (SD) levels. In other words, we are dealing with an unstable scenario. We evaluate how the set of routes managed the cargo distribution between themselves. Therefore, Table 7 describes the standard deviation values related to each set of routes and its cargo allocation at scenario 4. A higher SD value means a weak performance on the balancing the cargo load. So, we present two analyses: (A) one analyze that consider all the routes' cargo load and (B) another one that the sample does not have the route with the smallest level of cargo loaded.

Table 7: The cargo balance analyses on scenario 4.

The cargo loaded among the routes: higher demand and higher Standard Deviation – Scenario 4		
Sample	Current Routes SD (units)	Proposed Routes SD (units)
All Elements (*routes*) - **A**	2,383	7,083
The smallest route`s cargo took off - **B**	2,016	2,640

Considering all the materials supplied in the scenario 4, the item **A** indicates that the proposed set of routes has higher SD value than the current ones. On the contrary, the item **B** presented a significant performance improvement of the proposed set of routes. That result means that we are dealing with only one route that is not well balanced. Then, that route produces a high negative impact on the cargo distribution criterion, regarding the proposed set of routes.

Finally, the current set of routes is compound by 6 routes that can travel up to 3,959 meters in one period and presents a total cost of 4,573.43. On the contrary, the proposed set of routes is compound by 3 routes that can travel up to 2,779.8 meters in one single period and presents a total cost of 3,084.16, as indicated by the Table 4. Therefore, it can be observed that the proposed routes outperformed the current ones.

6 CONCLUSION

This work studies and analyses a real case of a warehouse shipping and routing problem at a car-assembling factory. We propose a mathematical integer linear model for the deterministic version, and afterward, we develop a simulation procedure based on Monte Carlo simulation to evaluate the performance of the routes on a realistic stochastic environment using company's KPIs.

The first KPI is the delayed demand in each period, for this one, the proposed routes were able to deliver all the demand on time and without delays. The second KPI is the number of the empty spots in convoy. The proposed set of routes presented a better performance on this KPI than the actual one through the simulated scenarios. The total average number of empty spots for the new routes was 45% lower than the current ones. The third KPI is the total number of routes needed to do the warehouse shipping. The current set of routes presents 6 routes, and the optimized one presents 3 routes. So, the proposed routes are the half of the actual ones. Finally, the fourth KPI is the total distance traveled during the studied period (Table 4). The current set of routes has a total of 3,959 meters, and the proposed one has a total of 2,779.8 meters. Another important aspect is the loaded cargo balance among the routes, which should be reviewed, in future work. Even the proposed routes can work properly according to the balanced specifications; this aspect could be improved by including specific constraints on the model.

Overall, we can conclude that the proposed optimized set of routes can be implemented in a real context. The applied methodology enables decision makers to evaluate the performance of a mathematical model's output in a more realistic context, via the Monte Carlo simulation phase. Therefore, we have a better knowledge about the strengths and the weakness of the mathematical model's solution. Moreover, one of the main applications of this work is to enable the company to obtain better insights and to plan, more efficiently, when it launches a new car model, for instance.

We are working in the development of a Metaheuristic based on Iterated Local Search, (Lourenço, Martin, and Stützle 2010), to be able to solve large-scale problems in short running times. This approach will also be useful if the company decides to implement an online optimization, i.e., at each period, the demand is collected, and the routes are calculated in function of the real needs of each consuming point at the production line. Future works may focus on developing strategies to improve the interface between the Optimization and the Simulation phases (Osorio and Selvam 2017), by feeding the mathematical models definitions with insights from the simulation phase. That approach can be made using a simheuristic, (Juan et al. 2015; Grasas, Juan, and Lourenço 2014), that integrates the optimization and simulation phase in a repeated cycle with the objective to improve even more the solution. Furthermore, we could extend this work by considering the sales and the production forecast. These areas could help to plan the impact on that forecast in the logistics activities and, in particular, the warehouse shipping problem at a car manufacturer.

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