Computational simulation and voracious algorithm to calculate the least cost route

Simulación computacional y algoritmo voraz para calcular la ruta de mínimo costo

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Artículo de investigación científica y tecnológica

***Abstract*—Transportation logistics aims to deliver products at the right time and place at the lowest possible cost. Within this activity are the problems of optimizing the routing of cargo vehicles that must travel a minimum cost route for the delivery of goods. The impact of the use of information technologies in the context of the supply chain can be measured basically in integration and in the benefits it brings. The objective of this research is to use computational simulation to evaluate restrictions of a messaging system and to show the shortest route found for three package delivery lines, optimizing the time and allocation of packages for each line. The project was developed under an empirical and exploratory methodology, where four phases followed. An algorithm was designed that used a voracious and stochastic approach, with an objective function that was evaluated in each of the n-simulations, to find the shortest route on the three delivery lines. To test the effectiveness of the algorithm, two test scenarios were carried out. In both scenarios, it was possible to show that the greater the number of simulations, the distance found was shorter, which was the objective of the investigation.**

***Index Terms*— computational simulation, route optimization, stochastic process, supply chain, voracious algorithm.**

***Resumen*— La logística de transporte tiene como objetivo la entrega de productos en el momento y lugar correcto al menor costo posible. Dentro de esta actividad se encuentran los problemas de optimización del enrutamiento de vehículos de carga que deben recorrer una ruta de mínimo costo para la entrega de mercancías. El impacto que tiene el uso de tecnologías de la información en el contexto de cadena de suministro se puede medir básicamente en la integración y en los beneficios que aporta. La presente investigación tiene por objetivo utilizar la simulación computacional para evaluar restricciones de un sistema de mensajería y arrojar la ruta de menor distancia encontrada para tres líneas de entrega de paquetes, optimizando el tiempo y asignación de paquetes para cada línea. El proyecto se desarrolló bajo una metodología empírica y exploratoria, donde siguieron cuatro fases. Se diseñó un algoritmo que utilizo un enfoque voraz y estocástico, con una función objetivo que se evaluó en cada una de las n-simulaciones, para encontrar la ruta de menor distancia en las tres líneas de entrega. Para comprobar la efectividad del algoritmo se llevaron a cabo dos escenarios de prueba. En los dos escenarios, se logró evidenciar que, a mayor número de simulaciones, la distancia encontrada era menor, lo cual era el objetivo de la investigación.**

***Palabras claves*— algoritmo voraz, cadena de suministro, optimización de ruta, proceso estocástico, simulación computacional**

I. Introduction

NOWADAYS, globalization and customer satisfaction are two fundamental principles that every organization must have as objectives to fulfill. To achieve this, quality management throughout the supply chain and the impact it has to achieve sustainable practices [1], and achieve a competitive advantage over the market, go hand in hand with the use of information technologies, as a differentiating element, allowing to optimize distribution times, transport costs [2], and improving the quality of delivery service of products, which has a correlation with customer loyalty [3]. In this order of ideas, Supply Chain Management (SCM) aims to facilitate communication between the parts of the business, improve the delivery of products to the final customer [4] and achieve a more environmentally friendly organization, on the fact of that freight vehicle fleets contributed 58% of CO2 emissions for 2017, and that the transport industry in general contributes 83% of all CO2 emissions today. For this reason, it is clear that alternatives must also be sought to improve and optimize the movements of this type of vehicle [5].

For a couple of decades SCM, and its main areas such as transportation management, resilience and reverse logistics, have gained interest in various sectors of society, education and the economy, which seek through their study to identify the variables that affect their operation, and thus improve their methods, allowing organizations to meet the challenges of

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modern and dynamic economies, and the increasingly demanding requirements of customers [6], by adopting emerging technologies such as Internet of the things (IoT), Artificial Intelligence (AI) and Big Data that improve the decision-making process [7-11], and the evaluation of threats and weaknesses that put the system at risk [12].

Transportation logistics is one of SCM's activities, and it aims to deliver products at the right time and place at the lowest possible cost. Generally, transport logistics is one of the factors that most influences the economic growth of organizations and a country, allowing better results to be obtained in the global market [13]. Within this activity are the problems of optimization of the routing of cargo vehicles (VRP) that must travel a minimum cost route for the delivery of goods [14], the programming of vehicles with time windows (VRPTW) that considers the daily scheduling [15], and trained vehicle routing (CVRP), which helps identify routes that start and end at a distribution center [16].

The impact of the use of Information Technology (IT) in the context of the supply chain can be measured basically in two aspects: in the integration and in the benefits that it brings [17]. Several investigations show the advantages of using IT to propose new SCM evaluation models [18], calculate operating profits [19] and improve management in merchandise distribution processes in the metal-mechanic sector [20], leather goods [21], food [22] and textile [23]. Likewise, computer design and programming techniques have been used to: a) optimize routes using genetic algorithms [24], b) compensate for the shortage of delivery vehicles using web-based systems [25], c) solve the CVRP problem with the help of metaheuristics [26], d) the planning of distribution routes using a mixed integer programming model [27] and, e) the optimization of routes of a multimodal container transport system using dynamic programming [28].

The objective of this research is to use computational simulation to evaluate restrictions of a messaging system with a VRP approach and to show the shortest route found for three package delivery lines in an area of 150 km^2, optimizing time and package allocation for each line. The types of packages are divided into: documents and boxes. A line that we call “Moto” is oriented to the delivery of documents. The other two, called “Box truck 1” and “Box truck 2”, are aimed at delivering boxes. An algorithm was designed that used a voracious and stochastic approach, with an objective function that was evaluated in each of the n-simulations, to find the shortest route on the three delivery lines. Such algorithm was implemented in an application in the Java programming language with GUI, which allowed to randomly generate the data related to the packages (address and type of package) and enter the entries for the restrictions, display the map and the order of delivery to be followed by the drivers of the three lines. To test the effectiveness of the algorithm, two test scenarios were carried out. The first scenario consisted of simulating the delivery of 30 packages. To find the least cost route in distance, a test bench was performed that consisted of running the simulation 1,000, 10,000, 50,000, 500,000, 1,000,000 and 10,000,000 times. The second scenario consisted of simulating the delivery of 200 packages. In this case, a test bench was carried out with the same number of simulations of the first scenario, but executing each simulation size 5 times, and taking the distance and the execution time of each one, to finally calculate their average. In both scenarios, it was possible to show that the greater the number of simulations, the distance found was shorter, which was the objective of the investigation.

A. *Computational Simulation*

Freight transport companies often use computer simulation to assess risks associated with traffic, packing time, distance to travel, routes and delivery times, among other factors, and thus anticipate situations that affect their normal functioning [29]. In this sense, computational simulation is one of the areas of Computer Science that provides techniques that help in situations where it is very difficult to know and evaluate the behavior of unpredictable systems, such as weather or environmental conditions [30]. One of the methods applied in simulation is the voracious algorithms that are commonly used in optimization problems, and that evaluating an objective function make short-range decisions based on immediate information. This allows you to make the optimal choice locally at each stage, with the expectation of finding a global optimum [31].

The computational simulation, in combination with stochastic processes allow to represent the behavior of complex systems, which makes them a strong technique in solving problems in sectors such as economics, astronomy, physics, or industry where deep analysis is required. of all the components involved in its operation [32]. For example, a simulation would allow: a) finding the optimal route for a worker to follow in the order preparation process [33], b) reduce delivery time and total CO_2 emissions from trucks [34-35], c) provide solutions to intermodal transport that minimize costs and reduce the negative impact of transport activities, such as costs, time and environmental [36-37], d) to support Intelligent Transport Systems (ITS) applications in public transport by combining optimization models with data from ITS [38] and, e) identify the distribution routes of electric vehicles (EV) considering the distribution centers and charging facilities [39].

II. Methodology

A. *Problem formulation*

Given in a list of addresses that represent the physical location for package delivery, find the least cost route in distance, using computational simulation with a stochastic approach to select each address and calculate the total distance, and store it as a probable answer. At the end of the simulation show the least cost route.

B. *Description of the methodology*

The project was developed under an empirical and exploratory methodology. Basically the following phases were followed:

1. Research phase: to build the theoretical framework, information was collected from scientific articles published in the last five years, under the search terms "supply chain", "route optimization", "computational simulation", "transport

logistics", "Voracious algorithm" and "stochastic process", in databases such as Scopus, Web of Science, IEEE Explore, Elsevier and Computer Source, and scientific journals, which allowed to contextualize and delimit the study.

2. Design phase: based on the collected data, we proceeded to design the algorithm that ran the n-simulations. Likewise, the objective function was constructed, which evaluated the distance of the route generated randomly. To verify the reliability of the random number generator, the Chi-square test was performed.

3. Implementation phase: The Java programming language was used to implement the algorithm, and the objective function. The application had a GUI that allowed entering the input values to randomly generate the data related to the packages (address and type of package) and enter the entries for the restrictions, display the map and the delivery order to be followed the drivers of the three lines.

4. Test phase: Based on the random data generated in the previous phase, two test scenarios were carried out. The first scenario consisted of simulating the delivery of 30 packages, divided into 9 documents and 21 boxes. The second scenario consisted of simulating the delivery of 200 packages, divided into 97 documents and 103 boxes.

C. *Chi-square test*

In order to validate the random number generator, the Chi-square test was applied, which checks the uniformity of the numbers, measuring the degree of fit between the distribution of a sample of random numbers and the theoretical uniform distribution. This is based on the null hypothesis that there is no difference between the two distributions.

To develop the test, 100 random numbers were generated in Java, and the statistic was compared with the Chi-square with alpha of 0.05 and 9 degrees of freedom. Table I shows the distribution of the numbers and the results.

TABLE I
CHI-SQUARE TEST

Intervals		Oi	Expected frequency	Statistical
			Ei	((Ei-Oi)^2)/Ei
0.0	0.1	10	10	0
0.1	0.2	9	10	0.1
0.2	0.3	7	10	0.9
0.3	0.4	8	10	0.4
0.4	0.5	12	10	0.4
0.5	0.6	7	10	0.9
0.6	0.7	12	10	0.4
0.7	0.8	10	10	0
0.8	0.9	9	10	0.1
0.9	1	16	10	3.6
Summation:		100	100	6.8
			Chi-inv:	16.9189776

Since the sum of the statistics is less than Chi-inv, it is not rejected that the sample numbers follow a uniform distribution, therefore, the number generator is accepted.

D. *Proposed system*

An application was developed in the Java programming language that used computational simulation to evaluate restrictions of a messaging system with a VRP approach, and to show the shortest route found for three package delivery lines in an area of "150 km^2", optimizing time and packet allocation for each line. The types of packages are divided into: documents and boxes.

A line that we call "Moto" is oriented to the delivery of documents. The other two, called "Box truck 1" and "Box truck 2", are aimed at delivering boxes. An algorithm was designed that used a voracious and stochastic approach, and an objective function that was evaluated in each of the n-simulations to find the shortest route on the three delivery lines. Such an algorithm was implemented in an application in the Java programming language, which allowed the data related to the packages (address and type of package) to be generated randomly and the entries for the restrictions were entered, the map and the order of delivery were displayed. the drivers of all three lines must follow.

The hypothesis to determine the effectiveness of the proposed system is based on the fact that the greater the number of simulations, the lower the cost of the route found.

Inputs:

- *C* = number of simulations.
- *P* = number of packages.
- *D1C* y *D2C* = physical location (address) of distribution center.
- *D1T1* y *D2T1* = range of addresses in which the "Box truck 1" line operates.
- *D1T2* y *D2T2* = range of addresses in which the "Box truck 2" line operates.

The application allows:

- Enter the number of simulations to run.
- Generate n-quantity of packets randomly and related data (address and type of packet). The address has the format "Calle / Carrera ### - ### ###".
- Read the data of the packages to be delivered from a text file.
- Enter the physical location (address) of the distribution center.
- Enter restriction in terms of address ranges for lines "Box truck 1" and "Box truck 2".
- Determine the restriction zone for the lines "Box truck 1" and "Box truck 2". If the restriction = 1, the western zone restriction applies for "Box truck 1" and the eastern zone restriction for "Box truck 2". If the restriction = 2, the restriction north zone for "Box truck 1" and south zone for "Box truck 2" applies.
- In each valid simulation, the total distance of the three lines is calculated and stored as a probable answer.

Restrictions:

- The delivery area is set at "150 km^2".
- The three delivery lines depart from the distribution center.
- Randomly generated package delivery addresses range from 1 to 150.
- The package type is an integer random number between 0 and 1. 0 = document, 1 = box.

- If the package type = 0, it is assigned to the “Moto” delivery line. Otherwise it is assigned to the lines “Box truck”.
- “Box truck 1” and “Box truck 2” lines must be balanced in package allocation.
- The “Box truck 1” and “Box truck 2” lines can only be assigned packages according to the restriction of address ranges.
- The “Moto” line has no restrictions regarding address ranges.

Outputs:

- Cost for each delivery line and total cost.
- Map with the best calculated delivery route of the three distribution lines.
- List of addresses that the drivers of each line must follow.

Simulation and optimization algorithm:

```
Function simulate_route(C, can_ boxes , x_paq_boxes[],
            y_paq_boxes[], z_paq_boxes[], text_paq_boxes[]){
  random = 0
  array x[can_ boxes], y[can_ boxes], z[can_ boxes],
  text[can_ boxes]
  selected[can_ boxes]
  for (i = 0; i < C; i++) {
   fill(selected, false)
   for (j = 0; j < can_ boxes;) {
     random =  between (0, can_ boxes)
     if (!selected[random]) {
       selected [random] = true
       x[j] = xPaqCajaT1[random]
       y[j] = yPaqCajaT1[random]
       z[j] = zPaqCajaT1[random]
       text[j] = textPaqCajaT1[random]
       j++
     }
   }
   call function_objective(x, y, z, text)
 }
}
```

Objective function:

```
function_objective(x[], y[], z[], text[]){
  x1p1 = x_center_distribution
  y1p1 = y_center_distribution
  x2p2 = 0
  y2p2 = 0
  distance = 0
  distance_min = Double.MAX_VALUE
  for (j = 0; j < can_ boxes; j++) {
    x2p2 = x[j]
    y2p2 = y[j]
    distance+=calc_distance(x1p1, y1p1, x2p2, y2p2)
    x1p1 = x2p2
    y1p1 = y2p2
  }
  if(distance_min > distance){
    distance_min = distance
    save_route_coordinates(x, y)
  }
}
```

III. Results

To test the effectiveness of the algorithm, two test scenarios were carried out. The first scenario consisted of simulating the delivery of 30 packages, divided into 9 documents and 21 boxes, where the “Box truck 1” line was assigned 10 boxes, and “Box truck 2” 11 boxes. To find the least cost route in distance, a test bench was performed that consisted of running the simulation 1,000, 10,000, 50,000, 500,000, 1,000,000 and 10,000,000 times.

The second scenario consisted of simulating the delivery of 200 packages, divided into 97 documents and 103 boxes, where “Box truck 1” was assigned 51 boxes, and “Box truck 2” 12 boxes. In this case, a test bench was carried out with the same number of simulations of the first scenario, but executing each simulation size 5 times, and taking the distance and the execution time of each one, to finally calculate their average.

It should be noted that the tests were performed with the same input data and restriction values, making the results more reliable.

In the graph showing the best calculated route, the distribution center and the end points of each delivery line are represented by a circle in fuchsia, the line "Moto" in red, "Box truck 1" in blue and "Box truck 2 "in green.

A. *First scenario*

Inputs:

- *C* = 1,000, 10,000, 50,000, 500,000, 1,000,000 and 10,000,000.
- *P* = 30.
- *D1C* = 75 y *D2C* = 5. Distribution center location.
- *D1T1* = 1 y *D2T1* = 60. Range of addresses in which "Box truck 1" operates.
- *D1T2* = 61 y *D2T2* = 150. Range of addresses in which "Box truck 1" operates.

In this case the applied zone restriction will be: west and east.

Output**:**

Fig. 1 shows the best route calculated when performing 10 million simulations, with a distance of "Moto" = 32,742, "Box truck 1" = 33,941 and "Box truck 2" = 40,177. Total “106,860 km”.

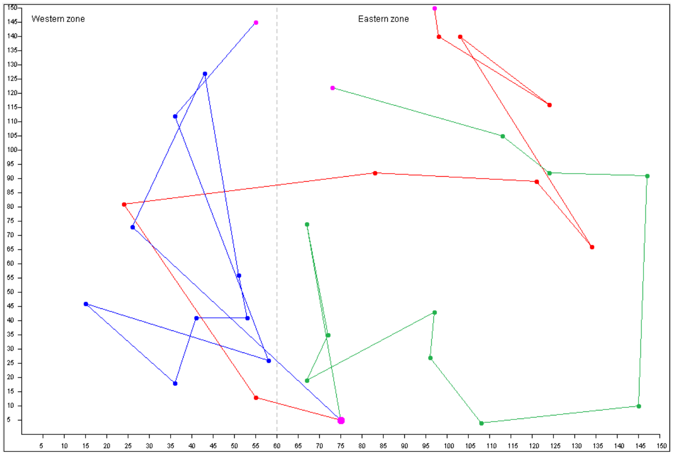

Fig 1. Best route - first scenario.

As you can see, all the delivery lines leave from the distribution center. Box truck lines only operate in the assigned area. The western and eastern zones are also demarcated.

Table II and Fig. 2 summarize the data obtained in each simulation and the percentage of improvement in each simulation.

TABLE II
SUMMARY - FIRST SCENARIO

Number of Simulations	Minimum distance reached			Distance total	Percentage improvement
	Moto line	Box truck line			
		Western zone	East zone		
1,000	38,269	40,813	51,342	130,424	0
10,000	38,030	39,864	49,031	126,925	2.68
50,000	33,730	36,676	45,948	116,354	10.79
500,000	32,746	33,941	42,937	109,624	15.95
1,000,000	32,742	33,941	40,483	107,166	17.83
10,000,000	32,742	33,941	40,177	106,860	18.07

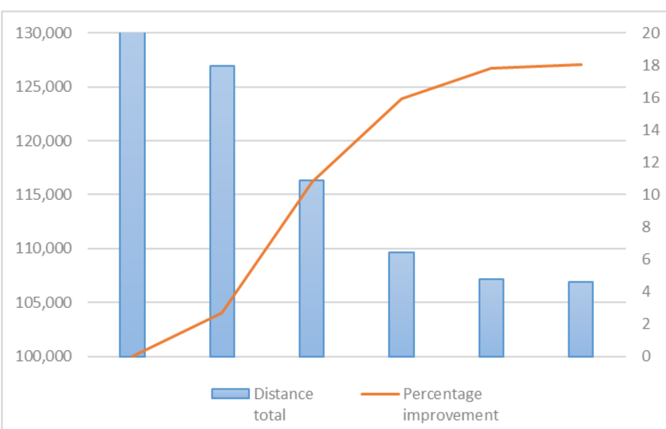

Fig 2. Improvement percentage between simulations - first scenario.

B. Second scenario

Inputs:

- *C* = 1,000, 10,000, 50,000, 500,000, 1,000,000 and 10,000,000. 5 times each simulation.
- *P* = 200.
- *D1C* = 75 y *D2C* = 5. Distribution center location.
- *D1T1* = 1 y *D2T1* = 60. Range of addresses in which "Box truck 1" operates.
- *D1T2* = 61 y *D2T2* = 150. Range of addresses in which "Box truck 1" operates.

Output**:**

After running the test bench, the best calculated route was: "Moto" = 588,956, "Box truck 1" = 245,764 and "Box truck 2" = 245,314. Total "1,080,034 km".

Table III and Fig. 3 summarize the data obtained in each simulation and the percentage of improvement in each simulation.

TABLE III
SUMMARY - SECOND SCENARIO

Number of Simulations	Average time of 5 simulations (sec)	Minimum distance reached			Distance total	% imp.
		Moto line	Box truck line			
			Western zone	East zone		
1,000	0.00	658,08	305,33	208,83	1,172,26	0
10,000	0.00	618,47	281,84	270,46	1,170,77	0.13
50,000	0.95	625,56	263,59	256,45	1,145,61	2.27
500,000	12.05	593,91	261,25	246,79	1,101,95	6.00
1,000,000	24.58	594,92	260,94	251,59	1,107,46	5.53
10,000,000	249.23	588,95	245,76	245,31	1,080,03	7.87

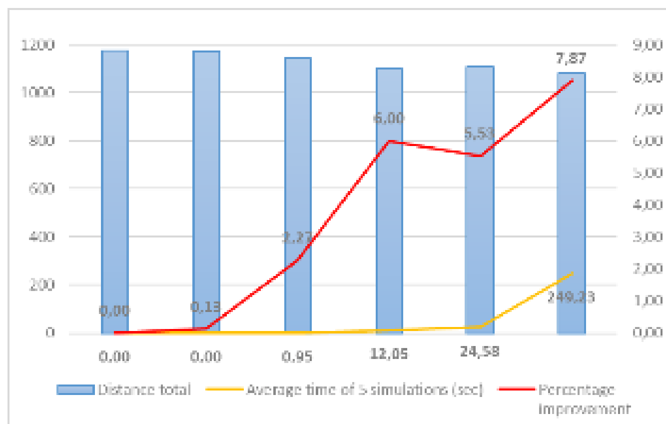

Fig 3. Improvement percentage between simulations - second scenario.

As can be seen, the two scenarios tested the hypothesis, that the greater the number of simulations, the better the result.

On the other hand, the distance calculated in the first scenario, although true decreases with each simulation, the percentage of improvement between the number of simulations 1 million and 10 million is very low, only 0.24% representing "0.306 km", which is very low compared to computational cost. The same is evident for the second scenario, where tests of greater weight and with a higher computational cost were carried out, but where it is observed that among the same number of simulations a better percentage of improvement was achieved, reflected in "27,430 km" less, than vehicles must travel.

If the results of the second scenario are taken as a basis, it can be assumed that, in a week, a courier company with the same characteristics as the simulation, would reduce the displacement of its vehicle fleet by an average of "137.15 km", which represents less travel time and savings in fuel consumption.

IV. Conclusions

The results obtained showed the advantages of using computational simulation techniques to imitate and predict the behavior of a complex system, where there are many variables that can affect its normal operation, but being stochastic processes do not provide the guarantee that the results are totally reliable. Similarly, if you want to obtain results that approach solutions with a high degree of effectiveness, it is necessary to involve an external variable, in this case, computational power to achieve the best result within a scenario with many possible solutions that seem the best, and escape from optimal venues. In this regard, and if the results of the second scenario are taken as evidence, and the prediction made, it is well worth increasing the computational capacity factor, but without neglecting the efficiency that algorithms must have, to optimize processes within organizations, which will ultimately be reflected in greater customer satisfaction, operating capacity and increased profits.

On the other hand, the tests also showed that the application of the voracious programming technique, the design of the optimization algorithm and the evaluation method of the objective function was successful, yielding the expected results, in a reasonable time.

Finally, it is hoped that the results of the research will help the academic and scientific community, and that they can be taken as a basis for future projects that improve the results obtained, applying techniques such as the Markov Chain, Big data, Artificial Intelligence and Deep Learning.

References

[1] M. Shaiq et al., "Quality Management as Driver of Vertical Integration in Service Chain: A Study of 3rd Party Logistics Industry", *Operations and Supply Chain Management*, 13(3) pp. 224 – 255. 2020. DOI: http://doi.org/10.31387/oscm0420266

[2] S. Pattnaik, and S. Pattnaik, "Relationships Between Green Supply Chain Drivers, Triple Bottom Line Sustainability and Operational Performance: An Empirical Investigation in The UK Manufacturing Supply Chain", *Operations and Supply Chain Management: An International Journal*, 12(4), 198-211. 2019. DOI: http://doi.org/10.31387/oscm0390243

[3] Uvet, H, "Importance of Logistics Service Quality in Customer Satisfaction: An Empirical Study", *Operations and Supply Chain Management: An International Journal*, 13(1), 1-10. 2020. DOI: http://doi.org/10.31387/oscm0400248

[4] A. Batwa, and A. Norrman, "A Framework for Exploring Blockchain Technology in Supply Chain Management", *Operations and Supply Chain Management: An International Journal*, 13(3), 294-306. 2020. DOI: http://doi.org/10.31387/oscm0420271

[5] M. Abdul-Hak, N. Al-Holou, Y. Bazzi and M. Alamir Tamer, "Predictive Vehicle Route Optimization in Intelligent Transportation Systems", *International Journal on Data Science and Technology*, 5(1), pp. 14-28. 2019. doi: 10.11648/j.ijdst.20190501.13

[6] H. Yalcin, W. Shi and Z. Rahman, "A review and scientometric analysis of supply chain management (SCM)", *Operations and Supply Chain Management: An International Journal*, 13(2), 123-133. 2020. DOI: http://doi.org/10.31387/oscm0410257

[7] A. Sharma and P. Khanna, "Relevance of Adopting Emerging Technologies in Outbound Supply Chain: New Paradigm for Cement Industry", *Operations and Supply Chain Management: An International Journal*, 13(2), 210-221. 2020. DOI: http://doi.org/10.31387/oscm0410263

[8] M. Akbari, "Logistics outsourcing: a structured literature review", *Benchmarking: An International Journal*, 25(5), pp. 1548-1580. 2018. DOI: https://doi.org/10.1108/BIJ-04-2017-0066

[9] J. Mageto and R. Luke, 'Skills frameworks: A focus on supply chains', *Journal of Transport and Supply Chain Management,* 14(0), 2020. DOI: https://doi.org/10.4102/jtscm.v14i0.458

[10] J. Alieva and R. Haartman, "Digital Muda - The New Form of Waste by Industry 4.0", *Operations and Supply Chain Management: An International Journal*, 13(3), 269-278. 2020. DOI: http://doi.org/10.31387/oscm0420268

[11] W. Yudhistyra, E. Risal and I. Raungratanaamporn, "Exploring Big Data Research: A Review of Published Articles from 2010 to 2018 Related to Logistics and Supply Chains", *Operations and Supply Chain Management: An International Journal*, 13(2), 134-149. 2020. DOI: http://doi.org/10.31387/oscm0410258

[12] R. Naudé and J. Badenhorst, 'The challenges behind producing a bottle of wine: Supply chain risks', *Journal of Transport and Supply Chain Management,* 14(0), 2020. DOI: https://doi.org/10.4102/jtscm.v14i0.471

[13] A. Botha and J. Badenhorst, 'Risk management in a bulk coal export logistic chain: A stakeholder perspective', *Journal of Transport and Supply Chain Management* 13(0), 2019. DOI: https://doi.org/10.4102/jtscm.v13i0.424

[14] M. Schneider, T. Gschwind and D. Vigo, "Advances in vehicle routing and logistics optimization: exact methods", *EURO J Transp Logist*, 8, 117–118. 2019. DOI: https://doi.org/10.1007/s13676-018-0139-6

[15] D.E. Mazzuco, et al., "A concept for simulation-based optimization in Vehicle Routing Problems", *IFAC-PapersOnLine*, 51(11), pp. 1720-1725. 2018. DOI: https://doi.org/10.1016/j.ifacol.2018.08.208

[16] M. Appiah and X. Qiang, "Route Optimization in logistics distribution based on Particle Swarm Optimization", *International Journal of Computer Applications.* 178. 23-27. 2019. DOI: 10.5120/ijca2019919179

[17] E. Huddiniah and M. ER, "Product Variety, Supply Chain Complexity and the Needs for Information Technology: A Framework Based on Literature Review", *Operations and Supply Chain Management: An International Journal*, 12(4), pp. 245-255. 2019. DOI: http://doi.org/10.31387/oscm0390247

[18] N. García, J. Moyano and J. Maqueira, "Planteamiento de un modelo de evaluación de lean supply chain management", *Revista De Estudios Empresariales. Segunda Época*, (1). 2019. DOI: https://doi.org/10.17561/ree.v2019n1.8

[19] M. Asrol, M. Yani and E. Taira, "Supply Chain Fair Profit Allocation Based on Risk and Value Added for Sugarcane Agro-industry", *Operations and Supply Chain Management: An International Journal*, 13(2), pp. 150-165. 2020. DOI: http://doi.org/10.31387/oscm0410259

[20] K. Salas, J. Meza, T. Obredor and N. Mercado, "Evaluación de la Cadena de Suministro para Mejorar la Competitividad y Productividad en el Sector Metalmecánico en Barranquilla, Colombia", *Información tecnológica*, 30(2), pp. 25-32. 2019. DOI: https://dx.doi.org/10.4067/S0718-07642019000200025

[21] F. Caballero, O. Walteros and F. Santofimio, "Desarrollo y aplicación del Supply Chain Management en las empresas de marroquinería en Bogotá", *Apuntes Contables*. 24, 2019. pp. 107-123. DOI: https://doi.org/10.18601/16577175.n24.07

[22] E. Rodríguez, "La gestión de la cadena de suministro sostenible en la industria alimenticia", *AD-minister*, 33, pp. 113 – 134. DOI: 10.17230/ad-minister.33.6

[23] D. Ruiz, J. Bonilla and C. Masaquiza, "Ajuste estratégico en la cadena de suministros para la creación de valor de la marca Jean up", *Revista Universidad y Sociedad*, 10(1), pp. 25-32. 2018. Available at: http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S2218-36202018000100025&lng=es&tlng=es

[24] R. Huarote, Y. Vega, H. Aradiel and J. Valverde, "Optimización de ruta corta usando algoritmo genético generacional", *Ciencia & Desarrollo,* (22), pp. 50-57, 2019. DOI: https://doi.org/10.33326/26176033.2018.22.745

[25] Ma. Hajghasema and A. Abbas, "Optimal Routing in Supply Chain Aimed at Minimizing Vehicle Cost and Supply", *Procedia Economics and Finance*, 36, pp. 353-362. 2016. DOI: https://doi.org/10.1016/S2212-5671(16)30047-8

[26] J. Galarcio, et al., "Una nueva metaheurística aplicada al problema de ruteo de vehículos capacitados (cvrp) para la distribución de productos

perecederos", *Ingeniería E Innovación*, 5(1). 2017. DOI: https://doi.org/10.21897/23460466.1107

[27] J. Velarde *et a*l., "Optimization of territories and transport routes for hazardous products in a distribution network", *Journal of Industrial Engineering and Management*, 10(4), pp. 604-622, 2017. DOI: http://dx.doi.org/10.3926/jiem.2107

[28] Y. Congli, "Optimization on Combination of Transport Routes and Modes on Dynamic Programming for a Container Multimodal Transport System", *Procedia Engineering*, 137, pp. 382-390, 2016. DOI: https://doi.org/10.1016/j.proeng.2016.01.272

[29] C. Osorio and K. Kumar, "Simulation-Based Optimization: Achieving Computational Efficiency Through the Use of Multiple Simulators", *Home Transportation Science*, 51(2), 2017. DOI: https://doi.org/10.1287/trsc.2016.0673

[30] M. Trigila, A. Gaudiani, E. Luque and M. Naiouf, "Simulación computacional, ciencia de los datos, cómputo de alto rendimiento y optimización aplicados a mejorar la predicción de modelos de simulación que representan la evolución de sistemas complejos", XX Workshop de Investigadores en Ciencias de la Computación. 2018. Available at: http://sedici.unlp.edu.ar/handle/10915/68228

[31] L. Lasso, D. Franco and A. Agudelo, "Voracious and Heuristic Algorithms: A focus on the Minimum Path Problem", *INGE CUC,* 16(2), 2020. DOI: https://doi.org/10.17981/10.17981/ingecuc.16.2.2020.05

[32] I. MENES *et al*., "Simulación computacional de procesos de producción, caso de estudio: Proceso de producción de queso en la planta de lácteos FCP-ESPOCH", *Revista Publicando*, 4(3), pp. 248-265, 2017. Available at: https://revistapublicando.org/revista/index.php/crv/article/view/847

[33] M. Bučková, M. Krajčovi and M. Edl, "Computer Simulation and Optimization of Transport Distances of Order Picking Processes", *Procedia Engineering*, 192, pp. 69-74. 2017. DOI: https://doi.org/10.1016/j.proeng.2017.06.012

[34] F. Silva, et al., "Simulation Optimization for Analysis of Sustainable Logistics Systems", *Pesquisa Operacional*, 37(1), pp. 145-171. 2017. DOI: https://doi.org/10.1590/0101-7438.2017.037.01.0145

[35] J. Peng, "Optimizing the transportation route of fresh food in cold chain logistics by improved genetic algorithms", *Int. J. Metrol. Qual. Eng*. 10, 2019. DOI: https://doi.org/10.1051/ijmqe/2019013

[36] M. Hrušovský, *et al*., "Hybrid simulation and optimization approach for green intermodal transportation problem with travel time uncertainty", *Flex Serv Manuf*, 30, 486–516. 2018. DOI: https://doi.org/10.1007/s10696-016-9267-1

[37] Ch. Shaviraa and B. Kara-Sal, "Optimization methodology of intraurban transport routes of automobile passenger transport", *Economics*, 6(72), 2018. DOI: https://doi.org/10.23670/IRJ.2018.72.6.034

[38] C. Iliopoulou and K. Kepaptsoglou, "Combining ITS and optimization in public transportation planning: state of the art and future research paths. EUR". *Transp. Res. Rev*. 11(27). 2019. DOI: https://doi.org/10.1186/s12544-019-0365-5

[39] C. Ma *et al.,* "Distribution path robust optimization of electric vehicle with multiple distribution centers", *PLoS ONE* 13(3), 2018. DOI: https://doi.org/10.1371/journal.pone.0193789

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