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Optimization of Terrestrial Distribution Routes for Mass Consumption Products using Genetic Algorithm

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Abstract. This research aims to show the results of applying optimization in the distribution network of high consumption products, using metaheuristics for the design of distribution routes, applying genetic algorithms, performing the simulation in the HeuristicLab software. Achieving the optimization of the distribution processes of high consumption products which has grown in recent years to the increase of the population and the increase of the vehicular congestion, in the big cities, hindering the achievement of common objectives between the different actors in Urban Distribution of Merchandise (DUM).
The research was quantitative cross-sectional non-experimental, because the situations and subjects of study, could not be manipulated by the researcher, the information was provided by the company, which, for reasons of confidentiality, will not be named.
Keywords: VRP, optimization, land routes and metaheuristics.

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1 Introduction

There is a special importance when referring to the distribution of goods or services; being a fundamental element for trade, since logistics activities have the function of bridge or nexus between the source of production and consumer markets, which are separated from each other by a certain time and space. Additionally, the distribution and commercialization of high-consumption products is a phenomenon that has registered significant changes in the last two decades according to those referred to by Gasca & Torres (2014). They are considered as products of intensive distribution according to Bello, Vázquez and Trespalacios (2005), since it is intended that the products can cover a very high number of points of sale, trying to achieve the greatest possible coverage of the target market, covering convenience products, those of frequent consumption and low involvement, such as food products, or carbonated beverages. Obeying the modality in which companies work, which is more efficient when a massive mobilization of the products demanded by today's cities is carried out; one more is located in the logistics capacity of companies which seek to reduce both costs and times of transfer of goods.

The Vehicle Routing Problem (VRP) is the name given to all classes of problems where a set of routes for one or more land vehicles originates from one or more geographically located points, and must serve a number of customers or cities (Bermeo & Calderón, 2009). The origin of routing problems is represented with the "traveler's problem", which seeks the shortest path that joins a set of points whose distances between all of them is known, a set of clients or cities must be visited, and then return to the starting point (Benito, 2015). Most algorithmic research and software development in this area is focused on a limited number of problems, flexibility in optimization systems can be adapted to various practical contexts (Jean-François, Laporte, Savelsbergh, & Vigo, 2007). Juarismi, (2019) indicates that algorithms are instructions established in successive steps, perfectly identified for their implementation.

This kind of algorithms required a long computing time to find the optimal solution, for this reason, many researchers apply Metaheuristics, which are “strategies or general templates that 'guide' the search process" (Chicano, 2007), and help to obtain a faster and closer to the optimal solution. The most commonly used metaheuristic techniques are the following: genetic algorithms, taboo search, "dispersal" search, ant colonies, and the technique known as Greedy Randomized Adaptive Search (GRASP), which is mainly used in the design of transit networks, neural networks are also included among the metaheuristic techniques, although they are of a different nature.

Genetic Algorithm (GA), it´s a metaheuristic that's based on a DNA strand, where every feasible problem solution is considered as a "chromosome encoded by a set of genes" (Holland, 1992). Each of the variables that make up the chromosome is called gene, while the different values that these genes can take are called alleles. The genetic algorithm solves the problems of local optima that arise in problems that have a large number of options, since it works with a base population, which allows the simultaneous evaluation of several regions which can be very different from each other within the spectrum of solutions (Stockdale, 2011).

The use of the genetic probabilistic operator, provides optimums closer to reality, which aims at a convenient result for the study. Toth and Vigo (2002) describe the process as follows:

From an initial randomly generated population of chromosomes. X "1 = (jCj,.. . N. The simple Genetic Algorithm (GA) its described in table 1. Considering each iteration t = 1,. . . , T, apply k times. Steps 1 to 3 (k <TV/2), then apply Step 4.

Table 1. Genetic Algorithm (GA)

Step		
1	playback	Select two parental chromosomes from X'.
2	recombination	Generate two offspring of the two parent chromosomes using a crossover operator.
3	mutation	Apply a random mutation to each offspring (with a small probability).
4	generation replacement	Create Xt + 'from X' by removing the worst 2k solutions in Xr and replace them with the new 2k offspring.

Source: Toth and Vigo (2002).

In the algorithm "T" is the daughter-in-law of generations while "k" is the number of selections per generation, In Step 1 selecting the best chromosomes by probabilistically biased. In Step 2, new offspring are produced through crossbreeding by exchanging substrings of bits found in both parents. Each offspring can be modified slightly in Step 3 by changing a bit value from zero to one, or vice versa, with a small probability at each position, this is directly linked to the selected mutation percentage. In step 4, generation replacement occurs. Subsequently, chromosomes must be improved by the replacement of parents by better offspring.

In the case of VRP problems it is replaced by a route representation, where each integer represents a particular vertex, which represents the order to follow in the route, there is a scarce literature regarding the resolution of these problems, since there are usually time windows and restrictions of origin, being the Genetic Algorithms those that give the closest solutions to the optimal given its relative solidity in the existence of complex constraints, an interesting feature of this is that it uses the approach of route first, cluster second, this allows to use the classic route representation. The route ends before the maximum route time is exceeded. Using an OX cross operator and the exchange mutation operator, two randomly selected vertices will exchange their position improving the performance of the AG.

Resulting in the following function:

$$AGA = \left(P_0, \lambda, I, f_{sel}, f_{prod}, f_{mut}, f_{ext}, f_{red}, g, ct\right)$$

Donde:

$P_0 = \{I_0^1, \ldots, I_0^\lambda\} \epsilon (S^I)^\lambda$	*población inicial,*
λ	tamaño población,
I	longitud de la presentación,
f_{sel}	función de selección
f_{prod}	función de producción de hijos,
f_{mut}	función de mutación,
f_{ext}	función de extensión,
f_{red}	función de reducción,
g	función objetivo,
ct	criterio de parada

According to Stallman (2017), a software is programmed to work on an operating system and perform specific tasks. This project used two programs: for logistic model and a Geographic Information System (GIS).

The program for searching the optimal VRP solution was HeuristicLab©, that “is a framework for heuristic and evolutionary algorithms developed by members of the Heuristic and Evolutionary Algorithms Laboratory (HEAL) since 2002." (WikiStart, 2019). The version used was 3.3.15.15587, in addition to the accessibility of this software because it is for public use, it allows to establish strategies based on sets of solutions, called populations, that evolve in the search space using the elements of better results of the continuous generations and mutations in order to approach the optimal solution.

Problem Statement

Actually, cities of our country have a great growth in their population, this is reflected in road congestion, Reduction of operational speed and decreasing in levels of service, resulting in a challenge for physical distribution to final consumers customers; mainly in the so-called "last mile" or Urban Distribution of Merchandise (DUM), which has forced to look for new strategies to have a more efficient development in the distribution of physical goods in this segment, of the supply chain.

These problems are reflected in the occasional shortages of mass consumption products (Velásquez et al, 2017), such as basic necessities (drugs, food, etc.), are considered as supply problems when a high percentage is affected for 3 or more days or if a large majority of any of these products were affected during a single day. This is why the reduction of "shortages" in delivery to points of sale and / or end customers is required to solve these problems. Delivery companies have begun to bet on technology, which allows them to make their processes more efficient.

General objective: Optimization in the distribution network of mass consumption products.

2 Experimental procedures

This research established that the characteristics regarding road infrastructure, geographical location, and the authors involved, have a fairly close relationship, in terms of day-to-day delivery activities, planning depends on demand, so the planning area must work together with the rest of the areas involved, to achieve deliveries in the shortest possible time.

The methodology used is of a non-experimental cross-sectional quantitative nature, because the situations and subjects of study may not be manipulated by the researchers, considering a case study a unit is analyzed in detail to answer the problem, test hypotheses, and develop theories (Hernández et al., 2014).

Currently, there are many problems whose solution can be found within engineering applications. Several authors have identified some of the main problems: creating a minimum cost plan for the delivery of goods, the optimal allocation of workers in their respective tasks, establishing the optimal sequence in the production chain, among others (Moreno & Huecas, 2007).

These problems are considered combinatorial optimization problems, because they have the following considerations: 1) there is a set of objects (clients, tasks, jobs) that have to be placed in different positions; 2) there is a group of places in which these objects should be placed (Sánchez, 2000).

The research was developed directly in the company, being considered a case study, a direct relationship was maintained with the sources of information at the managerial level, who provided the information collected in the so-called day to day delivery.

First, it is discriminated by units and batch size, that is, if the batch size fits in the corresponding units, if it is so then the route assembly is available, otherwise it is reprogrammed for another day, if there is availability of operators or guard operators are needed, the route assembly is traced in the software which it gives the optimal solution based on distance between point of interest, Performance and restrictions, once the routes are assembled, the routes are shipped each in the assigned unit in collaboration with the pumps of the warehouse area, and once the units are loaded, they are passed to the maneuvering yard to wait for their departure time to route Most of the routes leave between a schedule of 8:00 am and 10:00 am.

The transport units used in the routes analyzed are Nissan NP300, with a fleet of 12 vehicles, which has a capacity of between 250 and 300 cargo units for each vehicle, taking 250 as a unit for analysis.

A data filtering is applied, in order to know and understand the behavior of the market, the current management of the distribution, subsequents and proceeds to the choice of the software touse, proceeding to empty them in the mathematical model and the software, ending with the comparison of the data.

Metaheuristic models will be, which are advanced algorithms for solving difficult problems, such as combinatorial optimization. Metaeuristics are based on artificial intelligence, in some cases on biological evolution or statistical mechanisms. (Vélez & Montoya, 2007).

Based on the information obtained and having selected the functions to be used, the data is loaded and according to this the constraints are elaborated, and with this achieve the simulation in the HeuristicLab© software.

After entering the information and restrictions, its proceed to the simulation of the routes and obtaining the results, the optimal route is determined.

The program performs a loop with the restriction of the vehicles assigning the maximum load to each of these, trying to satisfy all the restrictions of the elements (customers) to which it is associated, the cycle ends after reaching a certain number of iterations: if the vehicle cannot visit one of the "next clients", the algorithm tries to find another vehicle for that client, if it is unsuccessful (no more vehicles able to reach that client), it is a failed result for the chromosome, discarding This possible solution, if the validation was successful, is marked as valid and the suitability is calculated, the vehicle continues with the next customer and thus the process continues until the complete routes are defined, complying with the restrictions.

As a result, a feasible solution (route) is obtained, to which modifications are made with respect to the mutation algorithm, seeking to have a result with better performance.

All of the above mentioned is based on the genetic algorithm of the Capacitated VRP routing problem, the tests have used the same base configuration, so they can be easily compared with each other, with the mutator being the cause of the most relevant modifications.

3 Results

The software used was configured with the information provided by the company, considering these as the initial restrictions, using the capacity of 250 boxes per vehicle, the locations of retail customers, the start time of work, the average time of attention per customer, the fleet vehicles available, as well as the approximate cost for penalties for not complying with any of the customers, the demand for a week of work, all this is shown (Figure 1), the main data used are:

Vehicle capacity. - Using 250 standard measuring boxes, considering that the boxes with the largest volume will be transported for the simulation, being the maximum capacity with respect to the cargo volume; When using the maximum volume capacity, it does not exceed the load capacity of the vehicle, so this is not considered a limitation.
Coordinates. - The basis for the elaboration is considered, since each of these is a node, the point of origin / end is the distribution center, once the nodes are selected, new routes are generated until the number of iterations previously chosen is fulfilled.
Demand. - Based on the information provided by the company, and according to its procedures, it will be calculated how many vehicles will be used, according to the capacity, both volume and weight, for optimal distribution.
Start and end time (schedule). - Since the company and customers work with pre-established schedule, it can be considered a restriction, because within this schedule it must be covered with attention and service, it should be noted that there are no time windows since the only condition is that it is within working hours.
Penalties. - By not complying with any delivery or by making them outside the permitted hours.

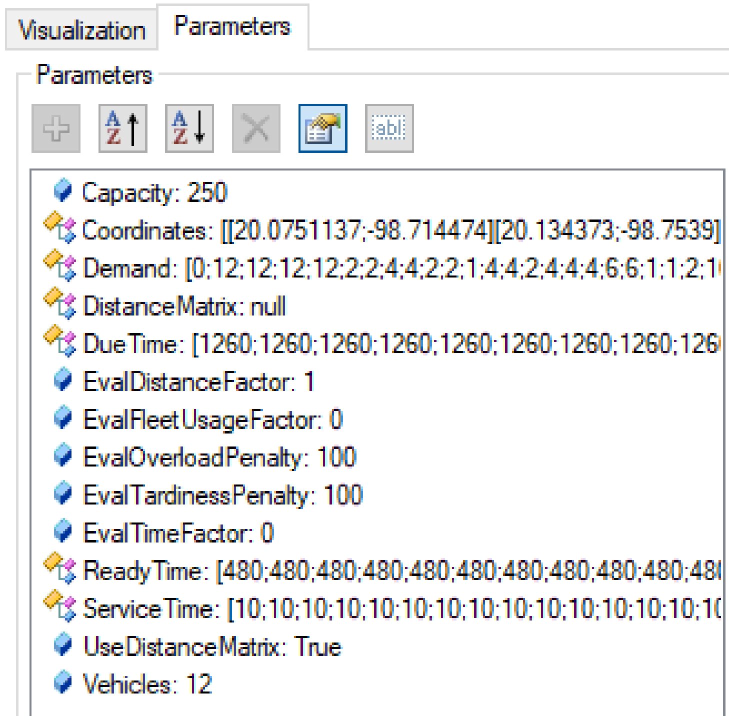

Figure 1. Parameters used for simulation. Source: Authors.

330 runs were made, based on the law of large numbers, which indicates that as we increase the number of runs, the frequency tends to stabilize at a certain number that is the probability of the event occurring, the set of patterns that the software has runs the simulation based on an analyzer that applies arbitrarily, thus achieving the closest results to the optimal.

Currently the company only works with two routes, in which they use the total of available units, deliveries are made from Monday to Saturday, there is a record regarding the distances of the route made by each of these units.
50 extra iterations were made, achieving a final distance of 20.50 km, a utilization of 10 units of the fleet, a time of 8040.50 minutes.

The processing times required to obtain this result in the software was 41:21 minutes, being one of the longest execution times, using the "GVRInversionManipulator" mutator (Table 2), and the final paths (Figure 2).

Table 2. Optimal Result

	A	B	C	D	E	F	G
1		Best valid VRP Solution Distance	Best valid VRP Solution VehicleUtilization	Best VRP Solution Distance	Best VRP Solution TravelTime	Execution Time	Mutator
2	MultiVRPSolutionManipulator Genetic Algorithm (GA) Run 44	20.5041106	10	20.5041106	8040.50411	41:21.0	GVRInversionManipulator
3	Genetic Algorithm (GA) Run 38	23.1416762	11	23.1416762	8533.14168	18:50.6	BiasedMultiVRPSolutionManipulator
4	Genetic Algorithm (GA) Run 57	33.5482944	12	33.5482944	9033.54829	05:14.8	GVRDisplacementManipulator
5	Genetic Algorithm (GA) Run 9	34.4234099	12	34.4234099	9034.42341	05:49.1	AlbaCustomerInsertionManipulator
6	Genetic Algorithm (GA) Run 52	34.5766006	12	34.5766006	9034.5766	05:09.8	AlbaIntraRouteInversionManipulator

Source: Authors.

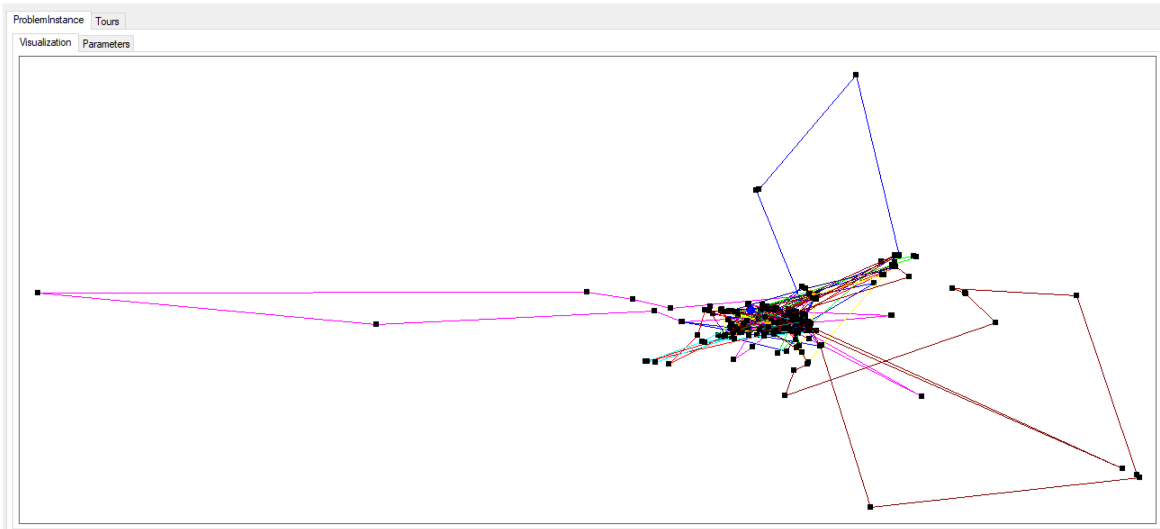

Figure 2. Final path shown graphically. Source: Authors.

As an optimal result the software yielded 6 routes, which can be considered integrated into a cluster to delimit each of the routes (Figure 3), in this final simulation there were reductions in both time and distance, initially having a total distance of 36.69 km, with a complete use of the fleet, a travel time of 9034.79 minutes decreasing to a final distance of 20.50 km, a utilization of 10 units of the fleet, a time of 8040.50 minutes.

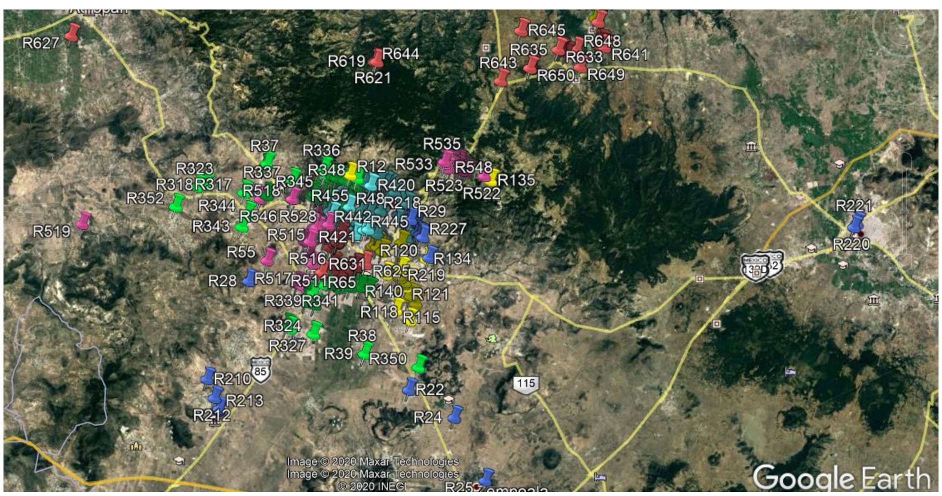

Figure 3. Route view in GIS

As observed, there was a reduction of 16.18 km of travel, also there was a reduction of 996.18 minutes of travel and 2 fleet units which may generate a decrease in maintenance and use costs.

The final solution assigned route 1 will be responsible for supplying 41 customers, route 2 would serve 30 customers, route 3 will cover the demand of 62 customers, route 4 will supply 78 customers, route 5 to 54 customers and route 6 to 52 customers, thus make a route per day with the use of only 10 vehicles, in a shorter period of time and with a shorter route, allowing to use the remaining 2 vehicles, for some extra activity of the company, the particular geographic information system (GIS) of each company can be integrated and which will allow the visualization of the routes.

Therefore, the software would have a direct impact on end users and will allow the comparison of routes and results obtained from different alternatives, achieving greater competitiveness and compliance with the company's commitments, as there is a better distribution, there is the possibility of better quality service for customers, The software contributes to a social improvement derived from a reduction in energy consumption and a reduction in pollutant emissions from road freight fleets, and also the improvement in the life quality of the employees which have an impact locally, nationally and internationally.

In the following table 3, the main results of the proposed scenarios are shown, being able to observe the differences and improvements according to the modifications made during the process, as well as the mutators applied.

Table 3. Main Results of the scenarios

	Mutation rate	Genetic population	Algorithm used	Execution time	Mutator
1	5%	100	GA	05:02.6 min	MultiVRPSolutionManupula
2	10%	100	GA	05:47.6 min	AlbaIntraRouter
3	15%	100	GA	05:49.1 min	Optimo GVRDisplacement
4	20%	100	GA	04:39.5 min	Optimo GVRDisplacement
5	25%	100	GA	03:56.3 min	AlbaIntraRouter
6	5%	100	GA	06:35.8 min	MultiVRPSolutionManupula
7	10%	100	GA	06:40.3 min	AlbaIntraRouter
8	15%	100	GA	06:54.6 min	Optimo GVRDisplacement
9	20%	100	GA	07:21.6 min	PotvinOnel
10	25%	100	GA	07:58.5 min	MultiVRPSolutionManupula
11	25%	100	GA	41:21 min	**GVRInversionManipulator**

Source: Authors.

4 Conclusions

It was possible to verify the potential of metaheuristic algorithms, to perform analysis of distribution networks, especially the versatility provided by genetic algorithms, for the scenarios that can be built with use, in addition, it can facilitate the integration of spatial analysis showing that they are currently used in many logistic models to improve decision making.

The proposed method allowed to integrate multiple objectives, for example: speed, travel times, distances, which demonstrates the convenience in the use of these methods for the design of distribution of physical goods. This integration improve efficiency of the route obtained in relation to the distribution route that is currently carried out.

The main effect identified when using the heuristic algorithm compared to a mathematical programming model, under the concept of last mile in the distribution network, is the reduction of the distance to be traveled by the vehicles, in addition to only using 10 of the 12 available vehicles, being able to consider that the optimization of the distribution network has been achieved.

References

1. Bello, A., L., Trespalacios, G., J. A., & Vazquez, C., R. (2005). Investigación de mercados: métodos de recogida y análisis de la información para la toma de decisiones en marketing. Ediciones Paraninfo, SA.
2. Benito, A. (2015). Vehicle route problems: models, logistics applications and solving methods. VALLADOLID : UNIVERSITY OF VALLADOLID.
3. Bermeo Muñoz, E. A., & Calderón Sotero, J. H. (2009). Man and Machine. Obtained from Universidad Autónoma del Estado de México Redalyc Scientific Information System: http://www.redalyc.org/comocitar.oa?id=47811604005
4. Chicano, J. F. (July 2007). Metaheuristics and Software Engineering. MÁLAGA, MÁLAGA, Spain.
5. Gasca , J., & Torres, F. (2014). El control corporativo de la distribución de alimentos en México. Problemas del desarrollo, 45(176). Recuperado el 30 de Enero de 2019, de http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0301-70362014000100007
6. Hernandez, Hernández y Baptista. (2014). Research methodology. Mexico: McGraw-Hill.
7. Holland, J. H. (1992). Adaptation in natural and artificial systems. London: The MIT Press.
8. Jean-François, C., Laporte, G., Savelsbergh, M. W., & Vigo, D. (2007). Handbook in OR & MS, Vol. 14. En C. B. (Eds.), Handbook in OR & MS, Vol. 14 (pág. 367). Elsevier.

9. Juarismi, A. (February 25, 2019). Wikipedia®. Retrieved from Wikipedia®: https://es.wikipedia.org/wiki/Algoritmo
10. Moreno, P., & Huecas, G. (2007). Combinatorial optimization metaheuristics: using simulated annealing for a scheduling problem. Journal of Science, Technology and Environment, 1-25.
11. Sanchez, M. (2000). Combinatorial optimization. Mathematics of the 20th century, a look at 101 articles, 115-200.
12. Stallman, R. M. (2017). Free Software. EUA.
13. Stockdale, M. L. (2011). The traveler's problem: a heuristic algorithm and an application. Buenos Aires : University of Buenos Aires.
14. Toth, P., & Vigo, D. (Eds.). (2002). The vehicle routing problem. Society for Industrial and Applied Mathematics.
15. Vélez , M. C., & Montoya, J. A. (December 8, 2007). SciELO (online scientific electronic library). Retrieved from SciELO (online scientific electronic library): http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S1794-12372007000200009
16. Velásquez, B., Chacha, H, Chanatasig, H., Oña, B.. (2017). Design of a mathematical model applied to the planning of the production and distribution of mass consumption products. Revista Publicando, 12, 348 - 364.
17. WikiStart. (20 de 06 de 2019). HuristicLab a paradigm independent and extensible enviroment for heuristic optimization. Obtenido de HuristicLab a paradigm independent and extensible enviroment for heuristic optimization: https://dev.heuristiclab.com/trac.fcgi/