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Design of Material Delivery Routes with Towing Equipment for the Automotive Sector Using a Von Neumann Topology of PSO under the Logistics 4.0 Paradigm

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Abstract. The supply chain increases its importance in the automotive sector continuously. Therefore, manufacturing systems such as Just in Time, entail a complex implementation, due to the ascending variety of models and components of the vehicles, since currently, the implementations of expert systems within the Logistics 4.0 concept, seek to accelerate the flow synchronized materials in the production lines, using technological tools of the environment Industry 4.0. This project was located in an engine production plant, in the material assortment part from the supermarket (decentralized warehouse of a plant) to the assembly line. A mathematical model of the process was made, and a genetic algorithm programmed in Matlab was used to optimize it, seeking to reduce line stoppages caused by lack of material. The experimentation shown focused on five of the currently implemented assortment routes, which provide 29 different part numbers to 25 workstations. The performance of the current routes and that of the optimization were validated by means of a simulation model.

Keywods: PSO algorithm, material delivery routes, logistics 4.0.

1 Introduction

In recent years, in the operational logistics stage, decision problems have been increasing due to a growing trend of mass customization, which has generated a continuous increase in the variety of vehicles and their components.

As a result of this situation, implementing the most used manufacturing methodologies such as "Just in Time" and "Just in Sequence", has become one of the biggest challenges of the current automobile production (Boysen et al., 2015). One of the steps that have been the most reason for study, due to the problems that arise in it, is the delivery of productive parts to the assembly line (Boysen et al., 2015).In addition, due to its complexity and the adoption of production system methodologies such as "World Class Manufacturing WCM" (World Class Manufacturing), used by leading companies in the automotive sector, which does not allow forklifts to enter the stations of work and limits the level of inventory in each station according to the classification that gives the part numbers, that the problems that involve the towing equipment as a means of transport are among the most studied.

For all the above, it is precisely the assortment of parts to the assembly line by means of towing equipment, the study area chosen for this project, since to allow a reliable supply of parts with the principle “JIT” (Just in time), the interdependent routing and programming problems need to be solved, being the routing, the assignment of the stations that will be supplied between the towing equipment and the programming, deciding the start times of the trips of each team through its assigned stations. With regard to the resolution of these types of problems, recently in the state of the art it has begun to mention the use of tools of Industry 4.0, mainly the use of simulation. The fourth industrial revolution, better known as Industry 4.0, is currently underway, which was named in 2011 at the Hannover Messe fair in Germany, and is characterized by the integration of digital and physical. The concept of logistics 4.0 starts from these same bases.

2 Formalization of the Problem

Based on the existing literature, we can mention that the most common problems when transporting material with towing equipment are:

1. Assign a subset of stations to each towing equipment.
2. Determine the number and types of parts to be loaded per trip of the towing equipment.
3. Determine a delivery schedule, for each towing equipment and its associated route. (Boysen et al., 2015).

In the present project, the first two problems mentioned above are studied in a real context, in a plant dedicated to engine machining and assembly, located in Saltillo, Coahuila, Mexico, which produces a 3.6-liter, 6-cylinder engine, which It has 4 different models.

In the plant there are three types of routes responsible for supplying the productive parts to the assembly line, which are differentiated by the means of transport used and the method of loading and unloading containers with empty material and containers. The first two types use towing equipment as a means of transport, while for the third type of route the main means of transport is the forklift.

There are two subdivisions of the routes used as a means of transport for the towing equipment. The first supplies part numbers with classification of material that allows you to have in stock in process, at each station where they are stocked, enough parts to assemble the engines produced in two hours or more. The part numbers supplied by these routes have among their main characteristics, a high number of pieces per unit container, these are thus sent from the supplier. The cycle time of these routes, that is, the frequency with which they supply material to the line, is two hours.

Another important feature is that the loading and unloading of containers with empty material and containers in the warehouse and in the assembly line is done manually by the equipment operator. The project is focused on the following subdivision, which covers the material assortment routes through towing equipment, in which the loading and unloading of material containers and empty containers is done automatically.

The process of this type of routes begins in two different material stores, in the first one the material is placed in such a way that the route operators can take the unit containers manually for their subsequent transfer. The second is the area where the complete pallets of material are located, that is, the material loading units (unit containers of material arranged on pallets, commonly protected with rubber and strapping), just as received from the supplier.

The material is transported from the warehouses already described to a supermarket area, which is also a warehouse, but decentralized located within the plant and closer to the assembly line, in which the material is placed in such a way that the Person responsible for this area, can take individual containers and place them manually in the supermarket facilities. These facilities are racks specially manufactured for each assortment route, adapted with pneumatic mechanisms so that the material placed in them is automatically transferred to special delivery trucks used for this type of route.

These cars are structures made of aluminum profiles and rails, designed and built to load and unload only certain sizes and quantities of material and empty containers. Each structure is fixed to a platform with tires which is anchored to a towing equipment, to be able to transfer it from the supermarket area to the work stations and vice versa. Each towing equipment pulls up to two cars at a time, for which the allocation of material that each one carries was made from the design stage of the routes, currently already implemented in the plant. The transfer of full containers from the supermarket facilities to the cars and the transfer of empty containers from the cars to these facilities, is done at the moment when each car is aligned with its corresponding facility, however, the loading of material to The facilities are done in advance of that time.

Each towing equipment is driven by an operator to the workstations corresponding to its route, where the transfer of material to the station and the transfer of empty containers to the cart are also carried out automatically. In each station where material is supplied, the empty containers accumulated up to that point must be loaded. In both the supermarket area and the assembly line, the loading and unloading of empty material and containers is done for some routes in a single step and for others in two steps for each carriage. It is important to mention that the carriage limit that each towing equipment can pull was given based on its ability to drag and make the necessary turns through the route assigned to each route. Currently, of this type of routes, 5 are implemented and are identified by colors, for reasons of practicality in this work will be identified by numbers.

For the design of the routes already implemented, the following variables were mainly considered: production speed of the assembly line (demand for material on each workstation in a given time frame), loading times and unloading of empty material and containers, permitted speed of towing equipment, cargo capacity of delivery carts, number of carts that can be used for each route, whose decision is given mainly based on the possibility of turning in aisles narrow without difficulty.

The production speed considered to perform the allocation and scheduling of the routes already implemented, was taken as a constant data of 105 engines per hour. In the plant you have a production time per shift of 11.5 hours, so when multiplied by the two daily shifts you have a total of 23 hours of production per day. If the 23 hours per day of production is multiplied by the 105 engines per hour, we would have a total production of 2415 engines per day, however, the current daily production target is 1840 engines. Based on this, it would be thought that producing at a rate of 80 engines per hour could reach the daily goal of 1840 engines, so the question arises: What is the reason for assembling the engines at a speed of 105 per hour?

On the production line there are several unexpected events, such as quality problems in the production parts, lack of parts due to delays in the delivery time of some supplier, failures in the machines, to name a few, which could cause delays in scheduled production. Because of this, there is a safety margin of 25 engines per hour, to ensure compliance with the daily production target. The problems that affect engine production are so unpredictable and have so many possible causes, that maintaining an invariable production per hour for a day is something that has not been achieved. As examples, it could be that in the early hours of the day engines were produced at a rate of 80 per hour, and that, due to engines rejected in the final quality review, by the middle of the shift the amount of production per hour would increase with the aim of reaching the Goal.

On the other hand, it could be the case that, during the first shift due to the absence of problems, they approached the target of 1840 engines per day and therefore, in the last shift the rate of production should be reduced to avoid exceeding the scheduled target, which would also not be suitable for the plant. This point is very important, since one of the main variables to consider for the design of the routes, is precisely the pace of production of the plant. Right after the implementation of the current routes, some issues began to arise. The most serious were line arrests caused by lack of material at workstations. These shutdowns decreased as the learning curve of the towing equipment operators advanced, but unfortunately they continued to occur.

In addition to this, since the implementation to this day, modifications have been made to the design of some tanks of the initial routes, due to the detection of waste in their volumetric capacity. In line with the above, as the learning curve of the operators progressed, downtimes were detected in some of them, contradicting the first recorded observations in which it was described, which due to the cycle time of the assortment process of the routes could not be reached to fill the material in time. In addition, the following observations were made to the assortment process:

1. Existence of routes of towing equipment to workstations without unloading material, by decreasing the demand for parts on the production line.
2. Problems with automatic transfers, when towing equipment again arrives to supply material to a workstation, before the material that occurred in the previous delivery cycle had been consumed.

Another situation that added difficulty to the design of the routes, is the existence of a narrow corridor (where it is not possible to pass) through which four different material assortment routes have their route, three of them of the type studied in this project.

Due to this situation, there have been problems of blockages between material delivery carts, generating the risk of stoppages due to lack of material derived from this condition.

Based on all the features of the problem listed above, it was classified as a routing problem for trained vehicles with time windows. This conclusion is based on the description given in the literature to such problems, which, in order to be classified within this category must meet the following characteristics:

1. Have a fleet of vehicles with limited and constant capacity.
2. The function of delivering various assigned goods according to customer demand.
3. They include the restriction that each customer is only willing to receive orders in the course of a defined time window (Sanches et al., 2016).

In addition to these characteristics, due to the aforementioned WCM philosophy followed by the plant, it is necessary to consider an additional restriction, which states that each workstation has a maximum WPI (Work in process) work inventory allowed, which depends on the classification of the part that is provided in that station, which directly affects the scheduling of the routes.

3 Proposed Methodology

3.1 Particle Swarm Optimization (PSO)

This method was described around 1995 by James Kennedy and Russell C. Particle Swarm Optimization (PSO) is an optimization/search technique typically used in large-ranging search spaces. This method is inspired by the behavior of insect swarms in the wild. You can think of a swarm of bees because they when looking for pollen look for the region of space where there is more density of flowers, because the probability of pollen is higher. The same idea was moved to the field of computing in the form of an algorithm and is currently used in the optimization of different types of systems. Formally speaking, it is assumed that you have an unknown function f(x,y), which can be evaluated at the points you want but as a black box, so you cannot know its expression.

The objective is the usual in optimization, to find values of x and y for which the function f(x,y) is maximum or minimum. F(x,y) is often called a "fitness" function, as it will determine how good the current position is for each particle. The idea that follows in PSO begins by placing particles randomly in the search space, but giving them the possibility of moving through it according to rules that take into account the personal knowledge of each particle and the global knowledge of the swarm.

Providing you with a simple ability to move through the landscape (fitness function) and communication between them, you can discover particularly high values for f(x,y), spending few computational resources (calculations, memory and time) (Sancho Caparrini, 2016). A leader can be global from the entire swarm, or local to a swarm neighborhood. Swarm neighborhoods have a structure that defines how information is concentrated and then distributed through their members.

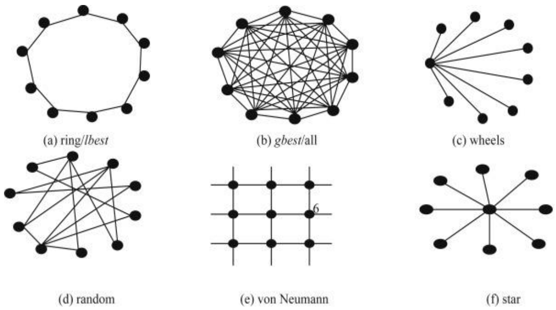


Fig. 1. Topologies used in PSO.

The most common organizations and swarms are: Star neighborhood structure, ring neighborhood structure, wheel neighborhood structure, Von Neumann neighborhood structure, and four-cluster neighborhood structure. The organization of the swarm affects search ability and convergence (Ochoa et al., 2009). 1. The pseudocode is shown below:

1. N: Number of particles,
2. w: Weight of inertia,,
3. c: Cognitive value,
4. pi: Best initial singles,
5. pg: Best Initial Global,
6. x,v' Assign initial random positions and speeds to the particles (N),
7. Start Cycle:
8. For each particle
   - o Update Speed (w,c,pi,pg)
9. x-Update Position (v)
10. Calculate new position fitness value (x)
11. "Upgrade Best Singles"
12. pg-Update Best Global
13. The end.

4 Experimentation with the Proposed Model

Four years later, in 2011, Nils Boysen and Stefan Bock in the article Programming for the Supply of Fair-to-Time Parts for Mixed Model Assembly Lines (Boysen & Bock, 2011), raise the problem of finding sequences, according to the philosophy "Just a Time" of boxes of material delivered from a central storage facility. In this case study, the distribution of parts by means of a forklift is bottleneck. Its objective was to improve the efficiency of supply handling for mixed model assembly lines, as well as to minimize the maximum weighted partial inventory that had to be stored near the assembly line of all stations and production cycles. The solution method used was limited dynamic programming and simulated annealed.

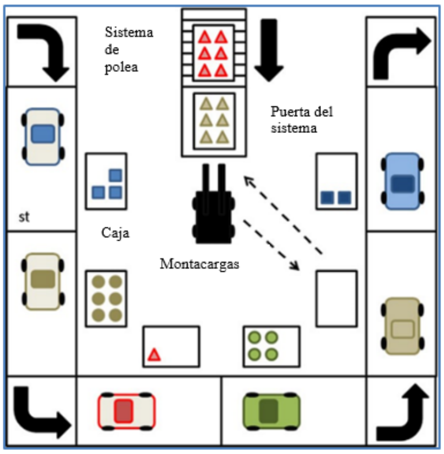


Fig. 2. Problem 2 Scheme. Source: Boysen 2011.

$$(HSP) \qquad Minimizar\ Z(\pi) = \max_{m \in M;\, t=1,\dots,T} \{w_m \cdot L_{m,t}\},$$

$$t^{\pi}_{\pi(s)} = p_{\zeta_{\pi(s)}} + \sum_{s'=1}^{s-1} 2 \cdot p_{\zeta_{\pi(s')}} + s \cdot p' \quad \forall s = 1, \dots, |B|.$$

Point in time where a box will be available at the workstation:

$$\Gamma_{m,t} = \{p \epsilon B_m | t^{\pi}_{p} \le t\} \quad \forall m \in M, t = 1, \dots, T.$$

Part boxes delivered on time at your station:

$$L_{m,t} = A_m + \sum_{p \in \Gamma_{m,t}} a_p - D_{m,t} \quad \forall m \in M, t = 1, \dots, T.$$

Inventory placed near each station on the assembly line. Fig. 3 Mathematical Model. 2. Source: Boysen, 2011. The restrictions considered were:

a) Variable demand.
b) The assortment of a single station per trip.
c) Point-to-point deliveries for a single vehicle.
d) Each box with a variable number of parts.
e) No idle time was allowed between two consecutive deliveries.
f) Fixed and determined travel times and forklift manoeuvres.
g) Time units normalized to the equidistant length of a production cycle.
h) Each box with a predetermined number of single-type units.
i) One-part assembly in each station.
j) Parts ready to be assembled right after the forklift positioned the box on the workstation.

k) The return of empty boxes was not considered in the problem.
l) The safety stock was not explicitly considered, but could be included to the demand of the first period.

Nils Boysen and Stefan Bock concluded that limited dynamic programming provided optimal solutions for moderate and medium sized cases (with up to 20 boxes). On the other hand, using simulated annealing, optimal solutions were produced for large cases (with up to 80 boxes). An important feature considered in this investigation was the variable demand of the material.

In the same year, 2011, Nils Boysen but now with Simon Emde in the article Optimal routing and programming of towing equipment for the just-in-time assortment of mixed model assembly lines (Emde & Boysen, 2012), propose to solve two problems simultaneously:

On the one hand, the routing problem, which is to determine the size of the towing equipment fleet that will be used for the assortment of parts and the distribution of stations among towing equipment (commonly known in the automotive industry as " tuggers"). In addition, the sequence of stops must be decided.

The second problem raised is the programming problem, in which a number of tours have to be determined for each towing equipment, where each tour comprises the loading operation in the supermarket (decentralized storage area within a plant), the cycle through all of its assigned stations, and the arrival time at each stop:

$\alpha_i = \beta_i - (CP_i - PD_i + dp_i)$ Current inventory,

$\delta_i min\left(\frac{K}{D_i},\right)1$ Filling Capacity Rate,

$\delta = \prod_{i=1}^{T} \delta_i$ Filling rate for current and previous routes if early loads are used,

$K \geq F^{-1}(\delta_{EL}, \sum_{i=1}^{N} d_i) \quad K \gg D$ Estimate the number of stations supplied by the same towing equipment:

$$\min w_i \sum_{i=1}^{TSC-MC} \sum_{j=1+MC}^{TSC} y_{ij}^{+} + w_2 \sum_{i=1}^{TSC-MC} \sum_{j=1+MC}^{TSC} x_{ij} + w_3 \sum_{i=1}^{TSC-MC} \sum_{j=1+MC}^{TSC} x_{ij} \sum_{K=1}^{N} \sum_{i=1}^{j} d_{ku}.$$

Minimize the number of towing equipment cycles and the possibility of early deliveries:

$$x_{ij} = \begin{cases} 1, \\ 0, \end{cases}.$$

1, If there is a towing equipment cycle that covers the cycles of stations from 1 to j
0, If not $min \sum_{s=1}^{N} \sum_{t=1}^{T} |\varepsilon_{st}|$.

Maximize the deviation between line inventory and ideal security stock levels figure 4 Mathematical Model 5. Source: Alnahhal and Night, 2015.

Continuing with the solution of problems within a line of assembly and / or production, in recent years several authors have continued to work in their study, but now using tools typical of manufacturing 4.0, as are simulation.

One of the most relevant advantages of simulation is that it allows for a simpler method of solution when mathematical procedures are complex and difficult.

In addition to this, analytical methods are almost always developed relatively straightforward, where a large number of assumptions are made, while in simulation methods it is possible to analyze systems of greater complexity including a better level of Detail. Below are several studies carried out within the area of interest of this project, but with a solution approach more oriented towards the use of simulation. Objective function is:

$$Maximizar \sum_{t=1}^{N} CWT_t \,,$$

where (t) Time measured in the number of engines produced.

N - Number of engines required to be manufactured in a productive day:

a) CWT_t: Inventory in process for all part numbers, at all stations, which will be assorted by towing equipment over time t.
b) Calculating the "CWT_t" as follows:
   a. $CWT_t = \sum_{i=1}^{NV}(CWI_i - (s * ups_i)) + \sum_{j=1}^{PT}\sum_{i=1}^{NV}\Big(CWp_{ji} - \big((dt_{ji} + rt_{ji} + at_{ji} + tll_{ji}) * ups_{ji}\big) + x_{ji} - \big(dif_{ji} * ups_{ji}\big)\Big) + \sum_{i=1}^{NV}(CWp_i - (MV * ups_i)),$

c) $\text{CWI}x_{ji} = \begin{cases} \text{(Valor de x\_ji, Si se llena el número de parte i en la estación j.} \\ \text{−0 si no se llena el número de parte i en la estación j)\}} \end{cases}$

d) $0 \le x_{ji} \le WSL_i.$

Variable that regulates the material consumption of each part number i:

1. Amount of inventory on workstations, part number i, from which the first part number is filled.

2. at-ji - Time it takes to align the towing equipment to fill the part number i at station j.

The time it takes to download part number i on workstation j.

Time to load empty empty containers of part number i at station j.

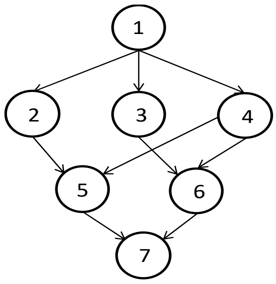
The time it takes for towing equipment to reach the assortment point of part number (i) at station j, considering only distance traveled:

1. x_ji - Amount of material of part number i to be supplied by the towing equipment at station j:

2. dif_ji - Excess of the quantity of the part number i filled in the workstation j relative to its upper limit of inventory in process allowed.

MV - Number of engines produced in the time the towing equipment comes out of supplying the last part number on the last workstation, returns to the supermarket and reloads material.

PT - Total workstations filled by towing equipment.

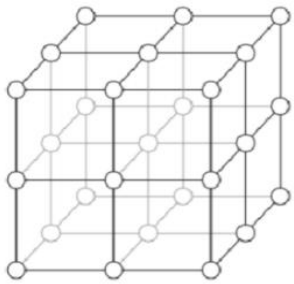


a1	a2	a3	a4
a5	a6	a7	a8
a9	a10	a11	a12

a) Von Newman PSO Model. **b)** Area to explore.

Material Resurshyent Car

MRC	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11	12
1	7	3	9	4	9	4	3	3	1	2	9	9
2	4	7	18	3	2	7	7	2	7	8	7	5
3	8	2	19	4	7	1	2	8	4	4	4	1
4	9	9	17	3	2	7	9	1	2	2	3	5
5	4	8	10	5	9	9	8	8	9	1	4	9
6	5	5	9	8	2	3	5	4	5	8	8	4
7	2	3	11	2	3	3	3	7	3	2	7	3
8	7	5	14	4	7	5	5	5	5	3	3	4
9	3	4	20	3	4	4	4	4	2	4	1	4
10	1	5	2	7	2	5	5	5	10	7	3	2



c) Design of experiments using our model.

Fig. 5. Process of implementation of our solution.

NV - Number of part and total numbers, assorted by towing equipment.

WSL_i - Maximum inventory capacity in process of part number i.

4.1 Particle Swarm Optimization

The next technique experimented with was particle swarm optimization, better known by its acronym PSO.

The code was programmed in MATLAB, using the same evaluation function as in the genetic algorithm, but making some adaptations required by the algorithm itself.

Table 1. Experimentation PSO Algorithm, 105 MH. Source: Own elaboration.

PSO Tabla Comparativa 105 MH											
Número de Experimento	Número de iteraciones (MaxIt)	Tamaño del enjambre (nPop)	Peso de Inercia (w)	Radio de expansión del peso de inercia (wdamp)	Coeficiente de aprendizaje individual (c1)	Coeficiente de aprendizaje global (c2)	Valor de función objetivo	Tiempo CPU (seg)	Tiempo Real (seg)	MH	Equipos de remolque
Basal	NA	NA	NA	NA	NA	NA	-1737237.707	NA	NA	105	5
1	500	100	1	0.99	1.5	2	-40999420.47	1.23E+03	1.23E+03	105	3
2	1000	100	1	0.99	1.5	2	-10063176.81	3.12E+03	3.08E+03	105	4
3	2000	100	1	0.99	1.5	2	-261367.8381	7.17E+03	7.14E+03	105	4
4	3000	100	1	0.99	1.5	2	-51059131.31	1.03E+04	1.03E+04	105	5
5	500	200	1	0.99	1.5	2	-52025743.05	3.53E+03	3.53E+03	105	4
6	1000	200	1	0.99	1.5	2	-51025756.56	7.73E+03	7.71E+03	105	4
7	2000	200	1	0.99	1.5	2	-50003199.68	7.88E+03	7.87E+03	105	3
8	3000	200	1	0.99	1.5	2	-12085673.52	2.49E+04	7.07E+04	105	5
9	500	100	1	1	2	3	-42322031.29	1.29E+03	1.29E+03	105	5
10	1000	100	1	1	2	3	-15250043.68	1.66E+03	1.65E+03	105	4
11	2000	100	1	1	2	3	-42398393.92	5.13E+03	5.10E+03	105	5
12	3000	100	1	1	2	3	-10632227.33	4.42E+03	4.38E+03	105	5
13	500	200	1	1	2	3	-9369976.68	2.04E+03	2.04E+03	105	5
14	1000	200	1	1	2	3	-1823862.003	7.83E+03	1.06E+04	105	6
15	2000	200	1	1	2	3	-50015404.96	1.56E+03	1.55E+03	105	3
16	3000	200	1	1	2	3	-18177578.49	1.39E+04	1.38E+04	105	5

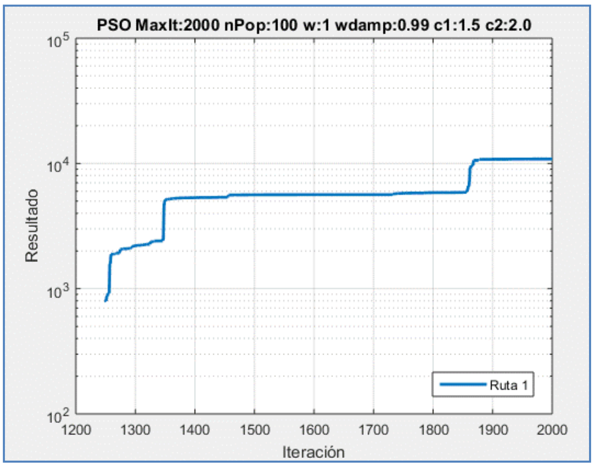


Fig. 6. Convergence Graph, PSO Experimentation, 105 MH, Experiment 3, Route1. Source: Own elaboration.

The topology used for this algorithm was wheel neighborhood structure, which was mentioned in the theoretical framework. The main code is attached in the annexes section. Tables 1 shows the results of the experimentation performed with PSO varying in the algorithm the parameters of, number of iterations (MaxIt), swarm size (nPop), inertia weight (W), radius of expansion of the weight of inertia (wdamp), these two most recently used to get the feed rate in the algorithm.

In addition, variations were made in the individual learning coefficient (c1) and global learning coefficient (c2) parameters. The experimentation was carried out considering a production speed of 105, 90 and 80 engines per hour.

The experiments were conducted based on a custom orthogonal design with 16 runs. The results are shown below and highlighted in green in each table, the best result of each experiment group, corresponding to a different production speed.

5 Conclusions and Future Research

The maximum value of the target function, for the material assortment process with a production speed of 105 engines per hour, was found using a Genetic Algorithm with general crossover type, population of 200 individuals, 300 generations. The time it took to run the algorithm was 22.28 minutes.

The maximum value of the target function, for the material assortment process with a production speed of 90 engines per hour, was found using a Genetic Algorithm with general crossover type, population of 200 individuals and 100 generations. The time it took to run the algorithm was 5.13 minutes.

The maximum value of the target function, for the material assortment process with a production speed of 80 engines per hour, was found using a Genetic Algorithm with general crossover type, population of 200 individuals and 200 generations. The time it took to run the algorithm was 9.49 minutes.

It could therefore be concluded that the best optimization technique for the mathematical model developed was Genetic Algorithm.

Validation by means of simulation, of the results obtained when performing the optimization, considering a production speed of 105 engines per hour, showed a reduction of line stops from 2.42% to 1.30%, using the same 5 towing equipment, but decreasing the total number of kilometers travelled over a 23-hour period, from 448.8 to 410.71 kilometers.

In the current process the amount of material that is sent to the assembly line remains fixed, even if the production speed of 105 motors per hour decreases, so it was expected that in experiments where production speeds of 90 and 80 mots are considered you decrease the amount of material that is sent per cycle, the impact of optimization was greater. However, although the optimization results for lower speeds decreased the use of 1 towing equipment, the validation by means of the simulation did not show good statistics, since, although the value of the target function increased with compared to baseline, a higher percentage of line stops than the current process was obtained in the simulation at the same speeds.

An important detail observed when simulating, was that the solution generated, gave a part number a low amount of material to be sent per cycle (see Figure 93 and 98), which affected the total result of the percentage of line stops of all workstations considered in this study. The above gives rise to consider continuing experimentation with other optimization techniques, or even with it, but with a variety of different parameters, in a future work.

The implementation of the results obtained would require changes in the structure of the facilities of the supermarket area, delivery carts, and special facilities for automatic transfers found at the workstations, for which they are would have to do a cost-benefit analysis that would justify the change considering the cost of the changes.

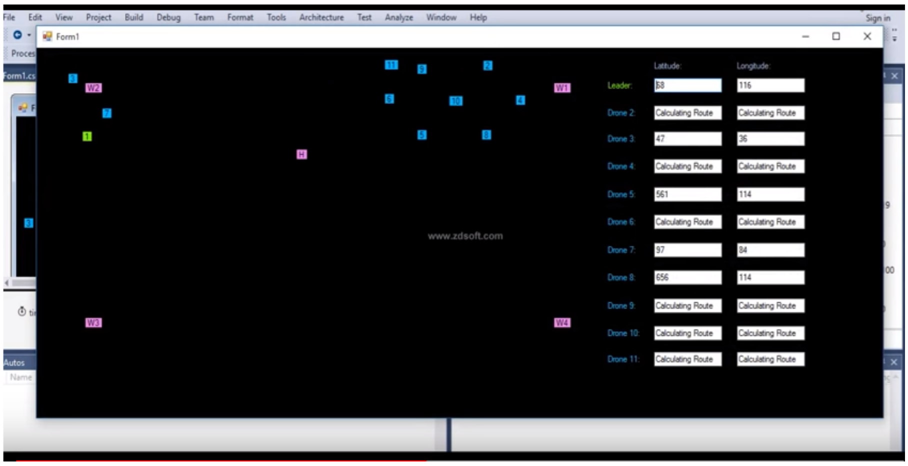


Fig. 7. Simulation software proposed.

Simulation of individual assortment routes showed no greater difficulty. The problem arose when testing all the routes running at the same time, since the interference of each other in corridors where it is not possible to go over, cause the simulation of the 5 routes, in the simulation of the process with waits, to stop 2 hours with 52 minutes. The complexity was found in representing the decisions that towing route operators make so as not to block each other.

Another practice they perform to avoid these blockages is to return to the supermarket area with the material that was loaded at the beginning of the cycle without unloading it at the workstation, seeing that the material from the previous cycle has not yet been consumed, which occurs when the Production speed decreases, this causes unnecessary material handling and is a very bad practice carried out in the current process.

5.1 Future Research

Perform the optimization of material assortment routes using the simulation model. Develop in the Plant Simulation software a graphical interface to facilitate the use of the simulation model of the current process and subsequently perform the optimization of that model.

Improvement of the developed mathematical model, adding considerations such as, the percentage of material damaged by part number present in the workstations, storage capacity of supermarket facilities or loading times and different download per workstation, to name a few.

Experiment incasing with optimization techniques other than those studied in this research, such as ant colony, simulated annealing or dynamic programming, to mention some of the most outstanding techniques in the study of state of the art.

Perform in Matlab a graphical interface, in order to facilitate the use of the programmed genetic algorithm, to obtain the routes of assortment of material.

5.2. Simulation

This research still needs to be complemented with simulation and testing prior to implement it in a real environment. Beside the engineering challenges of a physical Material Resurshyent Cars, the developed algorithm described in section 4 will be simulated for fine tuning and validation. For this, the above is why in the mathematical model wait times are sanctioned, so that the solution that searches for the algorithm avoids them.

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