Article

Methodology to Analyze the Productive and Environmental Performance of a Supply Chain through Simulation Scenarios

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Abstract: This article aims to serve as a guide for the construction of supply chain simulation models designed with a lean approach, using Promodel software. To achieve this, a supply chain was designed for a fictitious company located in the City of Celaya, Guanajuato and a set of suppliers located in different cities within the same State. It was used as a google tool to define the distances between each of the companies. As a final result, a representative model of a supply chain was obtained, as well as a methodology that allows the construction of lean supply chains regardless of the number of companies that comprise it. The effect of the variability in the delivery times between suppliers was incorporated into the simulation model, as well as an equation that calculates the pollution emissions of the vehicles that integrate the network that moves the products between the companies. With this work it is possible to represent networks of supply chains of real world companies, where the variability and contamination factor is included, to facilitate the decision making regarding the number of vehicles, inventory levels, quantities to be shipped, frequency in the shipments, etc. with the purpose of contaminating as little as possible and at the same time preventing interruptions in the supply chain using the least amount of resources possible.

Keywords: supply chains; simulation model; contamination; variability; inventory levels; shipments

1. Introduction

The increase of the competitiveness in all the industrial sectors due to the globalization of the economies is a source of pressure so that the companies must optimize their processes; the foregoing also generates new forms of collaboration between companies that are part of the supply chain. To achieve this, techniques and information technologies are needed to support decision-making; One of these tools is the simulation of systems. The simulation models allow analysis of the type What

 doi:10.20944/preprints201809.0015.v2

happens if ...?, To evaluate and quantify the benefits derived from the collaboration of all companies in the supply chain [1].

Ramanathan in [2] proposed a simulation model to understand the performance of a supply chain; this highlights the importance of collaboration between companies that belong to the chain. Chatfield in [3] developed a simulator for the integration of the operation of the supply chain; generating a robust and flexible tool that allows to design and analyze supply chain models. This tool measures five important characteristics of the models: the storage model, the architecture of the system, the ease of use, the depth of the model and the characteristics of the outputs.

A supply chain faces changes that contribute to increasing its complexity and vulnerability to shocks; a supply chain must resist changes in the environment to survive. Through the simulation alternative supply chains can be evaluated to improve the capacity of recovery to a disturbance [4]. There are numerous simulation models built for the design, evaluation and optimization of the supply chain [5].

Discrete events simulation is a widely used approach as a support tool in logistics and for the analysis of supply chains since it is a tool that allows to emulate the behavior of this kind of systems [6]. It should be noted that in the supply chains the factor that is always taken into consideration in the design phases is the transportation of the goods; there are three ways to transport goods: land transport, air transport and maritime transport.

Based on the above, an 18-step methodology is proposed that facilitates the construction and analysis of supply chain models; and that helps professionals make decisions; the methodology is based on the Promodel package.

On the other hand, Mexico is seeking to establish a global leadership in relation to the care of the environment. Recently it has committed to establish 2026 as the peak year of its greenhouse gas (GHG) emissions; as of that year, said emissions should be reduced.

The Mexican government has proposed a road map which has been described as a "detailed climate change plan that is the first of its kind among developing nations" [7].

At a global level, the fight against climate change has become one of the main topics of international debate [8]. As an example, the following pair of reports is mentioned: Young, Min, young and Jinsoo in [9] measured the CO_2 emissions that are generated internationally due to globalization; on the other hand, Yee et al., in [10] made a detailed analysis of greenhouse gas emissions due to the transport of goods; focusing mainly on the measurement of CO_2.

According to the above, for the design of supply chains not only should efficiency be considered in terms of inventory levels, delivery times, total costs, etc., but also in environmental factors. To achieve this, supply chains called Lean - Green are currently proposed, with which they are intended to be the most environmentally friendly and at the same time efficient. In this sense, proposals have been developed to design supply chains called Lean Green [11, 12]. In [13] Song et. al., purposed a novel method for selecting a green supplier in a dynamic environment. The method is based on the Third Generation Propect Theory. Demonstrated its feasibility to case of study successfully. The main disadvantage of this approach is the level of complexity, we considered that with simulation is possible to get excellent results in a minor time to get the best solution. In this case we propose to model a difficult system in a software and use the model to perform experiments to find the best conditions to the supply chain.

It is very difficult to optimize two factors that oppose each other such as achieving the highest efficiency of the supply chain and at the same time generating the least amount of greenhouse gas emissions, such as CO2, however, a balance can be achieved through of the development of different experiments.

This article focuses on two main factors, in the green sense, focusing on the generation of the least amount of CO2 in the supply chain and in the lean sense, we intend to reduce one of the more expensive waste for companies such as the inventory levels. To achieve this, a methodology is proposed that includes tools such as: lean manufacturing, simulation and design of experiments.

The design of experiments is applied to identify the factors that significantly affect the response variables as well as to define the optimal operating conditions [14]; in our case, the aim is to reduce delivery time, the inventory levels, the CO2 pollution rates and the percentage of leisure in companies due to untimely delivery.

Finally, it should be mentioned that variability is considered within the analysis; this factor is presented in a supply chain in the cycle times of every company in its process [15].

The paper is structured as follows: In section 2 is presented the literature review, in section 3 is described the model used in order to explain the methodology, in section 4 the method is described with a fictional case, in section 5 the results are presented, in section 6 a brief discussion is presented, finally the conclusions are presented in section 7.

2. Literature review

The literature review includes topics like supply chain, sustainability, lean manufacturing and simulation. We start talking about supply chain. In [16] Cigolinia et al., analyzed the dependencies between supply chain performance, i.e. stock and stock-outs, and both supply chain management decisions and supply chain configuration parameters. In [17] Prajogo mentioned that the Increasing competition has driven firms to not only improve their internal operations (including through process control and inventory management), but also focus on integrating their suppliers into the overall value chain processes. The contribution of suppliers in building competitive capabilities (quality, delivery, flexibility, and cost), hence delivering values to customers has been well recognized. Much has been written on the importance of supply chain management on firm's performance. According with Mollenkopf et al., the Firms in the twenty-first century are grappling with a constantly changing world. Three supply chain trends in particular are converging to create an increasingly complex business environment: a move towards green initiatives, the utilization of lean processes, and globalization.

The globalization of supply chains involves dimensions such as offshoring of production, inventories, suppliers and customers, and differences Lean supply chain strategies focus on waste reduction, helping firms eliminate non-value adding activities related to excess time, labor, equipment, space, and inventories across the supply chain. Green supply chain strategies refer to efforts to minimize the negative impact of firms and their supply chains on the natural environment [11]. According with the third supply chain trend, transport and logistics activities contribute heavily to global sustainability problems, yet the implementation of corporate social responsibility and sustainability reporting in the sector lags behind [12]. Due to increasing concerns about the environment, potential economic benefits and legislation pressure; supply chain management has changed to focus on the environmental impacts of production and Earth resource preservation. Therefore, many managers are working hard on improving the sustainability of their supply chain systems [18].

Due to legislation constraints, potential economic benefits and environmental regulations, production firms are obliged to commit to the development of sustainable supply chains. Today, the attention of many academic researchers and company leaders is on the management and design of sustainable supply chains turn. As a result, company leaders are working hard to propose and establish new sustainable strategies, optimize designs and create innovative production practices, in order to curb carbon emissions and maximize profits. According with Kaur and Singh., [19] Globally increased awareness on carbon emissions forced business firms to optimize their carbon emissions. In a supply chain, carbon emissions are seen right away from the procurement of raw material till the delivery of finished goods. They proposed a model to address and optimize carbon emissions in the procurement and logistics problem, a multi-period, multi-part, multi-supplier and multi-carrier low carbon procurement and logistics. The problem was modeled for a carbon trading environment using MILP (Mixed Integer Linear Program).

One of the biggest problems in relation to the operation of large factories and supply chains, is the amount of CO2 that is emitted to the environment. In [20] Perera mentioned that Fossil-fuel combustion by-products are the world's most significant threat to children's health and future and are major contributors to global inequality and environmental injustice. The emissions include a myriad of toxic air pollutants and carbon dioxide (CO2), which is the most important humanproduced climate-altering greenhouse gas. To mitigate pollution problems in the Kyoto Protocol in 1997, 163 countries around the world, have agreed to reduce CO2 emissions and have been making an effort to develop technologies for its capture, sequestration and utilization, as well as emission reduction [21].

In [22] Idso mentioned that Concern has been expressed over the potential climatic and biological consequences of Earth's rising atmospheric CO2 concentration, which is expected to double above pre-industrial values sometime this century. This paper reviews several of the biological consequences that are likely to result, including enhanced plant photosynthesis and growth, an increase in plant water use efficiency, and the potential for atmospheric CO2 to reduce the growth-retarding effects of several environmental stresses. Implications of these phenomena are also briefly discussed, including the potential for atmospheric CO2 enrichment to enhance ecosystem biodiversity and carbon sequestration. In addition, other alternatives have been proposed to reduce the impact of the problems caused by the large quantities emitted to the CO2 environment for example the capture of the CO2. In [23, 24] were presented various methods to carbon capture storage update. In recent years, Carbon Capture and Storage (Sequestration) (CCS) has been proposed as a potential method to allow the continued use of fossil-fuelled power stations whilst preventing emissions of CO2 from reaching the atmosphere.

In [25] CO2 capture and conversion to fuels using renewable energy is being promoted as a climate change mitigation measure that reduces fossil fuel use by effectively recycling carbon. In this sense, we consider that this is a good idea develop technologies that let capture the CO2 but we considered that it could be expensive. The ideal is avoiding the generation o look for strategies in order to reduce the emissions of CO2. So, we propose lean supply chain.

The research findings indicate that, even given the same organizational constraints and resources, lean suppliers gain significant competitive advantages over non-lean suppliers in production systems, distribution systems, information communications, containerization, transportation systems, customer-supplier relationships, and on-time staging/delivery performance [26]. In [27] Lewis mentioned that the ambiguity of lean production in practice means that the implementation process can create strategic resources to underpin sustainable competitive advantage.

In [28] Vinodh mentioned that the contemporary manufacturing organizations recognize the importance of lean manufacturing as a tool to eliminate wastes, streamline processes and improve value addition. On the other hand, such organizations also focus on the development of ecofriendly products and processes. In this context, lean manufacturing concepts provide a pathway for attaining sustainable benefits. The modern manufacturing systems are focusing on the implementation of lean and sustainable manufacturing for ensuring waste elimination and development of ecofriendly processes and products, respectively. Lean manufacturing focuses on consistent elimination of wastes.

On the other hand, simulation is a tool that increase the possibility of success of the project related with lean manufacturing. According with Pierreval, Bruniaux and Caux most existing research works addressing the modeling and simulation of supply chains are generally based on a discrete event worldview [29]. Oliveira, Lima and Montevechi in [30] mentioned that the modeling and simulation in supply chains can be better integrated. The models could be more sophisticated to capture the dynamics and behavior of the networks. Simulations involving normative models and empirical applications can be useful to represent the reality of supply chains, generating alternative solutions that improve supply chain performance. Simulation can be a valuable tool for supply network analysis, planning, optimization, evaluation, and risk management [31].

Due to the above mentioned, is necessary develop methodologies that let us design supply chains that considered both, the environment and the efficiency of the supply chain. In this sense, in this article is proposed a methodology that evaluate the performance of the supply chain in relation to a big waste in relation a la philosophy lean manufacturing like the high levels of inventory and on the other hand to calculate the level of CO2 using scenarios of simulation and design of experiments applied in a supply chain fictitious to explain detailed how it works.

3. Model description

 doi:10.20944/preprints201809.0015.v2

According to García in [32], few people dedicate themselves to the art of modeling systems because it is not an easy subject to understand; in this work a simple but valuable system is proposed for the generation of ideas on how to simulate a slender supply chain with an ecological approach.

Consider a supply chain composed of 5 companies located in different cities of the State of Guanajuato, Mexico (Table 1). Each company was assigned a number from 1 to 5; each company has a geographical location. Table 1 also shows the part numbers that enter and leave each company, the cycle time to produce a single piece and the company to which they will allocate their product.

Table 1. Supply chain description.

i	City	Assembly description	Part	Cycle	Customer
1	Celaya	M0005, Sub 2 and M0001	Finished good	1 min	Final client
2	Salamanca	M0001	M0001	2 min	Company 1
3	Irapuato	M0002, Sub 1	Sub 2	1.5 min	Company 1
4	Silao	M0003, M0004	Sub 1	2.5 min	Company 3
5	León	M0004	M0004	1 min	Company 4

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

To facilitate the analysis, Google maps were used to calculate the distances between the cities; however, in a real case, the geographical position of each company must be exactly located.

According to the data in Table 1, the supply chain operates as follows: Company 5 located in León city processes and supplies part number M0004 to company 4 located in Silao city. In company 4 the part number M0003 and the part number M0004 are assembled to form sub 1. Part Sub 1 is sent to company 3 located in Irapuato city; there the number of part M0002 is taken and it is assembled with the sub 1; the result is the sub 2 assembly that is sent to company 1 located in Celaya city. In company 2 the part number M0001 is processed and sent to company 1. In company 1 the part number M0005 is taken and assembled with M0001 and Sub 2 to form a product as desired by the final consumer.

Figure 1 shows the supply chain with its companies, the material that enters and leaves each company and the flow that each of the products in the supply chain follows until the finished product is obtained and delivered to the consumer.

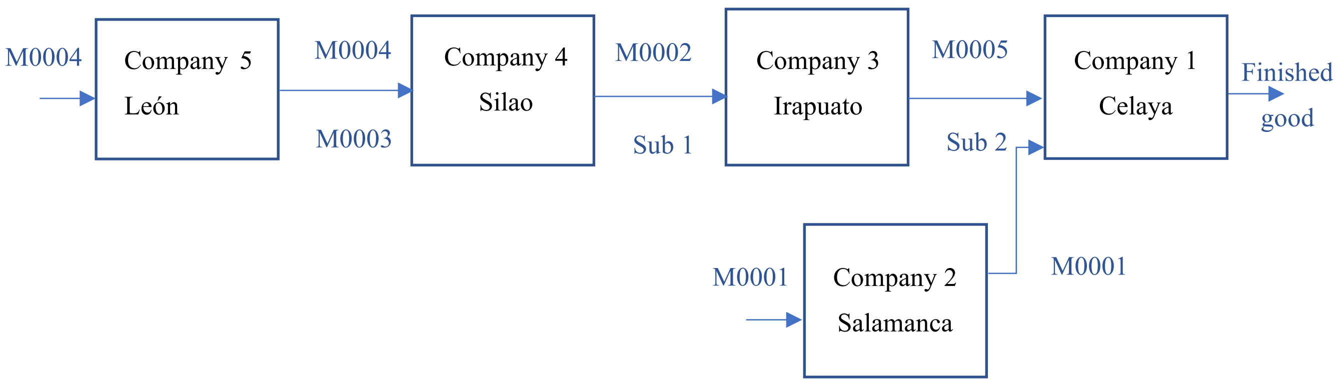

Figure 1. The supply chain and its inputs and outputs.

4. Materials and Methods

 doi:10.20944/preprints201809.0015.v2

In this section we propose a methodology of 18 steps for the construction of simulation models of supply chains to obtain measures of productive and environmental performance; this methodology was applied to the system proposed in the previous section; it should be noted that this methodology can be applied to any supply chain regardless of its size. Figure 2 shows the general methodology applicable to any size of the supply chain and detailed steps for its development are described later. The supply chain considers only suppliers and the plant where the final assembly takes place. In the figure is possible observe the input and the output of every plant. The output for a plant is the input for the next plant, for example, the output for the tier 3 is the input for the tier 2. The word tier is used to describe the level of each supplier (Plant). For example, Tier 1, is a first level supplier who supplies its finished good to the plant where the final product is assembled.

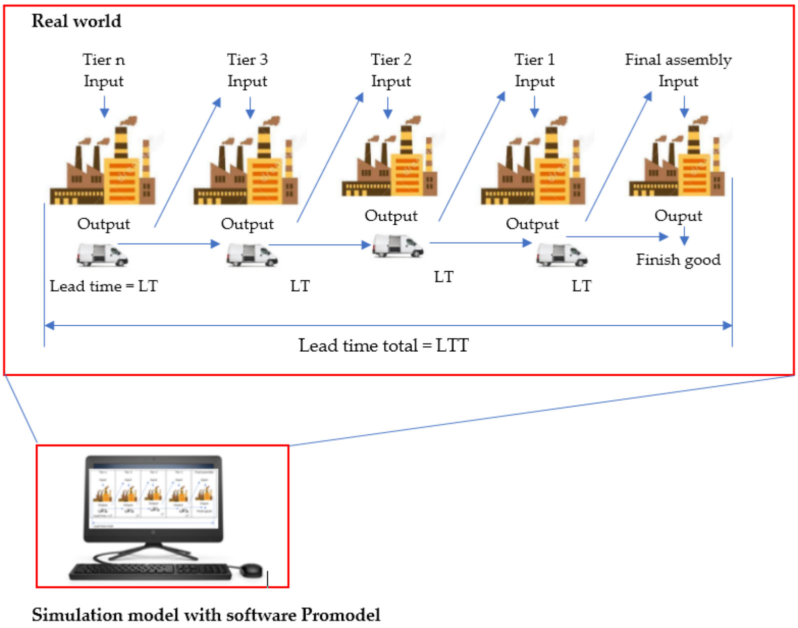

Figure 2. Graphical representation of the methodology in a generalized supply chain.

Below are the steps using the proposed example:

1. Identify the companies that are part of the supply chain and collect data.
   In this case, there are 5 companies located in the cities of Celaya, Salamanca, Irapuato, Silao and León. The necessary data are: number of part that supplies each company, batch sizes of the shipments, frequency of the shipments, cycle time for the elaboration of the individual products, time in making the shipment, speed of the transport vehicle full and empty, material download time.

2. Use a map to geographically locate each of the companies.
   The map of the State of Guanajuato was downloaded and added to the Promodel figures library. To use the image, Promodel has a tool called Graphic Editor. The sequence to load the map is Tool - Graphic Editor. Copy and paste the image in the layout of the graphic editor. Close the graphic editor; when the software asks if you want to save the changes, select accept. The map or image will be available as an icon in the model (Figure 3).

Figure 3. Graphic editor.

3. Use the map image in the layout, declare as background figure.
   Use the map image in the layout, declare as background figure. The sequence is: Build - Background of graphics - Behind of grid. (Figure 4)

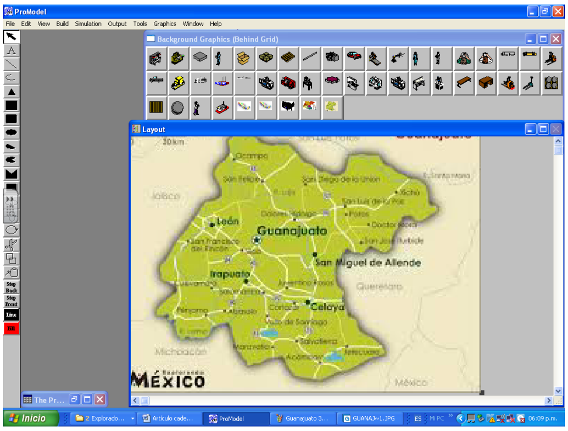

Figure 4. Example with the map of the State of Guanajuato, México.

4. Define the level of each company in the chain: tier 1, tier 2, tier 3, ..., tier n.
   For the developed example, companies 2 and 3 correspond to Tier 1, Company 4 is Tier 2 and Company 5 corresponds to Tier 3.

5. Define the sequence of the flow of materials through companies from tier n to tier 1.
   In Figure 1, the sequence of flow of materials through the chain is clearly seen from the previous section.

6. Determine the distances between each of the companies that make up the supply chain and build a network.
   It is recommended to use Google maps.

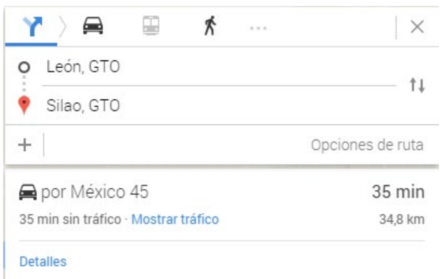

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Figure 5. Defining distances in Promodel.

Figure 5 shows the example of how to calculate the distance between the city of León Gto. and Silao Gto., where the calculated distance is 34.8 km.

Table 2 shows the summary of the distances between the cities involved in the supply chain.

Table 2. Distance between locations.

Source	Target	Distance (KM)
León	Silao	34.8
Silao	Irapuato	37.1
Irapuato	Celaya	64.1
Salamanca	Celaya	43.7

7. Define the locations.
   Each location corresponds to a company. The locations must be declared on the map loaded in step 3. The locations will represent each of the companies in the supply chain. Each company will have a warehouse of raw material to allow the arrival of raw materials from its suppliers; and a warehouse of finished product to temporarily store the final product until the quantity requested by the client is met and then the shipment is made. Figure 6 shows the companies and stores of each company.

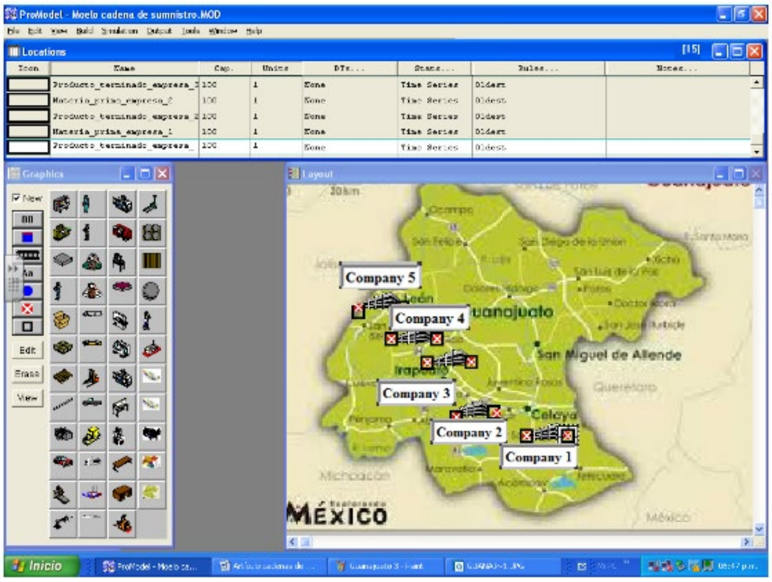

Figure 6. Location of the cities on the map.

8. Define the entities that will move through the supply chain.
   In the example, there are 8 entities, enough to exemplify the design of a supply chain consisting of 5 companies. The entities are: M0001, M0002, M0003, M0004, M0005, Sub 1, Sub 2 and Final product.

9. Define the arrivals.
   It is assumed that each company already has raw materials in its warehouses. Since each company already has its raw material (M0001, M0002, M0003, M0004, M0005); only arrivals must be declared for entities M0001 to M0005. Otherwise, one more link in the supply chain that would correspond to the supplier of the companies should be declared.

10. Define the process according to the sequence followed by the materials, from company 5 to company 1.
    To build simulation models, basic software knowledge is required.

11. Define the network. The network represents the road where the truck moves.
    The lengths of the segments between nodes represent the distance between cities, for this example the distances are taken from Table 2. To define "meters" as the unit of distance measurement, the following sequence is followed in Promodel: Build - General Information - meters. For example, the distance between the cities of León and Silao is 34.8 km; in Promodel you must enter 34800 meters. When defining the network, the interfaces must also be declared; It is recommended that these be from each of the nodes to the stores of entry and exit of each company. In total there will be 5 nodes, one for each company.

12. Define the resource (truck).
    A resource called a truck was defined, which will be responsible for transporting the materials from one company to another. Part of the experimentation consists in evaluating the number of trucks required. In the resource the user must specify the network through which the resource must move. In this case a network called "truck network" was declared. In addition, it is necessary to specify the speeds of the resource; for this example, it is assumed that a full truck moves at a speed of 80 km / hr; however, the software requires that the speed be entered in meters per minute (mpm), therefore a speed of 1333 mpm was specified; the speed when traveling empty was set at 95 km / hr or 1583 mpm. The time for the loading operation of a truck was set at 10 minutes and to unload it was set at 15 minutes; the model requires the times in seconds: 600 and 900 seconds respectively. In the experimentation, the variability of loading and unloading times was included; later, the three levels considered are shown.

13. Verify the model.
    First, a visual inspection of the operation of the model was carried out by executing a test run. You must ensure that the movements of the truck follow a logical sequence, trucks with material must arrive at their destination to make the delivery in the entry locations of each company; the finished products of each company must be picked up by the trucks at the collection points and must be delivered to the company to which it supplies.

14. Validate the model.
    There are different ways to validate a model; the most advisable is to compare the statistics of the real data against the statistics of the outputs of the simulation model. Nevertheless, in this example, the test is omitted for the moment given that it is an illustrative example.

15. Determine the stabilization period (warm up).
    In this case it is assumed that the steady state is reached when the first batch of finished product comes out. The stabilization period is different for each case of batch size to be produced.
16. Experiment.
    The application of the experimental design methodology is proposed; the variables are: the size of the lots to be transported, the number of trucks to be used and the variability; with respect to the lots, sizes of 20, 40 and 80 pieces were defined; for trucks the levels are 1, 2 or 3 trucks; for the variability three levels were defined: low, moderate and high. In total there are three variables with three levels each, so we have a design 33. To solve the problem of degrees of freedom for the error, two replicas are proposed per run. In total there are 27 treatments that replicate twice, resulting in 54 experimental runs. The response variables are: the CO_2 pollution indexes, the completion time of a batch requested by a customer, the level of performance of the trucks and the inventory levels in each company.

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To determine CO_2 emissions, it was considered a practical guide for the calculation of greenhouse gas (GHG) emissions. March 2011 version, proposed by the Interdepartmental Commission on Climate Change [33]. The automotive vehicle proposed for this investigation is the Ford vehicle, sub-brand Transit, version 2/4/5 doors, model 2018, manual transmission, diesel, 4 cylinders, with a power of 125 HP, a 2.2 Liter engine.
So that in the final results of each experimental run, the Promodel software was capable of throwing CO_2 measurements, it was necessary to enter 6 variables, the first 5 serve to control the number of trips made from one plant to another and from this way to calculate the total distance covered by the entire fleet, as observed in equation 1.

$$DIST\ TOTAL = (34.8XDIST\ 1) + (37.1XDIST\ 2) + (64.1XDIST\ 3) + (43.7XDIST\ 4), \text{ Ec. (1)}$$

Where:

$DIST\ TOTAL$ = Total distance covered by the entire fleet
$DIST\ 1$ = Number of trips from León to Silao
$DIST\ 2$ = Number of trips from Silao to Irapuato
$DIST\ 3$ = Number of trips from Irapuato to Celaya
$DIST\ 4$ = Number of trips from Salamanca to Celaya

The sixth variable was used to calculate the CO_2 emitted. For this purpose, the information provided by the government of Mexico was used in the link www.ecovehículos.gob.mx, where it is possible to determine the CO_2 emitted by any vehicle and vehicle model. In this case, according to the vehicle proposed in this article, there is a CO_2 emission of 270 gr / Km.
According to the above, the variable CO_2 that is programmed in the Promodel software is stable through equation 2.

$$CO2 = [(270XDIST\ TOTAL)X2]/1000 \qquad \text{Ec. (2)}$$

Where:
$CO2$ = Emission of CO2, by trucks and all trips made, in kilograms.
The reason to multiply by 2 the product of $DIST\ TOTAL$ and 270, is to consider when the vehicles return empty. The division between 1000 is because the final result of CO2 will be expressed in kilograms instead of grams.

17. Document results.
    The results of all the experimental runs were recorded and analyzed in detail in the following section entitled analysis of results.

18. Determine the best conditions of the supply chain and obtain the conclusions.
    Based on the results observed and the detailed analysis, the conditions of the supply chain that optimize the response variables defined are established. The details of this step are presented in the following section.

5 Results

The model was constructed according to the steps suggested in the methodology, it was run according to the experiments proposed, where 54 experimental runs were found. In the model, the different factors were included, such as lot size: lots of size 20, 40 and 80; the number of trucks: 1, 2 and 3 trucks and the level of variation: low, medium and high. To consider the effect of the variation, it was established that the average cycle times of the processes of each of the companies are distributed according to a normal distribution with the average time and standard deviation, as shown in Table 3.

Table 3. Variation in Cycle time per piece in every company.

 doi:10.20944/preprints201809.0015.v2

i	City	Cycle time	Cycle time with Variation		
			Low	Half	High
1	Celaya	1 min	N(1,0.5)	N(1,1)	N(1,2)
2	Salamanca	2 min	N(2,0.5)	N(2,1)	N(2,2)
3	Irapuato	1.5 min	N(1.5,0.5)	N(1.5,1)	N(1.5,2)
4	Silao	2.5 min	N(2.5,0.5)	N(2.5,1)	N(2.5,2)
5	León	1 min	N(1,0.5)	N(1,1)	N(1,2)

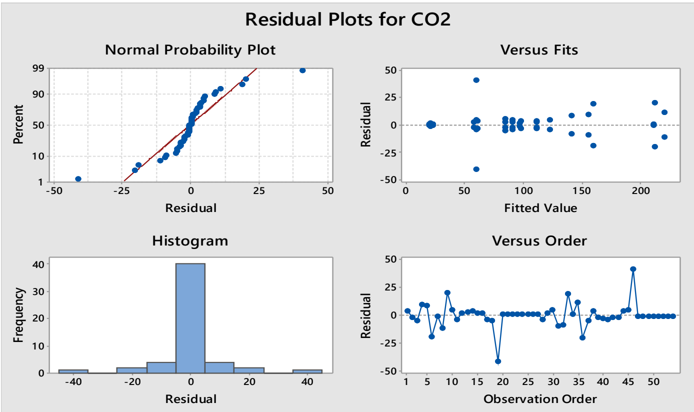
In accordance with the above, the results shown in Table 4 were obtained. The model was run until the production of a batch of 80 pieces was achieved, assuming that this is the amount required by the final customer.

Table 4. Results of the 54 runs.

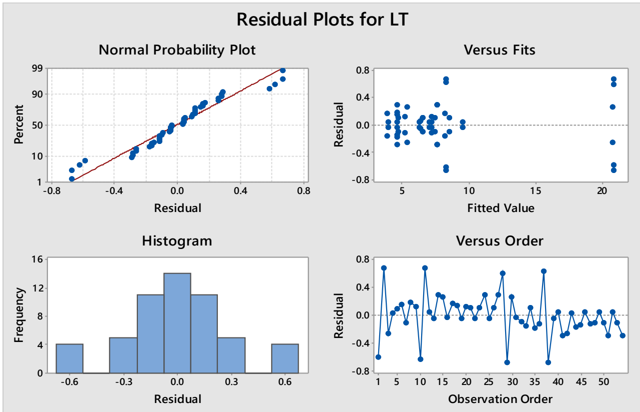
Run	*Factors*			*response variable*			
	Lot Size	*Trucks*	*Variation*	*CO_2 (Kg)*	*LT (Hr)*	*% Idle Trucks*	*Invetory level (Pieces)*
1	20	1	Low	115.28	20.28	1.79	113.19
2	20	1	Half	109.42	21.56	1.92	119.43
3	20	1	High	117.54	20.57	2.73	116.17
4	20	2	Low	165.35	7.24	5.02	90.97
5	20	2	Half	150.37	7.59	9.74	96.06
6	20	2	High	141.23	8.33	10.29	100.96
7	20	3	Low	210.57	4.6	28.78	60.49
8	20	3	Half	209.86	4.8	31.56	79.51
9	20	3	High	232.84	5.3	36.61	74.26
10	40	1	Low	64.71	7.68	8.93	105.12
11	40	1	Half	56.89	9	8.44	117.5
12	40	1	High	60.07	9.59	12.66	116.82
13	40	2	Low	93.49	4.57	54.88	83.18
14	40	2	Half	94.62	4.92	56.10	82.79
15	40	2	High	87.11	5.6	57.31	88.42
16	40	3	Low	98.57	3.94	65.26	73.71
17	40	3	Half	94.10	4.07	65.9	75.86
18	40	3	High	79.21	4.76	69.59	88.42
19	80	1	Low	18.97	6.99	54.73	111.13
20	80	1	Half	19.84	7.31	56.76	110.83
21	80	1	High	21.87	8.62	63.31	110.16
22	80	2	Low	21.08	6.29	80.41	105.71
23	80	2	Half	21.93	6.61	81.38	105.63
24	80	2	High	23.8	7.92	84.45	105.71
25	80	3	Low	21.08	6.29	86.94	105.71
26	80	3	Half	21.93	6.61	87.58	105.71
27	80	3	High	23.8	7.92	89.63	105.63
28	20	1	Low	107.93	21.46	1.44	117.64
29	20	1	Half	114.02	20.22	1.41	115.14
30	20	1	High	127.14	21.2	1.46	121.76
31	20	2	Low	146.4	7.17	11.59	93.86
32	20	2	Half	132.87	7.40	7.53	98.85
33	20	2	High	179.29	8.01	14.34	93.73
34	20	3	Low	212.06	4.82	28.78	77.04

35	20	3	Half	232.36	4.44	31.83	81
36	20	3	High	192.11	5.07	30.32	88.1
37	40	1	Low	55.09	8.93	7.37	117.97
38	40	1	Half	64.14	7.66	8.65	105.95
39	40	1	High	55.41	9.51	10.85	120.4
40	40	2	Low	87.97	4.66	53.07	86.45
41	40	2	Half	86.33	4.34	55.48	85.3
42	40	2	High	82.43	5.08	56.08	89.78
43	40	3	Low	94.89	4.01	65.04	75.34
44	40	3	Half	101.13	3.72	66.17	72.74
45	40	3	High	89.41	4.47	68	89.79
46	80	1	Low	101.13	7.07	55.30	112.3
47	80	1	Half	18.58	7.08	55.37	111.04
48	80	1	High	19.69	8.42	62.44	112.14
49	80	2	Low	19.83	6.39	80.68	107.6
50	80	2	Half	20.63	6.39	80.71	105.68
51	80	2	High	22.54	7.35	85.74	107.06
52	80	3	Low	19.83	6.37	87.12	107.6
53	80	3	Half	20.61	6.39	87.14	105.71
54	80	3	High	22.54	7.35	90.49	105.68

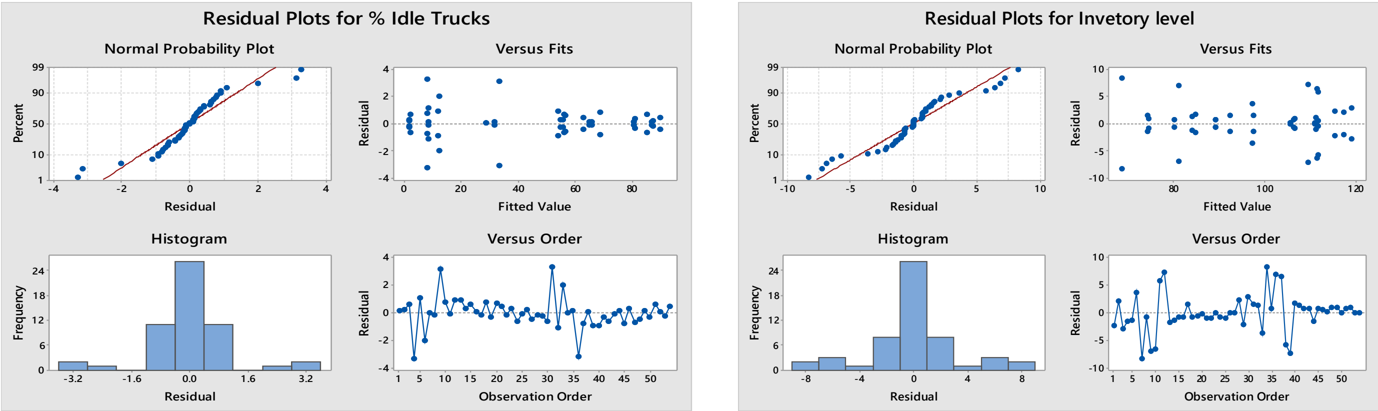
The results of the runs were introduced to the Minitab 17 software to perform the statistical analysis of the experiments through the analysis of variance (ANOVA). Before presenting the ANOVA for each of the response variables, an analysis is presented of the assumptions that must be met for residuals such as normality, constant variance and independence [34], which can be seen in figures 7 (a), 7 (b), 7 (c) and 7 (d).



(a)



(b)



(c) (d)

Figure 7. Verification of assumptions.

In each of the figures 7 (a) to 7 (d) it can be seen in the upper left corner that the blue points (Residuals) approach the red diagonal line, with which it can be concluded that the assumption of Normality is met. You can also observe the fulfillment of this assumption through each of the histograms. The assumption of constant variance can be verified by observing the figure located in the upper right corner, where it can be seen that the residuals do not have a funnel shape. Finally, in the lower right corner it can be seen that the order of the residuals has a completely random behavior, so the assumption of independence is also fulfilled.

Once the assumptions have been verified, the next step is to study each of the ANOVAS to determine which factors have a significant effect on the response variable. The first ANOVA observed in Figure 8 corresponds to the CO_2 response variable.

General Factorial Regression: CO2 versus Lot Size, Trucks, Variation

Factor Information

Factor	Levels	Values
Lot Size	3	20, 40, 80
Trucks	3	1, 2, 3
Variation	3	Low, Half, High

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	26	205065	7887.1	36.50	0.000
Linear	6	182026	30337.7	140.38	0.000
Lot Size	2	166970	83484.8	386.31	0.000
Trucks	2	14815	7407.5	34.28	0.000
Variation	2	241	120.7	0.56	0.579
2-Way Interactions	12	21490	1790.8	8.29	0.000
Lot Size*Trucks	4	20201	5050.2	23.37	0.000
Lot Size*Variation	4	718	179.5	0.83	0.517
Trucks*Variation	4	571	142.7	0.66	0.625
3-Way Interactions	8	1549	193.6	0.90	0.534
Lot Size*Trucks*Variation	8	1549	193.6	0.90	0.534
Error	27	5835	216.1		
Total	53	210900			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
14.7007	97.23%	94.57%	88.93%

Figure 8. ANOVA CO_2.

In Figure 8, it can be seen that the lot size and number of trucks has a significant effect on the pollution index (CO_2) since its p-value is less than 0.05. This means that depending on the number of trucks used to move materials between companies and the size of the lot moving between companies, they will cause the CO_2 that is emitted to the environment to increase or decrease. Later, an analysis will be carried out to determine the appropriate number of trucks and lot size, to minimize the contamination index. It can also be observed that the variation factor does not have a significant effect on CO_2 since its p-value is greater than 0.05, which means that the variability in processing times in each of the companies does not have an important effect in the CO_2 pollution indexes. Finally, it can be seen that the effects of double or triple interaction, the only one that significatively affects CO_2 is the interaction of lot size and number of trucks. An interesting value obtained is the coefficient of determination (R^2), which is 97.23%, indicates that the model explains 97.23% of the variability observed.

Regarding the lead time variable, the respective ANOVA can be seen in Figure 9.

General Factorial Regression: LT versus Lot Size, Trucks, Variation

Factor Information

Factor	Levels	Values
Lot Size	3	20, 40, 80
Trucks	3	1, 2, 3
Variation	3	Low, Half, High

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	26	1233.68	47.449	288.45	0.000
Linear	6	801.41	133.569	811.99	0.000
Lot Size	2	267.44	133.722	812.92	0.000
Trucks	2	524.97	262.486	1595.69	0.000
Variation	2	9.00	4.500	27.35	0.000
2-Way Interactions	12	431.45	35.954	218.57	0.000
Lot Size*Trucks	4	429.89	107.474	653.35	0.000
Lot Size*Variation	4	1.49	0.373	2.27	0.088
Trucks*Variation	4	0.06	0.015	0.09	0.984
3-Way Interactions	8	0.82	0.103	0.62	0.750
Lot Size*Trucks*Variation	8	0.82	0.103	0.62	0.750
Error	27	4.44	0.164		
Total	53	1238.12			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.405581	99.64%	99.30%	98.57%

Figure 9. ANOVA LT.

In Figure 9, it can be seen that the three main factors have a significant effect on the lead time (LT) since their p-value is less than 0.05. This means that depending on the number of trucks, the lot size that moves between companies and the variability of each of the companies, will be the lead time of the batch of 80 pieces to the final customer. From the effects of double or triple interaction, it can be seen that only the interaction between the lot size and the number of trucks is significant. According to the R^2, we have that 99.64% of the variability is explained by the model, which means that the model is able to predict the LT perfectly.

The ANOVA for the response variable percentage of idle of trucks can be seen in Figure 10.

General Factorial Regression: % Idle Trucks versus Lot Size, Trucks, Variation

Factor Information

Factor	Levels	Values
Lot Size	3	20, 40, 80
Trucks	3	1, 2, 3
Variation	3	Low, Half, High

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	26	51508.6	1981.1	850.22	0.000
Linear	6	48757.2	8126.2	3487.48	0.000
Lot Size	2	34433.8	17216.9	7388.88	0.000
Trucks	2	14178.4	7089.2	3042.44	0.000
Variation	2	145.0	72.5	31.11	0.000
2-Way Interactions	12	2722.4	226.9	97.36	0.000
Lot Size*Trucks	4	2707.3	676.8	290.46	0.000
Lot Size*Variation	4	13.2	3.3	1.41	0.256
Trucks*Variation	4	2.0	0.5	0.21	0.928
3-Way Interactions	8	28.9	3.6	1.55	0.187
Lot Size*Trucks*Variation	8	28.9	3.6	1.55	0.187
Error	27	62.9	2.3		
Total	53	51571.5			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.52647	99.88%	99.76%	99.51%

Figure 10. ANOVA % Idle of the turcks.

In Figure 10, it can be seen that the three factors, lot size, number of trucks and variation in processing times in the companies, have a significant effect on the % Idle of the turcks, response variable of the trucks, since their p-value is less than 0.05. This means that the idle percentage of the trucks can be increased or decreased depending on the number of trucks that are used, the size of the batch moving between companies and the variability observed in the processes of each company. Of the effects of double or triple interaction, it is appreciated that only the double effect between lot size and number of trucks, has a significant effect on the % idle of the turcks variable, the rest, does not

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have a significant effect since its p-value is greater than 0.05. In relation to R^2, we have that 99.88% of the variability is explained by the model.

Finally, in Figure 11, you can see the ANOVA for the inventory level response variable

General Factorial Regression: Invetory level versus Lot Size, Trucks, Variation

Factor Information

Factor	Levels	Values
Lot Size	3	20, 40, 80
Trucks	3	1, 2, 3
Variation	3	Low, Half, High

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	26	11305.4	434.82	20.25	0.000
Linear	6	8724.8	1454.13	67.73	0.000
Lot Size	2	2372.6	1186.29	55.25	0.000
Trucks	2	6206.4	3103.20	144.53	0.000
Variation	2	145.8	72.90	3.40	0.048
2-Way Interactions	12	2439.1	203.26	9.47	0.000
Lot Size*Trucks	4	2163.4	540.84	25.19	0.000
Lot Size*Variation	4	164.2	41.05	1.91	0.137
Trucks*Variation	4	111.5	27.87	1.30	0.296
3-Way Interactions	8	141.6	17.70	0.82	0.589
Lot Size*Trucks*Variation	8	141.6	17.70	0.82	0.589
Error	27	579.7	21.47		
Total	53	11885.1			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
4.63363	95.12%	90.43%	80.49%

Figure 11. ANOVA % Inventory level.

In Figure 11, it can be observed that the three factors, lot size, number of trucks and variation in the processing times in the companies, has a significant effect on the response variable level of inventory, since its p-value is less than 0.05. This means that the inventory level can be increased or decreased depending on the number of trucks that are used, the size of the batch moving between companies and the variability observed in the processes of each company. It should be mentioned that the p-value of the variability factor was very close to the critical region, since its value was 0.048, which means that it significantly affects the inventory level variable, but it does so to a lesser extent than the size of lot and number of trucks. Regarding the effects of double or triple interaction, it is seen that only the double effect between lot size and number of trucks, has a significant effect on the level of inventory, the rest, does not have a significant effect since its p-value is greater than 0.05. In relation to R^2, we have that 95.12% of the variability is explained by the model.

The previous analysis in the ANOVAS, serves to determine which factors can affect each of the response variables defined in this research to then determine the level that each of the factors must operate in order to operate the system or supply chain in the most efficient way possible. In this sense, the optimizer of the response variables included in the Minitab 17 software was used. Accordingly, a criterion must be defined for each response variable, such as between larger better, nominal is better or smaller better. For example, pollution is a quality feature whose increase is undesirable, so it would seek to minimize, so it is a variable between smaller better. Delivery time is a very important feature in a supply chain, whose high values cause breaks in the chains, so you always want to minimize its value, therefore it has the smallest best feature. With regard to the idle of trucks, according to the principles of lean thinking, you want to use the least amount of resources, so that idle is desirable to reduce it. Its characteristic is for this reason, the smaller the better. Finally, for the inventory level response variable, according to the lean manufacturing philosophy, inventories represent high waste that must be reduced, for this reason it has a smaller better characteristic and it is necessary to minimize it.

Once the above was clarified, the optimizer of the response variables included in Minitab 17 was used, as shown in Figure 12.

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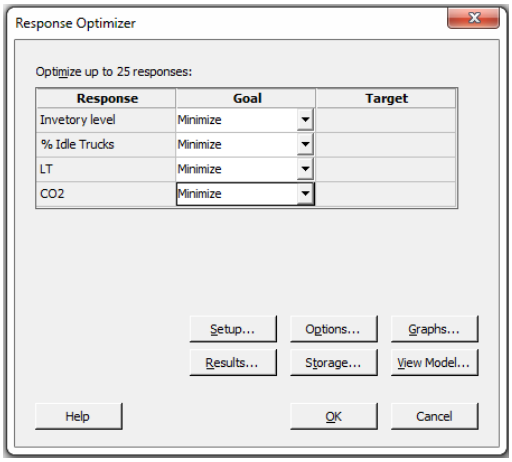

Figure 12. Response optimizer.

After the previous step, the result observed in Figure 13 was obtained.

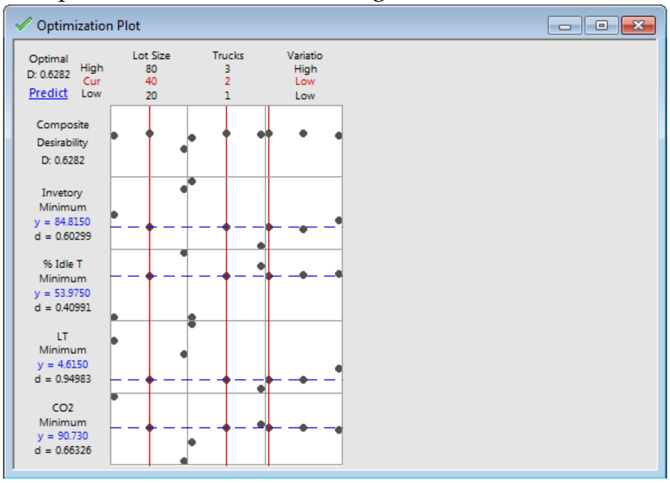

Figure 13. Optimal response.

According to the result shown by the optimizer, it can be seen that the lot size that must be moved between companies is 40 pieces, 2 trucks must be used for the movement of materials and, as expected, the level of variation in the Process times of the companies, should be at the lowest possible. When establishing the system according to the optimal response, we have the following average answers: Global inventory level, 85 pieces; idle percentage of the entire truck fleet that moves materials between companies, 54%; Average lead time, since the material arrives at the first company until the batch of 80 finished pieces is delivered to the final customer, 4.62 hours and finally; 90.73 kilograms of CO_2 emitted by the entire truck fleet to be able to move all the necessary materials between companies to produce a batch of 80 pieces for the final customer.

6. Discussion

The design of supply chains under a lean and environmental approach is necessary to achieve the objectives of each of the companies that comprise it. In this epoch, it is not only important to worry about the efficiency of the supply chain in terms of economic profitability, but also to think in environmental terms, for this reason it is proposed to integrate several tools, in this article we propose lean manufacturing, simulation and design of experiments. As future research it is proposed to apply the steps suggested in this methodology of construction of supply chains to a real case and document it. Add in the variability factor real data of process times by performing a goodness-of-fit test in the first instance, to determine which is the true probability distribution that the data follow. In addition, other response variables can be added that measure the economic and environmental impact by reducing the CO_2 levels of the supply chain.

It is more economical to design supply chains with the methodology that is proposed, it is better to carry out experiments on a simulation model and visualize the results before implementing them, instead of performing trial and error experiments.

The proposed methodology also has its disadvantages, among the most important, is that any of the companies interested in the analysis of the supply chain must have the license of some simulation software and an expert capable of handling the software. Some companies that are not very convinced of the application of the simulation refuse to invest in this tool, however, with its use, over time, the investment is recovered with the benefits granted by the tool in the execution of projects.

7. Conclusions

In this article we have presented a novel methodology to design supply chains with a lean green approach, based on simulation scenarios and design of experiments. Three response variables aligned to lean thinking were defined, such as inventory level, lead time and % idle of the trucks. In addition, a response variable was defined that focuses on the care of the environment, such as CO_2. As a strategy, all were defined as variables between smaller is better because it is most convenient to minimize them, in all cases. Three important factors were also defined that should be considered in a supply chain, such as the number of trucks, the quantities to be transported in each shipment from one company to another (lot size) and the variability that presents in their processes each company.

The methodology for a group of fictitious companies was developed, however, it is perfectly applicable for companies that are part of a real-world supply chain. It can be used as software to simulate the Promodel, or any other software that facilitates the discrete event simulation. In this case, the CO_2 pollution index, the lead time, the idle percentage of the trucks and the inventory level were considered as response variables, however, the methodology is not limiting and more response variables can be added, depending on of the needs of the company. Likewise, it is possible to add more factors to be analyzed that could affect the response variables, for example, capacities of cargo trucks, type of engine, truck brand, etc.

The results show that it is possible to simultaneously minimize all the response variables. It was found that the effects of double interaction between the factors lot size and number of trucks have a significant effect on all the response variables, means that, that the effect of one factor depends on the level of the other. In this case, for example, the effect of the lot size on the established response variables will depend on the number of trucks used.

It was also found that the factor number of trucks, lot size and variability of the processes, significantly affect the variable called % idle of trucks. In addition, it can be concluded that the factors lot size and number of trucks have a significant effect on all the response variables.

It was demonstrated that it is possible to establish a methodology that applies to the design of a supply chain with a lean green approach, which allows contemplating factors that can affect response variables established by those involved in the supply chain. The response variables and factors can be defined according to the needs of those involved. With this you can design supply chains that are friendly to the environment and at the same time efficient.

It is proposed as future research to apply the methodology to a real case and document it.

Author Contributions: José Alfredo Jiménez carried out the construction of the simulation model representative of a supply chain and analyzed the results of the simulation scenarios. Salvador Hernández collaborated with the translation and revised the whole paper. Edgar Augusto Ruelas and Roberto Baheza carried out the design of experiments. José Martín Medina proposed the way to measure CO_2 and proposed the equation to introduce it as a variable to Promodel software. Sandra Téllez and Vicente Figueroa designed the fictitious supply chain. Pedro Yáñez and Moises Tapia revised the results of the design of the experiments.

Funding: This research received funding from the National Technological Institute of Mexico in Celaya, the authors thank all the support received.

Acknowledgments: This work was supported by the National Technological Institute of Mexico in Celaya, Project No. 89u5f0 (4204).

Conflicts of Interest: The authors declare no conflict of interest.

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