SIMULATION AND OPTIMIZATION OF THE MANUFACTURING PROCESS OF E- BICYCLES: THE CASE OF INNOVAUNAM

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ABSTRACT

The electric bikes are a new concept of bikes designed to promote exercise and at the same time the reduction of road congestion and pollution, spending on fuel and autonomous mobility. In Mexican context, the entrepreneurial sector was the first producing electric bicycles, but its assembly system was not optimized. In fact, due to the high costs of production the lifetime of their enterprises is limited to less than three years. The aim of this paper is to develop a simulation model of electric bicycles manufacturing process maximizing the productivity as a tool for supporting the decision-making of Mexican entrepreneurs of this sector. We develop the conceptual model of manufacturing process based on requeriments of real demand of e-bicycles. Then, we implement the simulation model using AnyLogic software. The simulation model is validated via a sensitivity analysis. Finally, we maximize the productivity of the manufacturing process using the OptQuest™ solver.

Keywords: assembly process, electric bicycles, sustainability, simulation-optimization.

1. INTRODUCTION

Globally we suffer from high levels of pollution from the use of internal combustion vehicles, that creates serious effects on our life such as health problems, respiratory rate, saturation of transport routes and overweight, as a result of putting aside the physical effort to move from side to side. Perhaps the biggest problem in the world is pollution, before this have been raised solutions from government authorities such as traffic restrictions, encouraging the use of public transport, the use of hybrid and electric vehicles, the reduced speed limits and the encourage in the use of bicycles, creating pedestrian streets, some initiatives to share business vehicles and the supports to purchase electric vehicles and bicycles. In this direction, electric bicycles (e-bikes) are a cost effective alternative for industry and consumers, since these do not generate a high rate of pollution. E-bikes can be used anywhere, allowing the physical effort and even movement from the classic 13 km/hr offered by normal bike to 23-26 km/hr. The e-bike is very versatile and is adaptable to the needs of users, but perhaps its most important characteristic is the possibility of mobility free fuel costs. It requires a small parking space and even in the folding version could be saved within an office. Pike Research (2016) forecast that the worldwide market for e-bikes will grow at an annual rate of 7.4% between 2012 and 2018, resulting in global sales of 47.6 million vehicles at the end of 2018 (see Fig. 1). Almost 90% of the total world market is concentrated in China, followed by Western Europe.

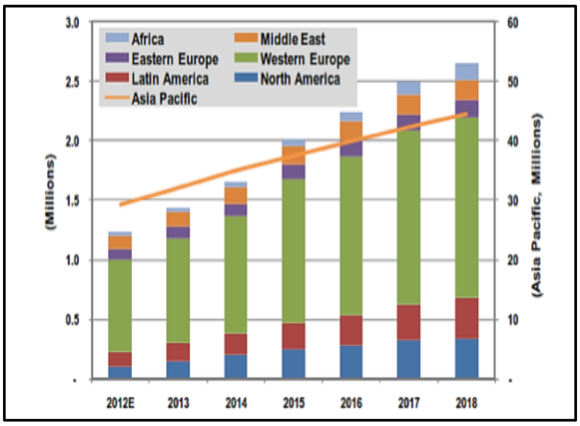


Figure 1: Electric bicycle sales by Region, World Markets: 2012-2018 (Pike Research, 2016)

In Mexico, in terms of business the entrepreneurial sector was the first producing e-bikes. At the beginning, the e-bikes in Mexico were neither good nor attracted attention and were on par with some attempts to work with internal combustion engines such as motorcycles. Just a decade ago, improvements were made, also experience was achieved and adequate profitability as well as an elegant, functional and highly efficient design were attained. Although the market is still small there is a future for e-bikes in Mexico but the number of suppliers is still limited by a few players. In this direction, Mexican entrepreneurs of e-bikes industry face a new challenge, the lack of theoretical tools for supporting the design and implementation of their production system, in order to increase the lifetime of their business which actually is limited to less than three years. The aim of this paper is to develop a simulation model of e-bicycles manufacturing process maximizing the productivity as a tool for supporting the decision-making of Mexican entrepreneurs of this sector.

In this paper, we present the case of InnovaUNAM whose entrepeneurs designed a new e-bike in order to comercialize it (see Fig. 2) based on the technical specifications presented in Table 1.
This paper is prepared as follows: the conceptual model of the manufacturing process based on real demand requeriments of e-bicycles by InnovaUNAM entrepreneurs is described in Section 2. The simulation model is developed considering discrete-event simulation approach, then it is implemented using AnyLogic™ software, and it is validated via a sensitivity analysis in Section 3. The productivity of the manufacturing process is maximized in Section 4. Concluding remarks are draw in Section 5.

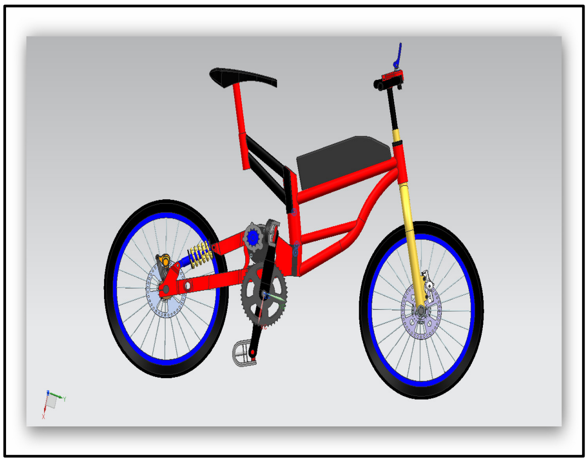


Figure 2: The e-bicycle designed by InnovaUNAM entrepreneurs

Table 1: Technical specifications of the e-bike designed by InnovaUNAM entrepreneurs

Technical specifications	
E bike	Folding
Distance	30 km
Battery	Li-ion
Time for recharging the battery	3 hours
Maximum velocity	25 km/hour
Weight allowance	90 kg
Frame material	Aluminum
Rolled rim	0.66 meters
Brake	Disc

2. THE CONCEPTUAL MODEL OF THE MANUFACTURING PROCESS OF E-BIKES

We propose a general methodology for designing the manufacturing process of e-bikes to support the decision making of InnovaUNAM entrepreneurs about the layout. The methodology starts with the definition of the product, which in this case is an e-bike. Then, the required supplies, resources and mediums are listed. Also, the legal aspects need to be verified and the entrepreneur vision needs to be identified. The work zone is selected as well as the suppliers. After that, the processes are designed and the layout is created (see Fig. 3).

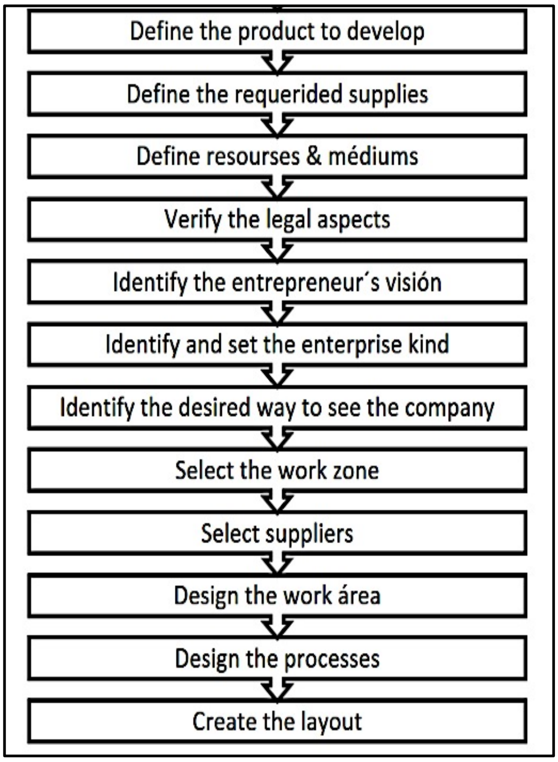


Figure 3: A proposed methodology for designing manufacturing process

In this study, the manufacturing process is modeled as a system that consists on processes interrelated. In general, the flow between the processes is a flow of mechanical and electric parts. As is observed in Fig. 4, the cross-functional diagram consists on five processes: cutting, bending, scuttled, welding, and assembling. The manufacturing of e-bikes starts with the general cutting of materials. Then, the load and force application continue as part of the bending process. After that, the tubes are drilled, as well as the bars and the mass. The drilled bars pass to the square belding process. While the mass drilled passes to the assembling process that starts with the wheels and finished with the electric and storage assembling (see Fig. 4). The e-bike manufactured is approved only if it passes the quality check, and then is carried on to the store for sale. If the quality required is not achieved, the e-bike is repaired, entering to the manufacturing process again.

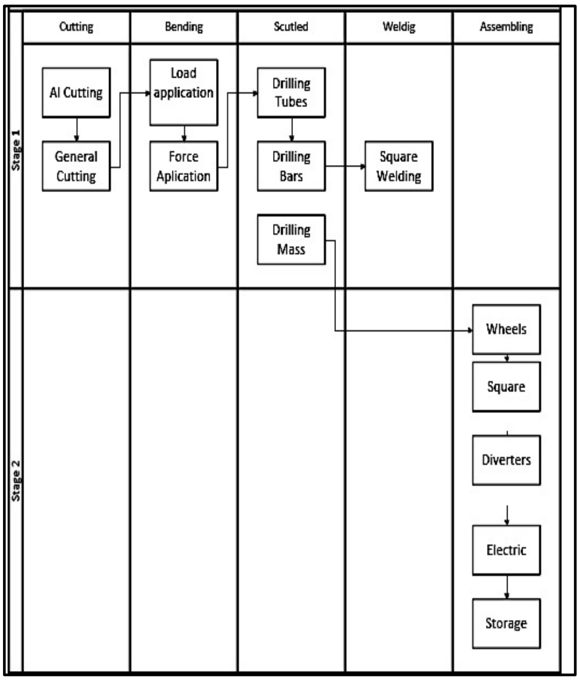


Figure 4: Cross - functional diagram of e-bikes manufacturing process

Based on the methodology proposed in Fig. 3 and considering the cross-functional diagram in Fig. 4, we design the layout (see Fig. 5). Each process is mapped in a physical area and the flow is sequential. We propose two storage areas, one of them for the materials and supplies and the other one for the e-bikes finished.

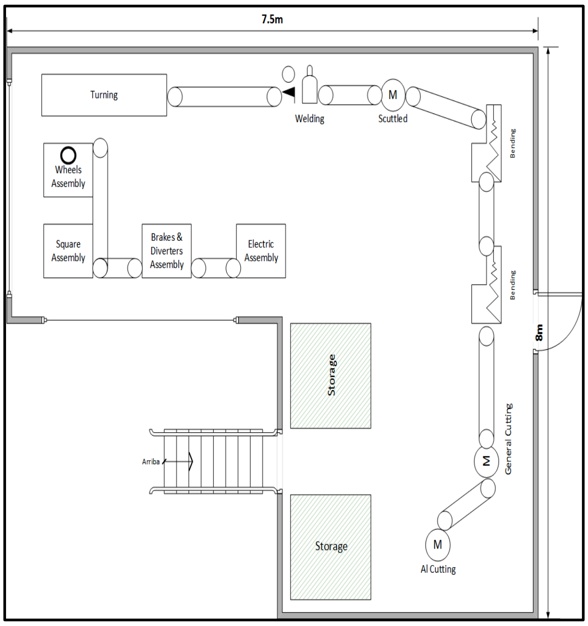


Figure 5: The layout

3. THE SIMULATION MODEL BASED ON DES APPROACH

We develop the simulation model of the manufacturing process using discrete-event simulation (DES) approach that is based on the top-down perspective (Robinson 2004; Banks 1998). In general, a DES model attempts to represent the components of a system and their interactions so the state variables change only at those discrete points in time at which events occurs, considering an event as an occurrence that changes the state of the system (Banks 1998). In this study, the events are generated by the internal changes in the five processes: cutting, bending, scuttled, welding, and assembling. The conceptual model of the manufacturing process of e-bikes is implemented in computer using AnyLogic™ software release 7.3. It is a Java-based and general-purpose simulation tool that takes advantage of the power of Java in any part of the model or in any library. These features make Anylogic™ a suitable tool for simulating complex systems such as manufacturing systems. Furthermore it allows the simulation of various domains using different approaches, and also provides animation, which can be useful in supporting the decision-making processes (Longo, Huerta-Barrientos and Nicoletti 2013). We use the Process Modeling Library whose blocks allow users to use combinations of agents, resources, and processes to create process-centric models of real-world systems (Grigoryev 2015). We use the source, sink, time measure, delay, service, assembler, and conveyor blocks (see Fig. 6).

Figure 6: Block of Anylogic´s Process Modeling library used in the simulation model implemented

The layout in the simulation model was built considering the real restrictions in space. The size of machinery was adjusted also to the real scale. The layout in the simulation model includes industrial safety signs that were allocated on the walls.

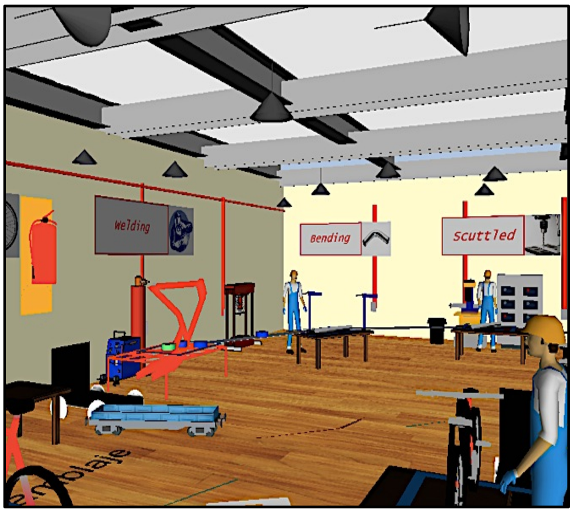


Figure 7: The simulation model of the manufacturing process of e-bikes: the welding, bending and scuttled processes

Figure 8: The simulation model of the manufacturing process of e-bikes: the general cutting and aluminum cutting processes

3.1. Simulation model verification

Simulation model verification deals with building the model right, but also with the accuracy in the conversion of a model representation in a micro flowchart into an executable computer program (Banks 1998). In this direction, we use a tool used rely heavily on human reasoning called *face validation*. During a technical visit, the potential users of the model, that means the entrepreneurs from InnovaUNAM-Engineering Unit, compared the simulation model and the manufacturing system behavior under identical operational conditions and they judged that results were reasonable. In this direction, it can be said that the simulation model represents the real system.

3.2. Simulation model validation via a sensitivity analysis

The model validation deals with building the right model within its domain of applicability (Banks 1998). In this direction, to validate the simulation model we use the dynamic technique called *sensitivity analysis* intended for evaluating the model based on its execution behavior. According to Banks (1998), through the sensitivity analysis values of input variables and parameters are systematically changed over some range of interest and the model behavior is observed. Using sensitivity analysis input variables and parameters to which model behavior is very sensitive are identified. We consider the turning process time as the input variable with two extreme values: 0.1 and 1 hour. The run time was during one month but considering just 40 working hours in the week.

Table 2: Input variables for designing the sensitivity analysis

Input variables		
	Low value	High value
Turning process time	0.1 hour	1 hour

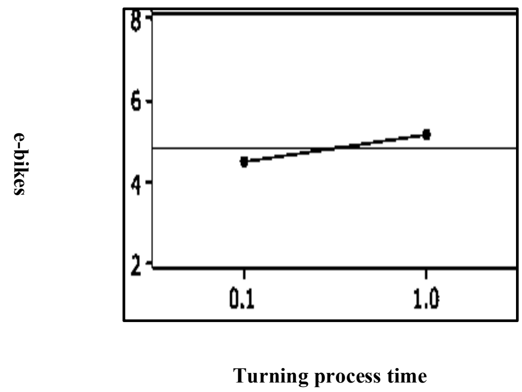


Figure 9: The sensitivity analysis results

As is observed from Fig. 9, the effect of the increment in the turning process is reflected on the increment in the number of e-bikes productivity, as it is in the real system.

3.3. Design of simulation experiments

We conduct a 2^4 factorial design (Montgomery, 2005) of simulation experiments. It means that we consider four factors (see Table 3): material flow, welding, turning, and electric assembly processes time in hours, with two different values. The simulation run time is one month but considering just 40 working hours per week.

Table 3: Time of different processes (hours)

Input variables and parameters			
Parameter	Input variable	Low value	High value
A	Material flow	0.05	0.1
B	Welding	0.5	1.5
C	Turning	0.1	1
D	Electric assembly	0.5	1.5

In Fig. 10, the individual effects of each factor (or the main effects) on e-bikes productivity are showed. The results of this factorial experiment indicate that material flow process time effect is larger than either the welding time or the turning time. We also obtain the metamodel (Eq. 1) that represents the e-bikes productivity considering the four factors with two values. From Fig. 11 to Fig. 15, the effects of the four different parameters are showed.

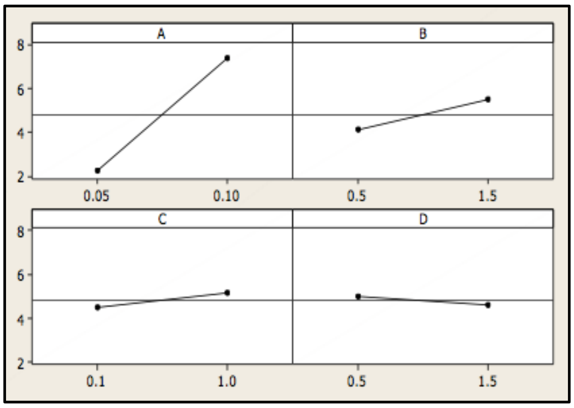


Figure 10: The main effects graphic of parameters A, B, C, and D on e-bikes productivity

$$Y = 169.44A + 6.11B - 2.50C + 3D - 56.67AB + 5.56AC - 58.89AD + 3.89BC - 2.22BD + 5CD - 33.33ABC + 33.33ABD - 11.11ACD - 7.78BCD + 66.67ABCD - 9 \quad (1)$$

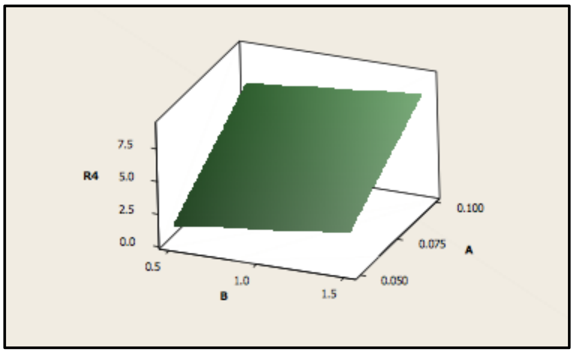


Figure 11: The effect of parameters A and B on e-bikes productivity

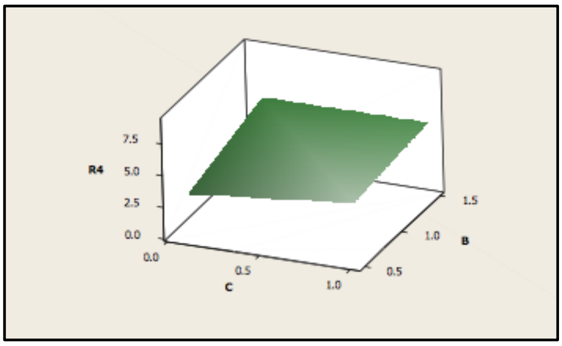


Figure 12: The effect of parameters B and C on e-bikes productivity

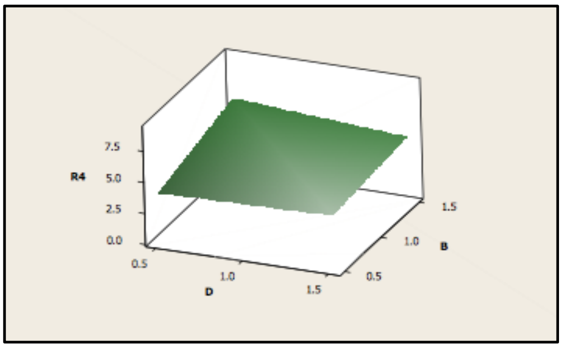


Figure 13: The effect of parameters B and D on e-bikes productivity

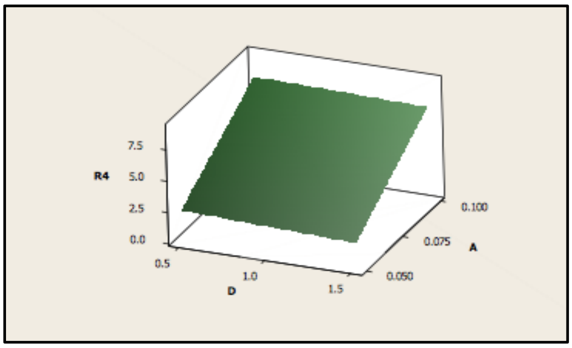


Figure 14: The effect of parameters A and D on e-bikes productivity

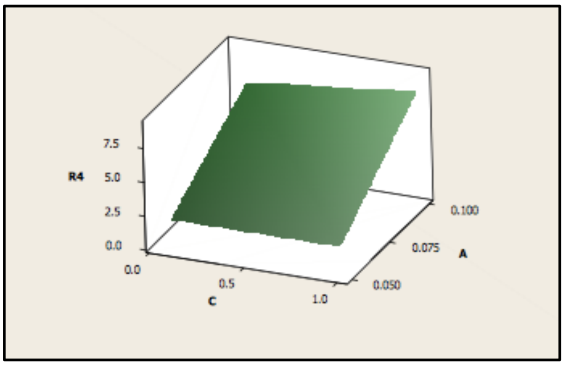


Figure 15: The effect of parameters A and C on e-bikes productivity

4. OPTIMIZING THE ASSEMBLY PROCESS OF ELECTRIC BICYCLES

In this study, we maximize the productivity, in terms of e-bikes assembled using the OptQuest^{TM} solver that is included in AnyLogic^{TM} software. OptQuest^{TM} (by OptTek Systems, Inc.) is a general purpose commercial optimization software that operates by treating the objective function evaluation as a black box allowing users to represent solutions as mixture of continuous, discrete, integer, binary, permutation and other variables (Laguna 2011). As suggested by Fu (2002), OptQuest^{TM} is an add-on to the underlying simulation engine. Also, OptQuest´s main optimization engine is based on the scatter search methodology, tabu search strategies, and neural networks. As is observed in Fig. 16, the metamodel of Eq. (1) is used to maximize the e-bikes productivity. Also, the parameters: material flow, welding, turning, and electric assembly processes time in hours, with two different values, were considered.

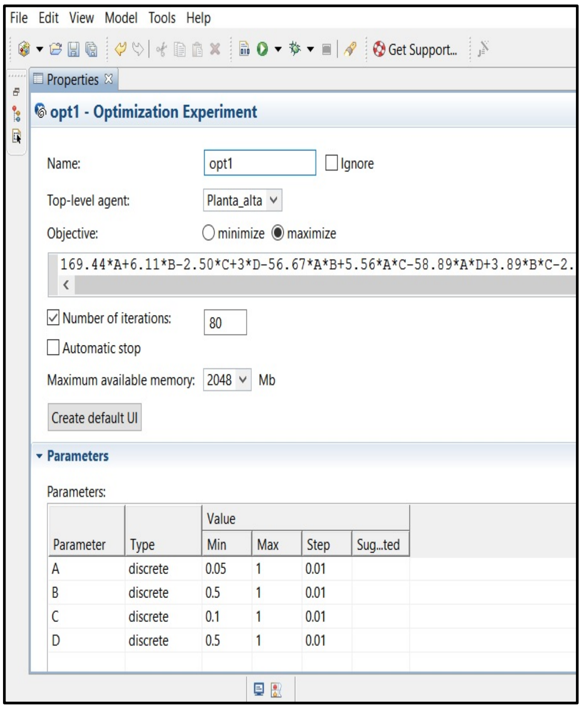
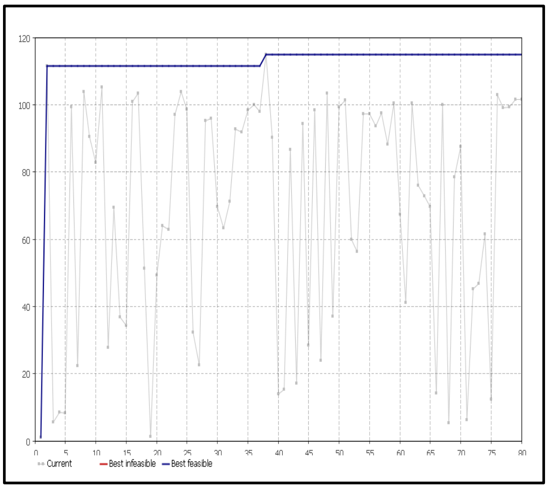
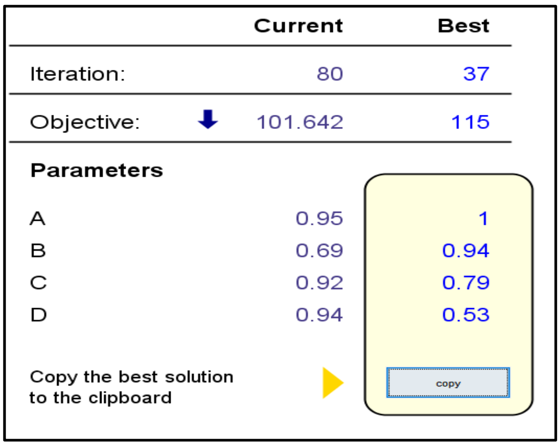


Figure 16: Maximizing the productivity of assembly process using OptQuest^{TM}

The optimization results of the e-bikes productivity are presented in Fig. 17 and Table 4. The best value for the productivity is 117 e-bikes during one month considering 40 working hours per week. The best time for the material flow process is set up in 1 hour, while for the welding process is set up in 0.94 hour and for the turning process in 0.79 hour. Finally, the electric assembly process time is allocated at its minimum value in 0.53 hour.



(a)



(b)

Figure 17: Productivity optimization results, a) the graphic of evolution in time, b) the best values found

Table 4: Optimized time of different processes (hours)

Input variables and parameters		
Parameter	Input variable	Best value
A	Material flow	1
B	Welding	0.94
C	Turning	0.79
D	Electric assembly	0.53

5. CONCLUDING REMARKS

We developed a simulation model of electric bicycles manufacturing process to maximize its productivity, as a tool for supporting the decision-making of Mexican entrepreneurs. The conceptual model of the manufacturing process of e-bikes was implemented in computer using AnyLogic^{TM} software release 7.3. The layout in the simulation model was built considering the real restrictions in space. The results of a 2^4 factorial design of simulation experiments indicate that material flow process time effect was larger than either the welding time or the turning time. The optimum values for the productivity was on 117 e-bikes during one month considering 40 working hours in the week. To reach this productivity, the time of the processes such as material flow, welding, turning, and electric assembly needs to be less than 1 hour per e-bike. Finally, we consider that the simulation model 3D animation can be used as a tool for suppoting decision making of entrepreneurs because it is useful to visualize the entire manufacturing e-bike process and recognize where improvements could be made.

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REFERENCES

Banks, J., 1998. Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice. Georgia: John Wiley & Sons, Inc.

Fu, M., 2002. Optimization for Simulation: Theory vs. Practice. Journal on Computing, 14 (3), 192-215.

Grigoryev, I., 2015. Anylogic 7 in three days. Aquick course in simulation modeling.

Laguna, M., 2011. OptQuest. Optimization of Complex Systems. OPTTEK SYSTEMS, INC.

Longo, F., Huerta-Barrientos, A., and Nicoletti, L., 2013. Performance analysis of a Southern Mediterranean seaport via discrete-event simulation. Strojniski Vestnik/Journal of Mechanical Engineering, 59, 517-525.

Pike Research, 2016. Available from: [http://www.greencarcongress.com/2012/03/ebike-20120327.html]

Robinson, S., 2004. Simulation: the practice of model development and use. Chichester: Wiley.

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