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Analysis of Productivity and Profitability of a SME through Collaborative Networks using Discrete Event Simulation tool: An automotive Case Study

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Abstract. Most companies seek sustainability and competitive advantage for optimal problem solving and value creation. Medium-sized companies that account for more than 90% of the world's total companies with a low research & development, tend to search for alternatives within the private and educational sector that allow them to increase their productivity without having to compromise their competitive activity in their sector. Collaboration with external actors represents an opportunity for organizations as it broadens their development of the productive system and their organizational behaviour. This interaction is known as Open Innovation. This concept has dismantled the traditional organizational archetype enabling universities to link the academy's work into the industrial sector. One-part of the academy, in collaboration with them, is the use of emerging technologies and digital tools that lead into a decision-making efficient process incorporating industry 4.0. A useful technology for this purpose is Discrete Event Simulation, a tool for system analysis, characterized by modifying variables without compromising the current productivity of the company. This document explains through a case study, the use of simulation in an enterprise of the automotive sector through the tool, in the lamination process of production line. The contribution of this paper is generating alternatives for the decision-making process in a real scenario, using the tool to achieve results in collaboration within the industry sector. The analysis shows the improvement, analyzing the productivity and choices, that increase in the profitability of the enterprise.

Keywords: Discrete Event Simulation, Industry 4.0, Value Creation, Collaborative Networks, Making-decision, SME, Automotive industry.

1 Introduction

Nowadays, Industry 4.0 plays an important role in competitive advantage for many enterprises. All the phases of the industrial revolutions have led great changes to

industries and part of their supply chains [1], considering the three key concepts to increase competitiveness advantage: cost leadership strategy, differentiation strategy and focus strategy [2]. To this regard, competitiveness on the manufacturing level has been based on core technologies and tools inherent to the fourth revolution which has impacted positively the economy axis of most enterprises. At present, most of the enterprises worldwide that seek innovation and competitiveness represent more than 90% medium-sized enterprise (SME). With the adoption of industry 4.0 in large enterprises and SME working as intermediaries, there has arisen the interest in adopting new technologies and methodologies for the purpose of competing and innovating their products. In the growth model [3], there is considered technological progress as an important factor in worker's productivity and consequently, in production processes. In recent years, the new technologies introduced by industry 4.0 have intensified changes in the economy of industry. In a study, it explains that the fourth industrial revolution will influence the condition of world industry, depending on the level of industrialization, the condition will be different in each country [4]. Increasing adoption of technologies has had a positive effect on the growth and development of SMEs. Nowadays, innovation in the most highly developed countries has had growth and development. On the other hand, developing countries have sought economic performance and competitive advantage. In 2019, Mexico ranked 51st related to competitive advantage [5]. This represents, approximately 4.1 million by national SMEs [6]. However, in the literature review, there are shown common factors that limit the investing of novel technologies and methodologies related to Industry 4.0, [7–12]. This problem is due to the lack of effective decision-making when designing, evaluating, analysing and modifying strategies and changes to the product or operating process in an SME. Notwithstanding, the low R&D level influences the decision-making of necessary tools, new knowledge and technologies to achieve innovation of the SME. Therefore, considering their limited financial resources, they are forced to look for alternatives with external agents such as universities. Collaboration with universities represents an opportunity for SMEs' because of their key role within industry 4.0. One role of the university is the use of emerging technologies and digital tools to propose alternatives to SMEs. An emergent technology that has reached maturity is Discrete Event Simulation (DES) for the decision-making process. DES has demonstrated the feasibility of improving production processes characterized by parametrizing multiple scenarios for analysis and evaluation of either production line or productive system. Furthermore, this tool is characterized by modifying factors in the simulation without compromising the physical design and productivity of the SME. These simulations are achieved using computational resources that work with existing information and allow modifications without modifying the physical system. Given the context described, this paper aims to show how SME's profitability is improved directly from the decision-making process using a DES tool. Nonetheless, this work could not be done without the Collaborative Networks (CN) that arose with the university and industrial sector. The structure of the paper states as follows: In section 2 there is described the collaboration with universities through the Open Innovation Laboratories (OIL), an alternative in which the SMEs can increase their R&D to improve their processes. Section 3 explains the use of the DES tool, how it works, its contributions and the impact of this tool for enterprises, as well as the simulation model that was used in

this paper. In section 4 shows the proposal, the analysis and evaluation for decision-making by using DES in collaboration with the SME case study and the university OIL, as well as the methodology to be used. In Section 5 describes the case study in the automotive sector, the development of the simulation according to the proposed methodology and the results found by each scenario. In section 6, the conclusions and contributions of this paper.

2 Collaborative Networks

SMEs don't have all the necessary capabilities and infrastructure [13], with limited knowledge in decision-making [14]. Justifying the collaboration with the universities previously, besides being entities that generate knowledge daily, originates a CN with the SME. The CN works with external actors to ensure that new knowledge and technology comes not only from within the organisation but also to outside, this interaction is known as Open Innovation (OI) and has dismantled enterprise's traditional innovation. Therefore, CN with universities helps to promote the generation of new ideas from different parts and the creation of new knowledge. The CN with university allows generating a horizontal integration because they're dedicated to carrying out research and development activities with the SME, improving the processes and the innovation of the products. Likewise, the SME is vertically integrated by increasing the efficiency of all its resources through technology and new knowledge with the university. In some universities, the collaboration with enterprises is carried through an OIL.

2.1 Open Innovation Laboratories

Nowadays, SMEs are seeking the adoption of the OI despite the application of methodologies and mechanisms that they have implemented by their organization [15,16]. OI has been defined by many authors as a process where flows coordinated knowledge [16,17], a support in organizations and in the industries [18]; implementing the concept. The OI model also suggests that enterprises should combine external and internal ideas and technologies like effective channels as technologies are advanced [19,20]. A part of the universities devotes itself to the collaboration with enterprises, these spaces are known as OILs. OIL is a resource leader of the universities that performs many functions, including collaboration with enterprises of different sizes and types of business activities. OIL has a significant impact on innovation, being a paradigm that focuses on the enterprise with the exploitation of external knowledge to improve the innovation of the internal process [21], (e.g. problem-solving by leveraging decision-making and praxis of innovation management [15]), as well as R&D and strategy projects. The OIL has a platform with technologies developed by researchers and students of the same university like methods, methodologies and on the other hand, a series of modern software and hardware and emerging technologies (simulation, big data, printing 3D, among others). For collaboration between university-industry in OI, some authors [13] have

selected some main keys that should be considered. In business model is proposed [13] for collaboration between universities and enterprises through the OI. Universities in different countries have implemented the OIL concept, in different ways, some CN collaborate from virtual spaces and the most are face-to-face. Some most well-known terms that have been dealt for OIL are Makerspaces, High Tech Lab, Learning Rooms and Fabs Labs [22].

3 Discrete Event Simulation

The university through its OIL are offering resources to the enterprises with the purpose of generating product innovation and the improving of their processes. In view of this rapid technological evolution, OILs have also been updated through the adoption of emerging tools and technologies. One of the most used tools for decision-making is simulation. Used in the production area, logistics, industrial engineering, among others, it corresponds to a pillar of Industry 4.0. Enterprises react ahead of time using DES cost-effectively and efficiently, allowing decision-makers to have a full perception of the design of the process or product. The results obtained by DES have ensured useful information for speeding up decision-making. So, focusing on DES as CN support for SME-OIL, it is possible to define as one of the useful tools in the CN to represent the real processes in a digital model [23], designing, analyzing and evaluating multiple scenarios and multi-criteria in the decision-making. DES efficiency has been proved by different case studies, [24–29].

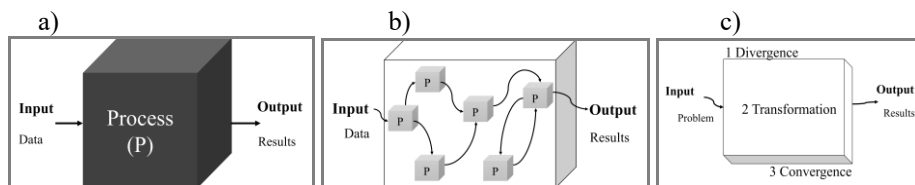


Fig. 1. Simulation Models Types. (a) Input-Output or Black Box, (b) Glass Box, (c) Three-Stage Process.

Nevertheless, the efficiency of DES depends highly on the availability, quantity and quality of information introduced to the models. There are three types of models according with their application and robustness: Black Box, [30,31] or also called "input-output", the Glass Box or also known as white box [30,32] and the Three-Stage Process [30] (See Fig. 1).

4 Use of DES as Support for Effective Decision Making in Analysis and Evaluation of Operative Processes

This section describes and illustrates procedure proposed for simulation using Act Research-Cycle (ARC). Finally, proposal for decision-making in the analysis and evaluation of operational processes an SME is described and illustrated.

4.1 Proceeding Simulation using Act Research Cycle

Although, simulation is an efficient tool, there is needed techniques or methodology support in the simulation models design. Bangsow [23] proposes VDI 3633 procedure which it's a methodology focused on simulation design and elaboration. Chavarria-Barrientos et al. [33], proposes a continuous improvement technique known as ARC. It's used for each VDI 3633 procedure stage (See Fig. 2). Methodology development provides precise information for results securing of simulation design.

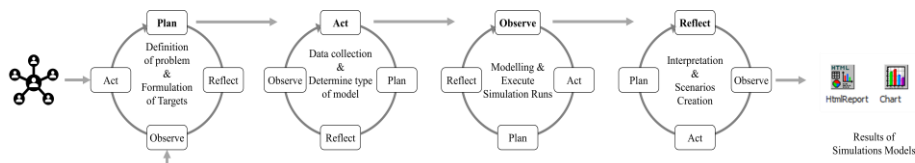


Fig. 2. Steps for development of Simulation models. Propose technique based on ARC

4.2 Proposal

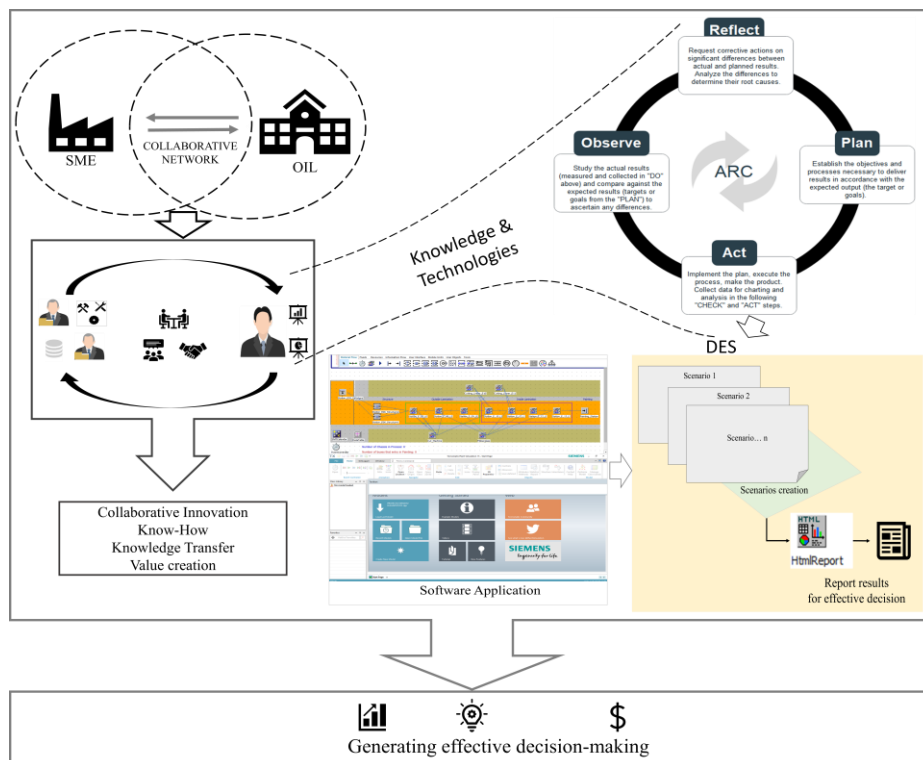


Fig. 3. Proposed framework for effective decision-making in CN for SME-University

According Schwab K. [34], productivity in processes and enterprises growth are

related to Industry 4.0. Nevertheless, most enterprises by SMEs have had a low R&D due to lack tools, technologies and practices necessary to make decisions correct when solving-problems in a timely manner. One of SMEs challenges have faced in effective making-decisions is the improving of operational processes to increase production volume and minimize downtime, giving to understand these processes that transform to the product and give sight to the customer [2]. At present, SME are engaged with universities that enable them to achieve their productive objectives through appropriate technologies and tools for decision-making. CN creation is put into practice between SME-University, but with the purpose of the major cohesion exists, some universities have an OIL, to collaborate, offering technologies, knowledge and tools necessary. Through CN, there arises the exchange and generation of information between SME-OIL, to generate an effective decision-making bearing in mind the limitation and management of the financial resources of the SME. This interaction generating collaborative innovation in the SME. CN proposes DES, a tool that allows to design, analyze and evaluate the operative process through creation of different scenarios, without compromising the financial investment, without changes in the design or the expense of the resources of the SMEs. Therefore, CN generates value creation by using DES, generating accurate and reliable results for decision-making. The simulation procedure [23] for generating results report is based on the ARC strategy, in order to make a cyclically compliant marked steps of DES (See Fig. 3).

5 Case Study

It was developed in a mexican SME in the automotive sector, under the Make To Order (MTO) segment, whose manufacturing business is semi-urban and urban passenger buses. It practices traditional manufacturing, furthermore, has little experience in manufacturing processes. The SME's local market includes large enterprises that offer a diverse product range, whereupon keep motivates to continue improving his operations and minimize costs. This paper was in collaboration with a SME to increase productivity and profitability of production line, specifically in lamination area. This area has different activities: grinding, assemblies of various metal parts, lamination of the chassis structure, fibber-glass molds, among others. In order to improve the productivity area real process, it proposed give alternatives to the SME for process decision-making in collaboration with Tecnológico de Monterrey's OIL through DES tool. Likewise, White Box Model (See Fig. 5a) and Three-Strategy-Process (See Fig. 4), simulated in scenarios different. The applied ARC presented:

Plan. Problem definition: The SME has need to increase its productivity, however, bad management has been detected generating bottlenecks in workstations in the area lamination as well as processing times of activities have a long times and generation of waste has been very high. Formulation of Target: Compare the traditional lamination process area with different in each scenario simulated by DES tool in order to generating effective alternatives for SME decision-making process. The feasible scenarios were evaluated through the productivity generated by processing times and energy consumption of workstations.

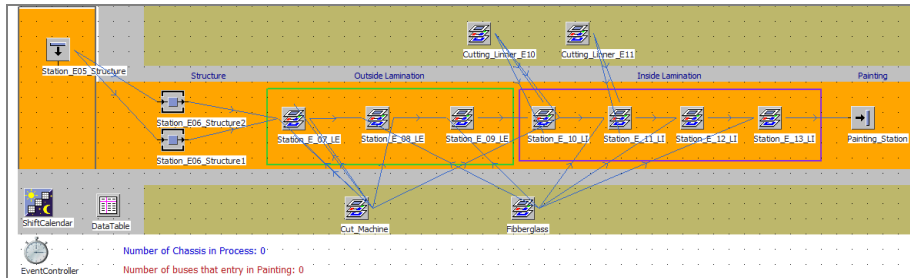


Fig. 4. Simulation lamination area in Tecnomatix by Siemens based in Three-Stage Process

Act. Data collection: The data was collected using a VSM. such as the processing times (including movement times), set-up time, recovery time, cycle time, availability and MTR for each activity. Determine Model Type: White box model [30,32] was chosen for the 7 workstations of real process (See Fig. 1b). Only considered processing times and failures, amount materials used (See Fig 6). General model used was the Three-Stages-Process (See Fig. 1c) due to the overall robustness of the simulation data quantities that make up the lamination area. Daily production scheme consists a 10 hours workday and 142.24 minutes time-out, operates for only five days. Model was developed and evaluated in Plant Simulation Tecnomatix by Siemens.

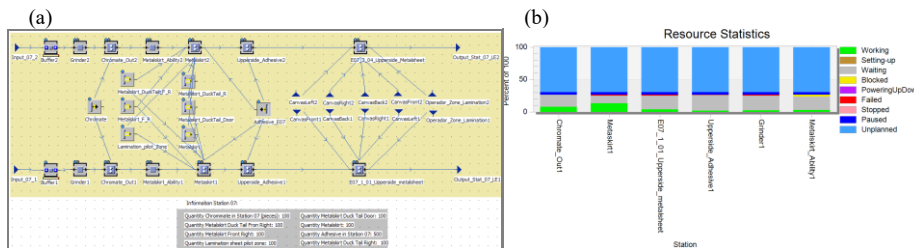


Fig. 5. Execute Simulation Runs on different stations. (a) Simulation of framework of Station E-07-LE, (b) Utilization chart for station E-07-LE.

Observe. Modelling Simulation: Simulation was developed representing the “structures”area, “lamination area” of the station 7 to 13 (for example E-07-LE, See

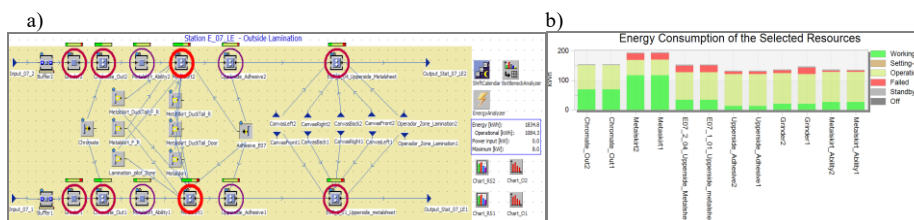


Fig. 6. Energy Consumption of Tools and Equipment in Real Situation - Station E-07-LE. (a) Energy Consumption Visualization (b) Energy Consumption Chart.

Fig. 5a) and the “painting” area (See Fig. 4.). Execute Simulation Runs: It was run for 37 days to calculate the estimated monthly production without non-working days. The

downtime, break time, paused time, unplanned time and failure time, are shown graphically (See Fig. 5b). Therefore, with the SME's time of experience and the simulation results (See Table 1) and the ARC [33], it's determined that the process is in the "introduction of the quality" according to the model of Integration and Modernisation of Small and Medium Mexicans Enterprise (IMMPAC) [35].

Reflect (Restart the cycle). Three different scenarios were executed with the DES tool based on the ARC and the objective is also contemplated. Through the results report by Plan Simulation, OIL proposed three scenarios in collaboration with SME to improve the simulation as well as to achieve profitability. In each scenario, the process improved by demonstrating positive results in productivity by eliminating failures, reducing downtimes and personnel management in the software. This gives an anticipation of the application of different proposed improvements, for example, IMMPAC good practices [35] and/or technologies application to reduce time. Scenario 1 (Quality Stage); was associated with orders compliance and addition of continuous production flow. Scenario 2 (Reliability), was designed with two 8-hours shift per day, reducing lead time and quantity to meet commitment to the painting area. Finally, scenario 3 (Profitability), involves three 8-hour shift per day, with development of cost indicators and time reduction by simulating the application of new technologies based on the criteria of the SME.

5.2 Results

Table 1. Results obtained for Plant Simulation (one month). Comparison real vs scenarios.

Scenario	Station	Available time (daily)	Scrap laminate (pieces/month)	Consumption Energy (kWh/month)	Volume (Buses/month)
Real Situation (Quality: In process)	E-07-LE	27,466 s	46	1084.3	84 buses laminated & (16 chassis in process)
	E-08-LE		28	129.2	
	E-09-LE		-	381.3	
	E-10-LI		-	607.3	
	E-11-LI		38	926.0	
	E-12-LI		-	890.7	
Scenario 1 (Quality)	E-13-LI	31,200 s	-	601.8	91 buses laminated & (17 chassis in process)
	E-07-LE		22	1157.8	
	E-08-LE		12	209.0	
	E-09-LE		-	417.0	
	E-10-LI		-	632.3	
	E-11-LI		20	1004.2	
Scenario 2 (Reliability)	E-12-LI	51,000 s	-	992.2	148 buses laminated & (16 chassis in process)
	E-13-LI		-	648.5	
	E-07-LE		43	1976.0	
	E-08-LE		43	352.9	
	E-09-LE		-	704.0	
	E-10-LI		-	1065.4	
Scenario 3 (Profitability)	E-11-LI	51,000 s	28	1696.9	152 buses laminated & (12 chassis in process)
	E-12-LI		-	1673.1	
	E-13-LI		-	1088.2	
	E-07-LE		33	2019.2	
	E-08-LE		44	352.5	
	E-09-LE		-	716.3	
Scenario 3 (Profitability)	E-10-LI	51,000 s	-	1063.7	1788.7
	E-11-LI		17	1788.7	
	E-12-LI		-	1666.2	
	E-13-LI		-	1085.8	

OIL presents the results below: The real situation productivity (84 units monthly) is low compared to the SME target (100 per monthly). On the other hand, scenarios 1, 2

& 3 increase productivity due to the time of each proposed Takt Time and reduction of downtimes, such as planning time, machine start-up time, time to go to the bathroom, meal time, among others. There are chassis that are in lamination process, however, the 3 proposed scenarios decrease or eliminate the bottlenecks. There is a gradual increase estimated for each simulated scenario in chasis volume production. The sheet scrap quantities are shown monthly with a normal distribution, declaring to the software a 5% pieces scrap of total produced. For scenarios 1, 2 and 3 was declared a scrap an estimated 4%, 3% and 2% respectively. The scrap generation is with respect to the engineering bill of materials. For the supply voltage, it was determined by the standard average through management by the software (Input: 1 kW of working, 1 kW of setting-up, 0.5 kW Operational, 0.5 kW Failed and 0.1 kW standby), multiplied by processing time of each activities (where the electrical equipment is used) and finally, by the number of chassis that move on to the next activity. The estimated productivity improvements for scenarios 1, 2, and 3 are 8.33%; 76.19% and 89.9% of productivity with respect to the simulated real situation.

6 Conclusions

The CN for this article is comprised of a private SME, academic reasearchers who have functioned as an interest between the two sides, creating OI for the SME and new knowledge and practices for University where the innovation emerging in the face of problem solving. The results, were evaluated considering economic and technological aspects and factors and restrictions provided by the OIL with the support of SME to improve its process. With DES tool and academy knowledge it was determined that the SME has a loss of 16 units in sales due to lack of productive time in its lamination process. This affects the SME's pocket money, in addition to the waste generated in the cuts management in the lamination. The energy use cost will depend on the decisions by the SME when making a proposed scenario to modernize or not equipment and tools. Thanks to CN, the information obtained by use of DES with the support of ARC and VDI 3633 by OIL has led to the value creation and viable alternatives creation in the future for the SME, impacting on profitability. Likewise, it's concluded that by working with DES in the CN, time and costs can be reduced, regardless of business type or process/producto type. For future work, it's intended to use DES for all the processes of production line in enterprise.

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