INDUSTRY 4.0 AND ITS IMPACT ON PRODUCTIVITY AND COSTS IN THE SOFTWARE AND TECHNOLOGY IN THE INDUSTRY OF MEXICALI

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ABSTRACT

This investigation was made to evaluate the impact of the industry 4.0 in the processes of development of software in the software industry of Mexicali, with respect to the parameters of productivity and costs. Two relevant tools analyzed were the (1) artificial intelligent and (2) simulation and predictions, which can be applied in the processes of the software industry installed in this border zone, located in the northwest of the Mexican Republic and is an important city of the Baja California State, which have a great commercial relation with the California State of the United States of America (USA). In this scientific study was evaluated the relevant factors that impacts in the development of software, to determine the indexes of productivity and costs in base of the ability, fast and efficiency of the programmers to create the software in according to the necessities of the customers. In the statistical evaluation was used the MATLAB software with the multiple regression and correlation analysis. This was very important aspect to obtain economic gains in any kind of industry. This investigation was made in 2021.

Keywords Industry 4.0, Software Industry, Productivity, Costs.

1. INTRODUCTION

The industry 4.0 is very important in the processes of the software industry, with the application of the tools that supports about the development of any type of the software, in according to the activities required of the customers (Eruval B, 2018). The use of tools of the industry 4.0 that supports to make innovations in the software, is considered as a technological revolution, where are some of these as mentioned next (Bourque, P et al, 2014).:

a) Artificial Intelligence (AI). It is a tool that evaluates the way in which a machine or automatic system can develop activities similar to those of a human; being with reasoning skills of reasoning, learning, creativity and planning skills.

b) Augmented Reality (AR). Describes the technologies used to visualize the real world through graphics generated by high-tech devices.

c) Big Data (BD). It has the ability to obtain and store large amounts of large-scale and complex data from computer processes for the development of mathematical and statistical analysis.

d) Collaborative Robotics (CR). It develops robotics systems that can improve processes and activities of daily life, agricultural, commercial, educational and industrial mainly so that they are elaborated in an accessible way and with the required safety.

e) Internet of Things (IT). It refers to a digital interconnection of objects that have a relationship with each other, to improve software development processes.

f) Semantic Web (SW). Represents a series of activities developed in platforms to publish data and information made with high technology systems.

g) Simulations and Predictions (SP). Is related to mathematical and statistical processes to estimate the behavior of parameters to control it and improve the activities of any type.

This research was developed in five micro and medium-sized companies called SME (Small and Medium Industries), from the software industry, with the evaluation of the ipact in the development of software and costs to generate high levels of productivity and quality. The small and medium company is a company that has certain occupational and financial limits located in various regions of the world. The SME are industries with logic, cultures, interests and a specific entrepreneurial.

Industry 4.0

It is considered the fourth transformation of the industry regarding factors of technology, economy and society; where innovations of industrial processes, system, equipment and innovative devices are concentrated, to achieve maximum efficiency in the manufacturing areas and the industrial processes involved in the manufacture of any industrial product (Philip, A et al, 2014). The first stage of the industry occurred with mechanization, followed by the second stage with assembly processes for mass production (Wang, X et al, 2012). The third stage was developed with the application of computing and automation, continuing with the fourth stage with physical cybernetic systems, managing to develop systems with artificial intelligence, with specialized computation algorithms, linking them with digital systems and devices; with the main objective of optimally planning the activities of the production processes in industrial companies. In the Mexicali city and the Baja California State located in the northwest of the Mexican Republic, are a few industries that apply the innovation as industry 4.0 (Lee J et al, 2015).

Computer activities in industry 4.0

They have been applied since the third stage of industrial transformation, for the development of innovations that generate improvements in industrial processes in manufacturing areas, managing to increase productivity and quality indices (Diebold, M. (2014). This is why it has been promoted in higher-level educational institutions (universities and research institutes), in conjunction with industrial companies, anywhere in the world, for the development of innovative systems and devices, as well as methods applied to areas of manufacturing in all industrial processes (Bano, M et al, 2014). Computer systems and programs have been developed to control, count, compare levels, and pack; among the most relevant in the industry of the city of Mexicali considered as part of industry 4.0. One of the actions developed in the industry of this city, is the use of micromemories to control of industrial process and store relevant information (Eghariani K, et al, 2016).

Productivity and Costs

It is an important factor in the agricultural industry that has a great relationship between these terms and with the production processes where economic gains or losses can be determined. Productivity is considered an economic measurement action, managing to calculate goods (products manufactured in industrial companies (Heikkila, V et al, 2015) and services (activities that are offered by companies that provide services to consumers). Figure 4 represents the balance factor of costs and benefits in industrial companies, where productivity and costs are involved for a better understanding of this relevant relationship (Heck P et al, 2016). In productivity, certain aspects are determined such as the number of workers and their skills and abilities, as well as investment capital, production times, distribution and delivery to customers. Productivity is associated with the quality factor, which in turn is related to manufacturing costs and is a relevant aspect in the growth or decline of industries. The link between productivity and quality is essential and is focused on the application of a very strict discipline so as not to generate economic losses, which is associated with cost analysis (Faller C, et al, 2015).

SME industries

Even when microenterprises and small and medium-sized industries form 70% of the industrial system in each region of the world generate a large number of jobs, achieving the production and quality of large industrial companies. The development of productive chains that incorporate companies of different size, giving special attention to small and medium, is an important requirement for the generation of jobs and salaries that reduce the heterogeneity of the economies of the region. A greater internationalization of these companies, particularly in their exporter work, contributes to improving the productivity and working conditions of their workers. The SME are of great importance

in the economy of all countries, generating the software required to increase the productivity and quality of large industries, generating the main reasons for its existence explicated:

a) Individualized products can be made, counterpart with large industries focused on more standardized products.

b) They are very useful at large industries, do0nde Most SMEs are hired by large industrial companies, to carry out services or operations to be included in the tissue of the Great Corporation would result in an increase in cost.

c) There are productive activities where it is more appropriate to work with small companies, such as the case of cooperatives.

d) Innovative products are generated continuously.

2. METHODOLOGY

In this investigation was made various activities, which are shown below, to determine with a specific analysis the impact of use tools of the industry 4.0 in the development of software from the software industry of this border city. This investigation was made in three steps, being the first four steps, about the two tools analyzed (artificial intelligence and the simulations and predictions) and the third step was an evaluation of the impact of the software industry in this border city, which are explained next:

Step 1. An analysis of the use of the artificial intelligence with software developed by specialized programmers was made, making a survey to 1000 persons with diverse factors that are mentioned in the results section. In Mexicali there are specialized researchers and professors of educational institutions; and some people with lot knowledge about theoric of artificial intelligence, but a few people with high experience of this thematic, being very relevant in this scientific study to use specialized programmers from the software industry of this city.

b) Step 2. An evaluation of application of software to make simulations and predictions was made to determine the best software to this tool to diverse activities in this city, with diverse factors that are mentioned in the results section.

c) Step 3. An analysis of the impact of the development by the software industry in this city was made, with diverse factors that are mentioned in the results section.

d) Step 4. An evaluation of productivity and costs of the development of software.

3. RESULTS

The investigation generated important information regarding the use of high-resolution technology using two tools of the industry 4.0, to determine the positive impact of this type of technology, which is mentioned in the next sections.

Regression and correlation analysis

In this investigation, a multiple regression and correlation analysis was carried out, indicating the relationship between the variables involved in the tables that are explained in the following sections of this scientific study. The process of this analysis consisted of two steps: (1) correlation evaluation and (2) development of the mathematical estimation model, to predict the behavior of the variables involved in this investigation. The steps performed in this analysis are shown below:

a) The analysis of the relationship of the variables involved was elaborated.

b) A mathematical model of statistical estimation was generated.

c) An estimation evaluation was made with the objective of estimating in the future the behavior of the variables involved in the investigation or in case of loss of numerical data to be able to recover them.

d) Identify the possible scenarios of the elaborated investigation.

e) Elaborate the conclusions of this step of the investigation.

The normal distribution was used for the regression and correlation analysis, following the statistical process of multiple regression according to the following mathematical expression as equation 1:

$$Y = 0 + \beta 1 X_1^n + \beta 2 X_2^{n-1} + \ldots + \beta n X_n^{n-n} + \varepsilon \qquad \text{Ec. 1}$$

A multiple regression and correlation analysis is shown below in table 1 with a sample of 100 persons to elaborate the mathematical expression, which is expressed now in equation 2 of this investigation:

$$Y = 4/5 X^3 - 6/7 X^2 + 2/3 X - 3/8 \qquad \text{Ec. 2}$$

Table 1 Multiple regression and correlation analysis (2021)

Persons, 100	Independent Variable	Dependent Variable	Correlation Analysis	Difference of Estimation
1	3	4	0.93	-0.20
2	4	5	0.92	0.35
3	2	2	0.95	0.44
4	5	6	0.94	-0.28
5	6	4	0.92	-0.39
:	:	:	:	:
100	12	15	0.90	0.48

In table 1, was observed the multiple regression and correlation analysis, where was illustrated the evaluation in according to each variable evaluated.

Impact of software in the artificial intelligence

In this step of the investigation was made an analysis of the survey elaborated to 1000 persons with various factors and characteristics of people mentioned in the table 2. The level percentages were obtained of the multiple regression and correlation analysis.

Table 2 Analysis of impact in the use of AI (2021)

Factors	Age, %			Economical Aspect, %			Education Level, %			Sex, %	
People Characteristics	18-30	31-45	46-65	L	M	H	L	M	H	F	M
Knowledge of AI	34	48	18	21	40	39	11	35	54	44	56
Importance Level	35	42	23	19	29	52	17	33	50	42	58
Complexity Level	30	44	26	15	30	55	14	28	58	45	55
Relation with Software	39	41	20	23	29	48	18	31	51	47	53

L. Low, M. Medium, H. High; F. Female, M. Male

In table 2, was observed the impact generated in the opinion of the 1000 persons, which were 500 women, and 500 men, representing the percentage levels of the factors and people characteristics; illustrating in the factors the next information:

1) Knowledge of AI. The major age with highest percentage was the 31 to 45 years (48%), being the highest percentage of the economical aspect with the medium level (40%), as the highest percentage of the educative level was the high level (54%) and finally the highest percentage of the sex was the male (56%).

2) Importance Level. The major age with highest percentage was the 31 to 45 years (42%), being the highest percentage of the economical aspect with the high level (52%), as the highest percentage of the educative level was the high level (50%) and finally the highest percentage of the sex was the male (58%).

3) Complexity Level. The major age with highest percentage was the 31 to 45 years (44%), being the highest percentage of the economical aspect with the high level (55%), as the highest percentage of the educative level was the high level (58%) and finally the highest percentage of the sex was the male (55%).

4) Relation with the Software. The major age with highest percentage was the 31 to 45 years (41%), being the highest percentage of the economical aspect with the high level (48%), as the highest percentage of the educative level was the high level (51%) and finally the highest percentage of the sex was the male (53%).

Use of software applied to make simulations and predictions

In this step of the investigation was made an evaluation of the survey elaborated to 1000 persons with various factors and characteristics of people about the knowledge of software to make simulation and predictions illustrated in the table 3. The level percentages were obtained of the multiple regression and correlation analysis.

Table 3 Evaluations of knowledge of the software to make simulation and predictions (2021)

Factors	Age, %			Economical Aspect, %			Education Level, %			Sex, %	
People Characteristics	18-30	31-45	46-65	L	M	H	L	M	H	F	M
Knowledge of Software	43	40	17	25	45	30	27	28	45	43	57
Development of Software	41	39	20	27	41	32	24	29	47	40	60
Application of Software	45	42	13	23	42	35	25	30	45	45	55

L. Low, M. Medium, H. High; F. Female, M. Male

In table 3, was showed the impact generated in the opinion of the 1000 persons, which were 500 women, and 500 men, representing the percentage levels of the factors and people characteristics; illustrating in the factors the next information:

1) Knowledge of Software. The major age with highest percentage was the 18 to 30 years (43%), being the highest percentage of the economical aspect with the medium level (45%), as the highest percentage of the educative level was the high level (45%) and finally the highest percentage of the sex was the male (57%).

2) Development of Software. The major age with highest percentage was the 18 to 30 years (41%), being the highest percentage of the economical aspect with the medium level (41%), as the highest percentage of the educative level was the high level (47%) and finally the highest percentage of the sex was the male (60%).

3) Application of Software. The major age with highest percentage was the 18 to 30 years (45%), being the highest percentage of the economical aspect with the medium level (42%), as the highest percentage of the educative level was the high level (45%) and finally the highest percentage of the sex was the male (55%).

Impact of the development by the software industry

An analysis of the impact that generates the development of software, where were evaluated five software industries located in the Mexicali city. In table 3 is presented the information obtained by the multiple regression and correlation analysis, illustrating the level percentages.

Table 4 Analysis of impact of development of software in the software industry of Mexicali (2021)

Software Skills Industries	Ability to Develop Software, %			Fast to Develop Software, %			Efficiency to Develop Software, %		
	L	M	H	L	M	H	L	M	H
A	17	41	42	13	38	49	14	42	44
B	19	39	42	16	40	44	18	38	44
C	15	40	45	17	40	43	15	42	43
D	19	38	43	15	37	48	17	35	48
E	17	40	43	17	39	44	16	41	43

L. Low, M. Medium, H. High; F. Female, M. Male

In table 4, was observed the impact of the software skills of the programmers that generate the idea to develop the software in base of the requirements of the customer. The analysis in the five industries that develop software in this city is represented now:

1) Industry A. In this industry is showed the percentage levels to the three software skills, where is observed that was classified by indices low, medium and high being presented the major as the high index from 40% to 50%, indicating that in this industry the ability of develop of software, fast to develop software and the efficiency of the develop of software, are relevant factors to create software made by the programmers.

2) Industry B. In this industry is showed the percentage levels to the three software skills, where is observed that was classified by indices low, medium and high being presented the major as the high index from 40% to 50%, indicating that in this industry the ability of develop of software, fast to develop software and the efficiency of the develop of software, are relevant factors to create software made by the programmers.

3) Industry C. In this industry is showed the percentage levels to the three software skills, where is observed that was classified by indices low, medium and high being presented the major as the high index from 40% to 50%, indicating that in this industry the ability of develop of software, fast to develop software and the efficiency of the develop of software, are relevant factors to create software made by the programmers.

4) Industry D. In this industry is showed the percentage levels to the three software skills, where is observed that was classified by indices low, medium and high being presented the major as the high index from 40% to 50%, indicating that in this industry the ability of develop of software, fast to develop software and the efficiency of the develop of software, are relevant factors to create software made by the programmers.

5) Industry E. In this industry is showed the percentage levels to the three software skills, where is observed that was classified by indices low, medium and high being presented the major as the high index from 40% to 50%, indicating that in this industry the ability of develop of software, fast to develop software and the efficiency of the develop of software, are relevant factors to create software made by the programmers.

Evaluation of productivity and costs of the development of software

An evaluation of a comparative situations with the use or not use specialized software developed by the software industry of this city, showed relevant information to determine that is necessary the creation of software by specialized programmers to increase the productivity of the development of software and its use in any type of activity and reduce the costs to this important process. In table 5 is represented the information mentioned above.

Table 5 Evaluation of productivity and costs the software industry of Mexicali (2021)

Software Characteristics	Productivity, %		Costs, %	
Industries	Without Software	With Software	Without Software	With Software
A	30	70	66	34
B	32	68	67	33
C	28	72	70	30
D	34	66	69	31
E	30	70	71	29

In table 4, was observed the percentage levels of productivity and costs, where was illustrated the difference of use specialized software and not use, and presented around the double of the percentage levels between one characteristic and other, as is explained in the next information;

1) Industry A. In this industry is showed the percentage of the productivity evaluating the not use the software with 30% and the use with 70%, and the costs when is no use the software of 66% and 34% using the software, indicating the necessity of the utilization of specialized software.

2) Industry B. In this industry is showed the percentage of the productivity evaluating the not use the software with 32% and the use with 68%, and the costs when is no use the software of 67% and 33% using the software, indicating the necessity of the utilization of specialized software.

3) Industry C. In this industry is showed the percentage of the productivity evaluating the not use the software with 28% and the use with 72%, and the costs when is no use the software of 70% and 30% using the software, indicating the necessity of the utilization of specialized software.

4) Industry D. In this industry is showed the percentage of the productivity evaluating the not use the software with 34% and the use with 66%, and the costs when is no use the software of 69% and 31% using the software, indicating the necessity of the utilization of specialized software.

1) Industry E. In this industry is showed the percentage of the productivity evaluating the not use the software with 30% and the use with 70%, and the costs when is no use the software of 71% and 29% using the software, indicating the necessity of the utilization of specialized software.

4. CONCLUSIONS

The use of specialized software is very relevant using the tools of the industry 4.0, where are software industries located in the city of Mexicali, which is a great advance to the processes of the development of software. This has helped to receive more industrial companies from our neighbor Mexico, and generate more job opportunities for the population of this city. In this research, the need to use high resolution technology was shown, with the use of specialized micro-memory to increase productivity and quality levels. This investigation expressed relevant information to researchers to obtain adequate information as represented the knowledges to they. Also, this analytic investigation can be support to people to want earn money and help to be easy any kind of actions of the daily life and to any type of activities.

5. REFERENCES

[1] Bourque, P., Fairley, R. (2014). "Guide to the Software Engineering - Body of Knowledge (SWEBOK)", Version 3.0, IEEE Computer Society, 2014.

[2] Diebold, M. (2014). "Agile practices in practice: a mapping study", in: Proceedings, 18th International Conference of Evaluation. Assessment Software, England. (EASE 14), 30, pp. 10.

[3] Ervural, B. (2018). Overview of Cyber Security in the Industry 4.0 Era. In Industry 4.0: Managing the Digital Transformation and MEMS, Technology Journal, Vol. 4, No. 2, pp 267-284.

[4] Eghariani K, Kama N (2016) "Review on Agile requirements engineering challenges", in: 2016 3rd International. Conference of Computer Information Science, 2016, pp. 507-512.

[5] Faller, C., Feldmüller, D. (2015). Industry 4.0 learning factory for regional SMEs and MEMS. Procedia CIRP, Vol. 5, No. 2, pp 88-91.

[6] Fujii, T., Guo, T., Kamoshida, A. (2018). A Consideration of Service Strategy of Japanese, Electric Manufacturers to Realize Super Smart Society (SOCIETY 5.0). In International Conference on Knowledge Management in Organizations, pp. 634-645.

[7] Geissbauer, R., Vedso, J., Schrauf, S. (2015). Industry 4.0: Building the digital enterprise and evaluating the costs, Industry, Technology and Economy Journal, Vol. 8, No. 5, pp 27-40.

[8]   Heck, P., Zaidman, A. (2016) "A systematic literature review on quality criteria for agile requirements specifications and costs", BookChapter, Springer, US, 2016.

[9]   Heikkila, V., Damian, D., Lassenius, C., Paasivaara, M. (2015) "A mapping study on requirements engineering in agile software development and costs", 1st Euromicro Conference Software Engineering Advances. Applications, 2015, pp. 199-207.

[10]   Inayat, S., Salim S., Marczak M., Daneva S. (2015) "A systematic literature review on agile requirements engineering practices and challenges", Computer Human Behavior Journal., 51 (2015).

[11]   Kenneth, A., Hendrickson, P. (2016). Toward realization of the new economy and society, Journal of Computer Science, Vol. 12, No. 8, pp 44- 56.

[12]   Lee, J., Bagheri, B., Kao, H. (2015). Cyber-physical systems architecture for industry 4.0-based manufacturing systems,. Manufacturing, Computer and Technology Journal, Vol. 3, No. 1, pp 18–23.

[13]   Medeiros, J., Alves, D., Vasconcelos, A., Silva, C., Wanderley, E. (2015) Requirements engineering in agile projects: a systematic mapping based in evidences of industry, in: CIBSE 2015 - XVIII Ibero-American Conference of Software Engineering, 2015, pp. 460-473.

[14]   Medeiros, J., Goulao, M., Vasconcelos, A., Silva, C. (2016) "Towards a model about quality of software requirements specification in agile projects and MEMS", in: 2016 10th International Conference Quality Information and Communication, 2016, pp. 236-241

[15]   Monostori, L. (2014). Cyber-physical production systems: Roots, Expectations and Technology Systems, Journal, Vol. 11, No. 7, pp 18-34.

[16]   Penprase, B. (2018). Higher Education in the Era of the Fourth Industrial Revolution, Computer Science Journal, Vol. 8, No. 3, pp 47-62.

[17]   Philip, A., Ali, S., Roliana, I., Mohd, N. (2014) A systematic literature review of software requirements prioritization research, Information and Software Technology, 56 (6), June 2014, Pages 568-585.

[18]   Wang, X., Conboy, K., Cawley, O. (2012) "Leagile software development: an experience report analysis of the application of lean approaches in agile software development", Journal of Systems Software, 85 (1), pp 1287-1299.

[19]   Wohlin C (2014) "Guidelines for snowballing in systematic literature studies and a replication in software engineering", in Proceedings of the 18th International Conference on Evaluation and Assessment in Software Engineering, EASE14, 2014, pp. 38.