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USE OF NOVEL FMEA METHOD IN THE MANUFACTURING PROCESSES OF ELECTRONICS INDUSTRY IN ARID ENVIRONMENTS

Elizabeth Romero Samaniego[1], Sandra Luz Toledo Perea[1], Margarita Cervantes Trujano[1], Gustavo López Badilla[2], María Marcela Acosta Gómez[2], Karina Cecilia Arredondo Soto[3]

[1]*Tecnológico Nacional, Instituto Tecnológico de Ensenada, Ensenada, Baja California, México.*

[2]*Tecnológico Nacional, Instituto Tecnológico de Mexicali, Mexicali, Baja California, México.*

[3]*Universidad Autónoma de Baja California, Tijuana Baja California, México.*

Abstract: *In this study was used a novel FMEA method called VEGAM matrix that was designed and applied to this investigation and was made from 2015 to 2016 in an electronics industry of the Mexicali city, which is considered an arid zone of the northwest of the Mexican Republic. The novel method was applied in the manufacturing processes where occurred some failures of industrial equipment and machinery and some errors of workers that affect the quality of manufactured products in this company evaluated. With the novel method, was very fast and easy found the causes and effects of failures. The manufacturing processes evaluated contain automated and manual operations, which included the manner of make the functions in each step. The manufactured products evaluated of the electronic industry analyzed were electronic boards to an automated system used in the automatic pilot of aircrafts and if this electronic board have failures can generate a catastrophic event.*

Keywords: FME method, VEGAM matrix, manufacturing processes.

INTRODUCTION:

The FMEA method is very used in industrial activities, where are evaluated all operations with specialized people and specific functions, to detect very fast some causes and effects that generates a disequilibrium in the manufacturing processes and with this decreases the quality of products manufactured and decreases competitiveness in the industries[1]. This originates loss of customers and some companies company's trends to decrease its capacity of sales and decreases its personnel being necessary the layoffs, where some people cannot have a job and create a conflict in the economy of a society. With this information was made a study in an electronic industry located in the Mexicali city where the climatic and pollution parameters, have an influence in some specific industrial operations because generates harsh environments in indoors of the majorly of industries located in this city[2]. In this study some specialized industrial equipment and machinery were failing and people was working with some disturbs because was seek of respiratory diseases diminish its capacity of productivity. For this reason, an information from the analysis was collected to design a novel technique to detect very fast and easy the industrial equipment and machinery and people that make a lot errors generating the rework and with this economic losses[3]. The novel technique supports all manufacturing processes being necessary in this industry and can be to other type of industries if this city and other cities of Mexico.

Systems of FMEA method:

The three types of systems of FMEA method used in this investigation are listed below[4]:

1. **System FMEA method (S-FMEA).** It was used to obtain an assurance of the compatibility of the system to evaluate where each part of the system is analyzed in order to know in detail each operation of the manufacturing process and can be evaluate, if is possible the necessity of any change.

2. **Design FMEA method (D-FMEA).** It is used with the aim of knowing in great measure how to design the design of a manufacturing process, the design of the product or service to be granted to the customer to improve every time about the time of production, quality and quantity of products manufactured.

3. **Process FMEA method (P-FMEA).** It is used for the purpose of analyzing in detail each section of the manufacturing processes that are required in the manufacture of the products or provision of services to be used by the customers to obtain the maximum satisfaction of the customers. The following diagram shows what was explained above to determine the actions to be followed in the FMEA method:

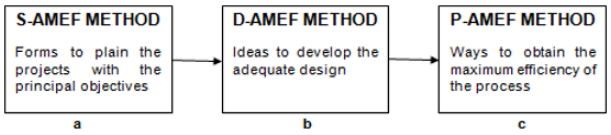

Figure 1: Squematic diagram of the sections of the FMEA method

The FMEA system of Figure 1a is used to ensure the compatibility of the system components to develop the activities in a synchronized way that can generate the right conditions to elaborate the industrial activities in a coordinated way, defining each part of the system in detailed form. The FMEA design of Figure 1b is used to analyze each section of the design of a manufacturing process, product to be manufactured or service to be granted to customers, always achieving the maximum performance in its operation. The FMEA process of Figure 1c is used to determine each component of any manufacturing process that is required for the manufacture of manufactured products and services to be granted to customers. The S-FMEA method is used to analyze the detailed composition of the system components. Focused on failure modes associated with the functionality of a system component or the entire system, caused by the operation of these. It also evaluates the subsystems of the product or service to achieve improvements that have a better satisfaction for the customer5. D-FMEA is part of the channels for the execution of optimum design that leads to the reduction and / or elimination of failures that could arise in the operation of the manufactured product or the service to be granted to the customers with the maximum efficiency. In this section the weaknesses of the design must be overcome and possible uncontrolled parameters such as meteorological and environmental variables, as well as human and economic capital should be evaluated. The P-FMEA is used to analyze the processes of manufacture, assembly or installation. It focuses on the inability to produce the required requirement, analyzing the failure modes that can be derived from causes identified D-FMEA. You can also assume that the product according to the design will fulfill its final intention in the manufacturing processes, as well as evaluate each process and its respective elements, used process analysis and transitions[4].

Applications of the FMEA method:

The FMEA method can be applied in the following ways[3]:

- In very complex process.
- Used in new products or services when are being designed.
- To a new a process created, improved or redesigned.
- In new forms of products, services or processes or new environments.
- To improve S-FMEA, D-FMEA and P-FMEA.

Determination of degree of severity:

To estimate the degree of severity is used the scale to determine the effect of the failure on the customers, using a scale of 1 to 10 where 1 indicates the consequence without effect, and 10 indicates the consequence a serious problem. In the next table is described the levels of the severity grade[6].

Table 1: Grade of satisfaction of customers

Effect	Range	Grade of Satisfaction	Criterion
No effect	1		Product or service with good function and without a negative effect, and customer without any claim
Very little	2		Product or service with a little negative effect, and customer with some discomfort
Little bit	3		Product or service with a little negative effect and customer little annoyed.
Less	4		Product or service with some moderate negative effect, and customer dissatisfied.
Moderate	5		Product or service with some moderate negative effect, and customer dissatisfied and annoyed.
Significant	6		Product or service with some negative effects affected in its function, but is operable and safe, with a partial failure but is operable, and customer with claim.
Higher	7		Product or service is affected with a serious negative effect but is operable and safe, and customer is very dissatisfied.
Extreme	8		Product or service is inoperable but safe, and customer is very annoyed.
Serious	9		Product or service has a high negative effect with a potential danger, being able to discontinue and not to be used, depending on the failure without function. It complies with the government regulations on risk, and customer possibility of demands to the manufacturer or service provider
Danger	10		Product or service with dangerous effect without function, with failures to comply with government regulations, and customer demands to the manufacturer or service provider

Source. Information of the study

Table 1 shows the manner of the satisfaction of customers that are important in a company of institution of activity services as part of its economy. In the world are a lot countries including Mexico where are using the operation services as public activities as educational services and government services, touristic services and engineering services of small, middle and big companies as private services. In table 1 can observe the grade of satisfaction of clients and make a measure of the quality of the services principally that is evaluated in this study.

Manufacturing processes:

Any type of industrial process is an important step of specific activities, which a specific goal achieved that develop specialized industrial operations. In the industrial engineering the concept of process us very important, for the application in industries[7], that requires the next steps:

1) Design a specific plain to develop each manufacturing operations integrated.
2) Organize the manufacturing operations with the optimal yielding.
3) Control all parameters involved in the manufacturing processes.

These activities allow to the industrial engineers achieve their objectives in the exercise of their profession, and must consider the production processes as a tool to:

a) Design and definition the manufacturing plains, programs and projects.

b) Design, integration, organization, management and control the parameters involved in each manufacturing processes.

c) Optimizing the work of the industrial activities.

d) Analyze the evaluation of results.

e) Establishment of quality standards.

f) Increasing and controlling efficiency

This support principally to evaluate the services engineering of indoor and outdoor services applied with the FMEA of a small company to the big electronics industry[8]. About the manufacturing process, can be designed with two definitions given:

1. Place to work done by hand or with the help of a machine.
2. Place where it is made as manual operations.

Climatic and environmental factors:

Mexicali is one of cities of the Mexican Republic with large contamination and its was be informed about its poor air quality in outdoors and indoors of industries, to government authorities in the city and the state to this city, in combination with people of Mexicali, can`t make anything to avoid the poor air pollution principally in indoors of industries. This complicates some specialized industrial operations, because the principal air pollutants (SO_2, as sulfur dioxide and NOX, nitrogen oxides), in this city evaluated from 20 years ago and have a principal effect, damaging metallic materials essentially, generating people seek and industrial equipment and machinery with failures, causing low productivity yielding[9].

Electronics industry in Mexico:

The electronics industry was born in our country during the sixties with the manufacture of electronic products as radios, phonographs and televisions. In the seventies the development decreases for the diminution of the external competition. In 1986, Mexico was added to the General Agreement on Tariffs and Trade (GATT) to restructure the electronics industry in our country (Lopez B. Gustavo, 2011).

In 1994 Mexico signed the North American Free Trade Agreement (NAFTA) with Canada and the United States and with this the electronics industry was a very important source of the Mexican economy. In the nineties, some transformations are made in the electronics industry with the NAFTA. With this occurs the installation in Mexico of global and national companies. This industry acquired great importance in the electronics plants to export electronic products and generate employments[10]. In this industry is necessary maintain environments in indoors with good conditions because if exists harsh atmospheres, can generates damage in the metallic parts of electrical connections of electronic and electrical devices and systems, causing low productive yielding and with this defective products manufactured.

Steps of manufacturing industry evaluated:

The manufacturing process evaluated consists of ten stages where different factors were analyzed in the different sections from the storage and delivery process of the materials for the automatic insertion area to the activity of the electrical test of the electronic components installed in the electronic boards9. Each stage evaluated is explained below:

1) Warehouse (Step 1). It is evaluated whether the materials received from the shipping area that receives the raw material from the company where the research was developed, coming from different suppliers located in foreign territory to the Mexican Republic, because it is a foreign company that depends on its parent company. The evaluation consists in determining if the raw material that are the electronic components at macro or micro level is damaged by the effect of the external atmospheric corrosion from the suppliers or are damaged by this same phenomenon inside the analyzed company.

2) Manufacturing process with automated operations (Stages 2, 3, 4 and 5). Analyzes are developed to evaluate the installation of microelectronic components with an automated system of microcomponents that are mentioned below:

   a) Installation horizontally on top of the board.

   b) Installation vertically on top of the board.

   c) Install horizontally on the bottom of the board.

   d) Installation vertically on the bottom of the board.

3) Manufacturing process with manual operations (Stages 6, 7, 8 and 9). Analyzes are developed to evaluate the installation of electronic microcomputers with a manual installation method of the macrocomponents mentioned below:

   a) Installation horizontally on top of the board.

   b) Installation vertically on top of the board.

   c) Install horizontally on the bottom of the board.

   d) Installation vertically on the bottom of the board.

4) Electrical test evaluation (Step 10). Electronic boards with microdevices and macrodevices are evaluated and the percentages of products of good and poor quality are determined.

VEGAM matrix:

Is an alphanumerical matrix used to evaluate sections of areas required to determine by quadrants the location of components or devices of any type[10]. The VEGAM matrix is explained below:

A) **VE (Veer).** It represents the section observation process to observe the parts quickly and analyze the activities of interest.

B) **G (Guiar).** Indicates the way to evaluate the sections guided by the established alphanumeric matrix.

C) **A (Analizar).** It is part of the analysis to quickly detect sections that can generate failures or be different in an activity of interest.

D) **M (Mejorar).** It represents the way to improve easily and quickly, the improvements to be elaborated in the activities of interest evaluated with the alphanumeric matrix.

In the case of the electronics industry, it can be used to determine sections of electronic boards with the aim of detecting electrical failures and defective electronic components and determining which electronic boards are in operation and not functioning and which is easier and faster to detect the damaged sections. The electronic boards are divided into a maximum of ten sections classified with the alphanumeric system (letters A to J and numbers 0 to 9, interlaced with each other, in the form of a numerical matrix). This system has been applied in various analyzes in the electronics industry when evaluating the presence of corrosion and its effect on the functionality of electronic components of electronic boards in activities of detection of electrical faults, rework of electronic boards to locate defective electronic components to be Replaced by electronic devices in good condition. The VEGAM technique has been tested on several occasions and can be used not only for the electronics industry but for any other educational, medical, space, aerospace, marine, submarine, livestock and agricultural industries or activities. The analysis of electronic boards in the electronics industry generates costs and it is necessary to evaluate those equipment and machinery when they are in operation, reason why it is necessary to stop its operation[9]. This can reduce the operational performance of equipment and machines of industrial plants. When this happens, salaries are stagnant and economic profits are not generated, and there is nonconformity in the operational, specialized and managerial personnel. The VEGAM matrix is shown in figure 5, as an example of an operation analysis of an electronic board of an industrial system.

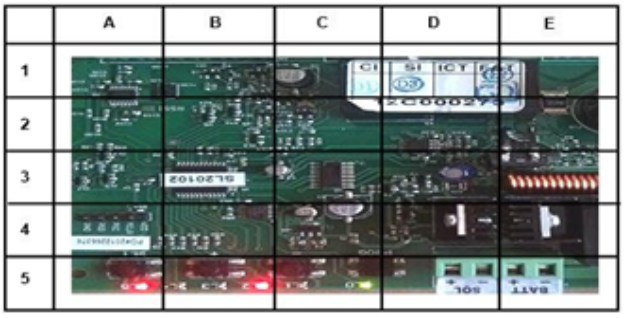

Figure 2: Analysis of functionability of electronic board with the VEGAM matrix

(Invented by Dr. Gustavo Lopez Badilla- Specialist in corrosion and materials in the electronics industry and applied to other type of industries)

Figure 2 shows the sections divided as alphanumerical matrix from A to E letters and 1 to 5 numbers to detect very fast and easy the electrical failures in the electronic board that not have good functionability. This was made with the AFEM method used in this investigation. This VEGAM matrix used before in the detection of electrical failures in electronic boards was applied to each step of the manufacturing processes of the electronics industry evaluated.

Numerical simulation:

The evaluation of numerical data was made with the MatLab software that was applied to analyze the mathematical information with simulations and statistical methods used in the evaluation of the manufacturing processes[11].

METHODOLOGY:

An analysis of FMEA in the electronics industry of Mexicali city was made, where were manufactured some defective products from 2015 to 2016 and consisted in ten steps as mention now:

1. Specific evaluation of the ten stages of the manufacturing area analyzed being three with warehouse activities (step 1), automated operations (steps 2 to 5), manual operations (steps 6 to 9) and the electrical test as the final stage (step 10).
2. Analysis of manufacturing processes.
3. Correlation of corrosion, climatic and environmental parameters in the manufacturing processes.
4. Evaluation of damaged electronic boards of industrial machinery and equipment with the VEGAM matrix.

RESULTS:

The use of novel FMEA method with the VEGAM matrix improved the manufacturing processes and quality of the electronics industry evaluated. The quality increase from 70% to 90%, and avoid the economic losses that was presented before the investigation. In base of this were made the analysis required that are explained next.

Evaluation of manufacturing stages:

The analysis of the functionability of industrial machinery and equipment are represented in table 1, where is illustrate the failures of different mode, the causes and the effect of each failure analyzed of 2015 and 2016. The FMEA method supports to evaluate the total information of each step of the manufacturing processes and organizes it, to observe better the occurrence of failures of industrial equipment and machinery and errors of people and change some factors to increase the quality of the manufactured products. The investigation illustrated the most typical failures of industrial equipment and machinery of electronic and electrical type principally, with automated functions composed of electronic macro and micro devices. Once the analysis of the most common failures was elaborated, the causes of the failures were determined and was made a proposal of immediate solution to elaborate the continuous improvement. The elaborated improvement consisted in the timely detection of failures of the industrial equipment and machinery and errors of operators that works in the manufacturing processes evaluated. The failures originate poor functionality of industrial equipment and machinery automated with electronic components of the manufacturing processes evaluated. Poor functionality generated defective products and late delivery times, being necessary the rework and economic losses. With the improvement made, there was a decrease in the unproductively times of 25% and reduces the application of the preventive and corrective maintenance programs. In the industrial activities are used a lot methods and techniques to the manufacturing processes and every time are utilized new models of these, based in other operations[1].

Table 2. Analysis of failures of industrial equipment and machinery in the manufacturing processes evaluated (2015 y 2016)

EFIM							
2015				2016			
Steps	**PFM**	**PEF**	**PEC**	**Steps**	**PFM**	**PEF**	**PEC**
1	X	X	1	**1**	X	X	1
2	1	1	1,2	**2**	1	1,2	1,3
3	1	1	2	**3**	1,2	2	1
4	1	1,2	3	**4**	1	2	2
5	1,2	2	2,3	**5**	1	2	1
6	1	1	2	**6**	1	1,2	1,2
7	1	1	3	**7**	1,2	1	1
8	1,2	1,2	1,2	**8**	1	2	2
9	1	2	2	**9**	1	1	1
10	2	1,2	2	**10**	2	2	2

EFIM. Electrical Failures in Industrial Machinery (one of each step);
PFM. Potential Failures Mode: 1-FIED.Failure in the Installation of Electronic Devices; 2-FTED. Failure in the Test of Electronic Devices.

PEF. Potential Effect of Failures: 1-PMF. Product Mal Function; 2- PNF. Product no function

PEC. Potential Failures Causes: 1-EDRPC. Electronic Devices Received in Poor Condition; EDDMP. 2-EDDMP. Electronic Devices Damaged in the Manufacturing Processes, 3-DED. Defective Electronic Devices.

X. Not apply.

In table 2, is showed the evaluation of the failures expressed by codes, depending of the type of failures, steps, causes and effects. In 2015 the principal failures in the potential effect mode was the option 1, which mention about the failure in the installation of the electronic devices in the electronic boards manufactured, being necessary detect very fast and easy with the VEGAM matrix, the spaces without electronic devices in the electronic boards, for the failures of installation of the industrial machinery of the industry evaluated. About the potential failures effects the main was option 1 as same the last factor, illustrated the product mal function, for be manufactured as a defective product. And the last factor evaluated was the potential failures causes where the main failures were the option 2 that represents the electronic devices damaged in the manufacturing processes for failures in the industrial equipment and machinery and errors of operative people.

Analysis of manufacturing processes:

After the evaluation of the failures of the automated and manual operations, was made an analysis of the quantity of industrial machinery that is more than industrial equipment in the manufacturing processes. This information is illustrated in figures 3 and 4 to 2015 and 2016 years evaluated. Figure 3 shows the analysis of defective products and quantity of industrial machinery and people used in the manufacturing processes in the analysis of 2015. As shows in this graph, the quantity of defective products was until 600 in average with evaluations in months, being a great quantity that decreases the competitiveness of the electronics industry analyzed. The quantity of industrial machinery was around 36 and people 90. In base of this in 2016 was applied the novel method of FMEA with the VEGAM matrix and the manufacturing processes improve and the quantity of defective products diminish and the

competitiveness of this company evaluated increase. The defective products in 2016, were 210 and with a reorganization of the manufacturing processes area, decrease the industrial machinery used to 30, but people was the same quantity.

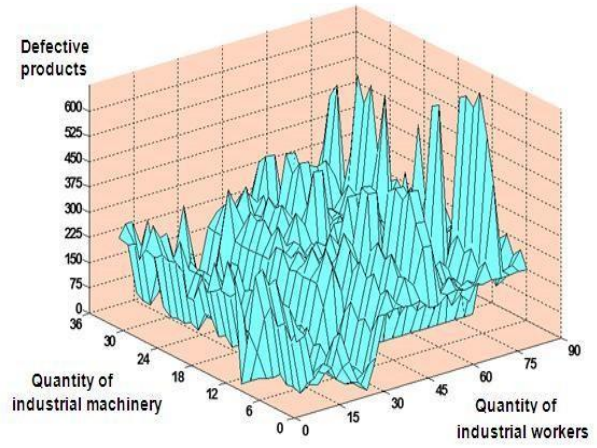

Figure 3: Productive yielding in manufacturing processes before use the VEGAM matrix in average at month (2015).

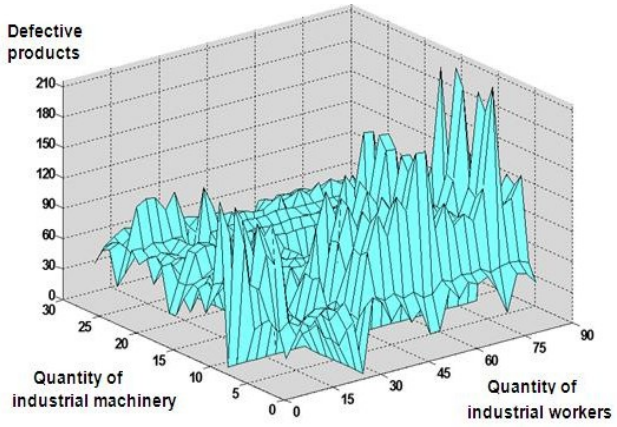

Figure 4: Productive yielding in manufacturing processes after use the VEGAM matrix in average at month (2016).

Correlation analysis:

In the correlation analysis was observed some different areas of the figures 5 y 6, where was illustrated the three principal colors as orang, blue and green representing the percentage of the quality level, being the orange color the low level of quality and the green color the high level of this factor. The analysis of both years (2015 and 2016), were in periods of six months in 2015, because the company need avoid the increase of defective products and was necessary support to the 2016 year, to diminish the defective products. In figure 5 that represents the analysis of the 2015, the orange color was presented in the month 3 with a high intensity with around 500 defective products and 40% of quality level. In change the blue color was presented from month 1 to month 5, being the major intensity in months 3 and 4, with 100 to 200 defective products with 50% of quality level. The green color in this figure was represented higher quality level with 60% quality level and observed in months 1 to 2 and months 5 to 6 with a low intensity.

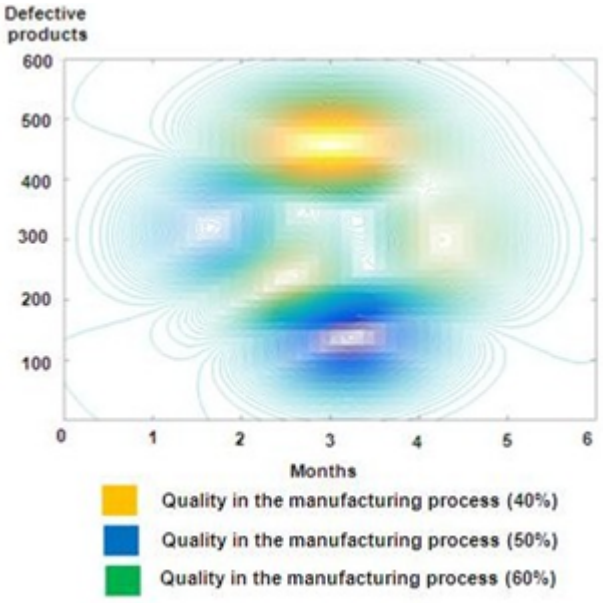

Figure 5: Correlation analysis of productive yielding by monthly periods (2015).

Figure 6 represents the same analysis of figure 5, but to the 2016 year, where the manufacturing processes was reorganized, and the quantity of defective products was decreased, being 360 as a the maximum value. With the VEGAM matrix was detected the majorly of the failures of industrial equipment and machinery and errors of people and was applied new strategies to reorganize the manufacturing processes.

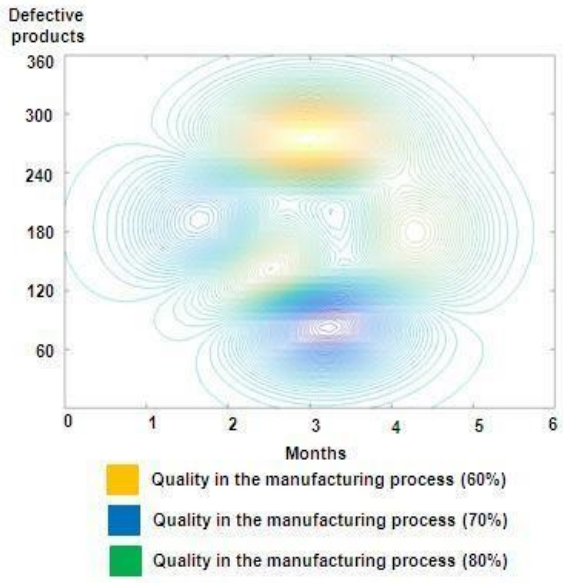

Figure 6: Correlation analysis of productive yielding by monthly periods (2016).

Evaluation with the VEGAM matrix:

The use of the VEGAM matrix applied in a layout of the manufacturing processes evaluated, was very important because was detected very fast the electrical and mechanical failures of the industrial equipment and machinery where were the zones of the manufacturing processes evaluated. In this area was the auto insertion zone where were 10 automated industrial machinery to install electronic devices in electronic boards. Other zone, which is presented low quality, was the manual operations zone where were 50 workers that install high power and electrical components added to the electronic boards made in the auto insertion zone. In this zone also was installed the cabinet and all type of electrical wires to send to the test zone. In this zone was made the final test of the electronic system fabricated in this part of the industry evaluated. Also the layout shows offices of supervisors, manager and people of support of manufacturing processes. In the final zone of this area, was the shipments zone where was located the final product of this manufacturing area to send to other areas to finalize the product and send to the customers.

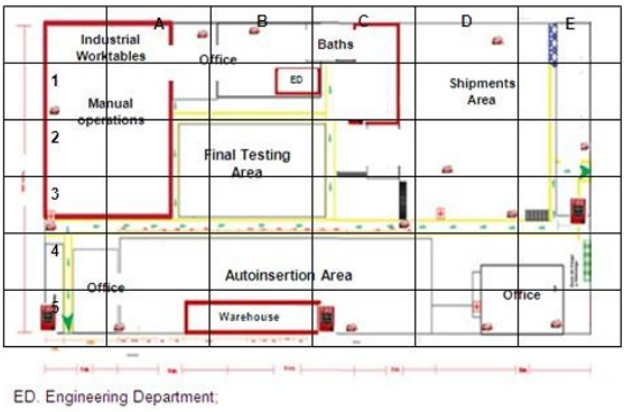

Figure 7: Evaluation with the VEGAM matrix of the manufacturing processes (2016).

CONCLUSIONS:

The application of the VEGAM matrix as a novel method was very important to evaluate and detect very fast and easy the electrical and mechanical failures of the industrial equipment and machinery, and the errors of workers, to decrease rapidly it and avoid rework and also economic losses by expenses not considered. The industry evaluated shows some problematic situations, where were analyzed some manufacturing processes step by step from 2015 to 2016, with a strict evaluation. The errors and failures were analyzed each one to detect very fast the causes and consequences and was talking with operative workers, supervisors and maintenance of industrial equipment and machinery, by some periods of the investigation, to shows the risks of lost customers by defective products manufactured. And also was apply some strategic methods to improve the manufacturing processes, and with this were reduce the errors of the operative workers and the electrical and mechanical failures of the industrial equipment and machinery of the industry evaluated. With the use of the VEGAM MATRIX, the quality in the manufacturing processes analyzed increased from 50% to 80% and with this the competitiveness.

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