Production Line Improvement Using DMAIC Tool in an Electrical Production Plant

Jessuelly E. Díaz Marrero
Manufacturing Engineering
Rafael Nieves, Pharm. D.
Industrial Engineering Department
Polytechnic University of Puerto Rico

Abstract-*Today, there is much competition between the manufacturers of electronics products. This creates a need for the manufacturers to develop processes that can supply the client demand within a required time and a specified quality. The studied production line had productivity problems, since it was never able to reach the 95% productivity level established by the company, and had a backorder cost of $26K. These factors affected the availability of products required by the customer. Using the DMAIC tool the main factors that affected the production output were properly identified to correct the problem of a production line that did not meet adequately the client demand. The initials stand for: Define Measurement, Analyze, Improve and Control. As a result of working with causes affecting the productivity problems of the studied area, the productivity was increased from 85% to 96.7% and Backorder costs were reduced to $4,300.*

Key Terms*: DMAIC, Sub. assemblies, Molding Parts, 5'S.*

INTRODUCTION

This project was conducted at a manufacturing plant of electronic products in Vega Baja, P.R. The project focused on one of the lines of manual production consisting of various work cells of a variety of products. At the present time, the company operates through multiple manufacturing divisions and subsidiaries located in North America, Puerto Rico, Mexico, Italy, Switzerland, and the United Kingdom. In Puerto Rico, the company has the only plant in the Caribbean. This company is located in Vega Baja. The Company has been an integral part of the growth of the electrical equipment industry, and is a pioneer in the development of new products and technologies.

The Vega Baja division is composed of four plants and a shipping area, two of which are in charge of supplying components to the rest of the final product plants.

MANUFACTURING PROCESS OF ELECTRICAL PRODUCTS

The area that was analyzed is located in the final product plants. This area is composed of seven cells of production, a storage area, and a sub-assembly production (see Figure 1).

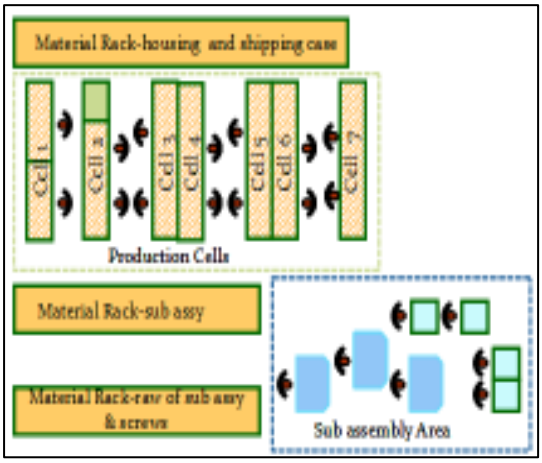

Figure 1
Layout of Area

Each production cell has a variety of products, classified by its similarity in components, the assembly process, and the complexity of the operation. In each production cell there are two operators working. The electrical products are used to connect industrial or commercial high voltage machines. Its basic components are Housing (the plastic covering of the internal parts), three sub-

assemblies, final screws (to shut the product), and final individual packaging (see Figure 2).

Figure 2
Parts of Product

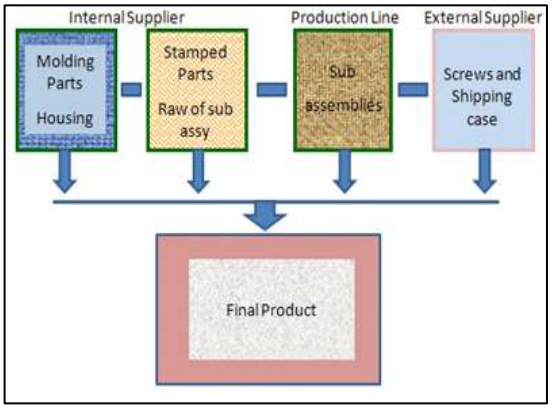

Figure 3
Product Suppliers Diagram

The components for these products are supplied by external as well as internal suppliers. The molded parts, referred to as housing, are supplied internally by plant A. Plant A has diverse machines that mold different parts for all the final products plants. The machines are grouped by molding, type of resin, and the color of the desired product. The internal parts of the final product are also supplied internally. These parts are provided by plant B. Plant B has machines dedicated to different parts by size and material. Final screws, as well as the packaging of the final product are provided by different external suppliers. Finally, the sub- assemblies are produced in the same area (see Figure 3). This sub-assembly area has various machines, each machine supplying the sub-assembly needed in the production cells.

Backorder is defined by the company as the additional cost to the company for not having the product available once the client has requested it. As days pass, and the availability of the product is zero, the cost continues to increase, until the order by the client is completed. Sometimes, partial orders are completed, nevertheless the backorder cost continues to increase until the full order is completed and shipped to the client.

In order to calculate the productivity of a cell area, and how much personnel is needed, a report is analyzed with the plant manager which offers information on total orders, compared to the work hours required. This report is published by the Finance Department, to determine the productivity of the area, and how much personnel should be reassigned to other cell areas, or how much additional personnel is needed to supply the demand of the cell area.

SIX SIGMA DMAIC METHODOLOGIES

Today, Six Sigma can be defined in two levels: operational and managerial. In the operational level, statistical tools are used to measure the variability of the process, and to identify the defects. Six Sigma seeks to perform improvement projects in order to visualize the opportunities and achieve great impact in areas or business. This performance of improvement projects is known as DMAIC (Define-Measure-Analyze-Improve-Control). Each initial represents a phrase, which is defined as follows:

- *Define* – in this phase, the requirements of the client are defined, seeking to understand which processes are affected.
- *Measure*- this phase consists of measuring the actual process performance to be improved.
- *Analyzed*- in this phase the analysis of the information collected is conducted to determine the root causes of the defects, and the improvement opportunities.
- *Improve*- solutions are designed that will determine the root cause, and that will also fulfill the expectations of the client. The implementation plan is also developed.
- *Control*- Once it is ascertained that the solutions work, it is necessary to implement

controls that will insure that the process will remain in its new course.

Six Sigma DMAIC was used in the development of this project, and each phase to be developed was properly defined. The data was observed retrospectively in order to compare the existing problem with the results obtained once the improvements were implemented. The data was taken from the October to December quarter of 2009.

Define Phase

In this phase, a description was made of the project and the problem statement was defined. A cause and effect diagram was used in order to find out those variables that affect the area of production. Another diagram that was used is the SIPOC diagram (Supplier-Input-Process-Output-Customer) in order to have a better idea of the process from the suppliers to the clients. Another tool for this phase is Voice of Customer in order to know the needs and expectations of the client concerning the product or service offered by the company.

Measure Phase

In this phase the method by which the data is collected was defined in order to know the process. A Pareto Chart was used to identify the most significant factors that prevent clients from receiving their products. A Pareto Chart was used to identify which suppliers and which product is the most affected, thus creating a backorder. A Failure Mode and Effect Analysis (FMEA) were used to focus on what was affecting the product, and to identify the areas of opportunity for improvement.

Analyze Phase

In this phase, the results of the data collected were analyzed to identify the opportunities that achieve the improvement of the process. The results obtained from the Pareto Chart were used to identify the supplier that affects the process of production the most. Also, a Pareto Chart was used to identify which components have not been available at the time the client requested the product. An analysis was made to determine the causes why this product was not available.

Improve Phase

Once the supplier was identified and also the causes for a product to not be available when requested by the client, possible solutions were generated to achieve the availability of the product. The possible solutions should eliminate the area backorders and increase the productivity of the manual assembly lines. An implementation plan for the corrective action or solutions that improve the process was generated in this phase.

Control Phase

Once the corrective actions were implemented to improve the process, the number of products in backorders and the productivity of the area were closely monitored. A final report was made to indicate the development and conclusions of the project. Any improvement actions not implemented in this project were suggested for future projects of the company.

RESULTS AND DISCUSSION

The following results were obtained from the application of the different phases of DMAIC (Define-Measure-Analyze-Improve- and Control) used in the development.

DEFINE PHASE

- *Problem description:* The area analyzed is composed of 134 different products, and is an area of manual production. These products are divided among 7 cells of production, according to its components and assembly process. The products have 4 basic components which are supplied by internal and external suppliers: before the improvements were implemented there was a service problem. The problem was that although the area had the capacity to meet the required demand, as far as operators were concerned, as the rate of production increased new work shifts had to be generated to meet the demand. The problem was that the

components required to complete the products were not available when the client placed the order. The products were classified according to its cost and how fast they are consumed from the central warehouses of the United States. Products that move the fastest (AA) require an amount in safety stock, based on calculated forecast. The object is to have the product available when solicited by the client. When orders are not supplied, products are converted into backorder, thus increasing the cost of the product not made available to the client that ordered it. The area of production had a great volume of orders, but since the components were not available, the productivity of the area was affected. The backorder before working the area was $26K, with a productivity of 87%.

- *Cause-Effect Diagram*: This diagram (Figure 4) is one of tools used to identify the possible causes why an area of production generates Backorders, and thus does not comply with the productivity of the area. The Cause and Effect diagram is used to determine possible causes of a problem, and these possible causes are placed in groups or affinities and help to develop a more focused analysis of the root cause of the problem. This is performed to correct the low productivity of the area.

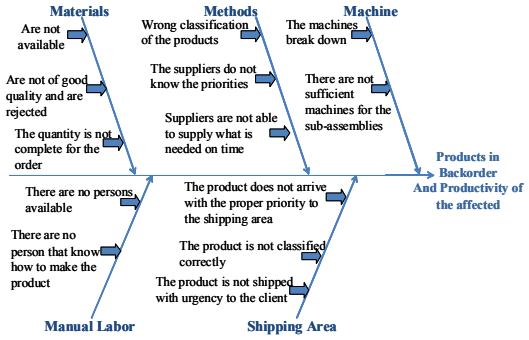

Figure 4
Cause and Effect Diagram

- *SIPOC Diagram (Supplier-Input Process-Output-Customer): The* SIPOC diagram shows the relationship that exists between suppliers, the input of the process, the process of the final product in the cells of production, the output of the area, and the clients for these final products of the area evaluated. There are internal and external suppliers of the area. Materials from external suppliers are received by the area from the warehouse of the company in Vega Baja. However, materials from internal suppliers are brought directly to the plant where the suppliers are located, in this case molding from Plant A, and Fabrication from Plant B. On certain occasions, some of the components of Plant A are sent also to the company warehouse, and then they are shipped to the different areas. The main components of the final product are: Housing, sub-assemblies, final screws, and shipping case. From the area we can obtain as output boxes of the final products which are packaged and sent with its corresponding documentation to a shipping area. Scrap is also removed from the area as well as the productions report. The clients for these final products are: Hospitals, Universal Studios, Sears, Schools, Fast Food Restaurants (especially McDonalds), Telephone Companies, and independent clients. In this diagram (Figure 5), shown in summary is the process of the final product in 6 principal steps, beginning when the order is generated to make the sub-assemblies, up to the packaged final product along with its documentation, and taken to a shipping area.

Supplier	Input	Process	Output	Customer
*Molding	*Housing	*See Below	*Boxes of the finished product	*Hospital
*Fabrication	*Sub-assemblies		*Scrap	*Universal Studios
*Fabrication	*Final Screws		*Documentation	*Sears
*Triem	*Shipping case		*Reports	*Schools
*Lianca				*Fast Foods
*El Morro				*Telephone Companies
				*Independent Customers

The order of sub-assembly is generated to the production area	The sub-assemblies are produced	The order of the final product production is generated	The cell of production is prepared	Final Assembly and packaging	Final product is taken to a shipping are
Step 1	Step 2	Step 3	Step 4	Step 5	Step 6

Figure 5
SIPOC Diagram

- *Voice of Customer (VOC):* It is important for a company to know the needs and expectations of its customers, since without them there is no business, and therefore no profits. It is

necessary to know what they expect from the products or services they request, and for what they are willing to pay. For this reason it is important to define and to know the following:

- What is it that the customer desires from the product?
- What is of value and importance to the customer?
- To know the specifications of the customer for the product.
- To know up to how much the customer is willing to pay for the product or service.
- To analyze if the company can meet the expectations of the customer.
- The goals and priorities of the company must be applied and focused on its customers.
- These are some of the ways that the company has to handle and collect information as to their requirements and expectations concerning the products.
- Interviews (Personal or by Telephone).
- Focus Groups to collect information from customer with similar needs.
- Direct conversations with the customers.

Table 1
VOC Voice of Customer

VOC	Complaint	Critical Customer Requirement
No cosmetic error	Product its not received on time	Visual Inspection
Fictional	Product has other color	100% Functional
Package	Package broken	Correct Package, without damage
Correct Voltage	Other voltage	100% correct voltage
Correct Documentation	Incorrect documentation included	Correct documents required
Wrong Catalog in package	Catalog is not the required	Correct catalogs
Component missing	Component not included	All components included
Final product Broken	Damage of any components	Corrects accessories included and perfect condition

The company has a client service department to allow the client to make known his needs or complaints. If the client has a complaint concerning a product, a document is generated with the information needed to make known to the area of production so that it can be corrected. The following table (Table 1) shows the actual requirements of our clients:

MEASURE PHASE

In this phase the necessary data was collected in such a manner that the major offenders of the area could be identified. The tool of choice was the Pareto Chart and FEMA (Failure Mode and Effect Analysis). These tools were used to determine which were the root causes that affect the products in a way that backorder is generated by the area. The data collected was from October to December 2009. The data was collected directly from the production report which shows in one page prepared in Excel the products, the demand, which is backorder, and the reasons that these products were not manufactured, and the customers did not receive the product ordered.

- *Data Collection Plan:* The following figure (Figure 6) shows how the data was collected and how it will be measured. With the data collected, Pareto Charts were generated to identify the principal causes that affected the productivity, and generate backorder each month during the quarter of Oct.-Dec. 2009

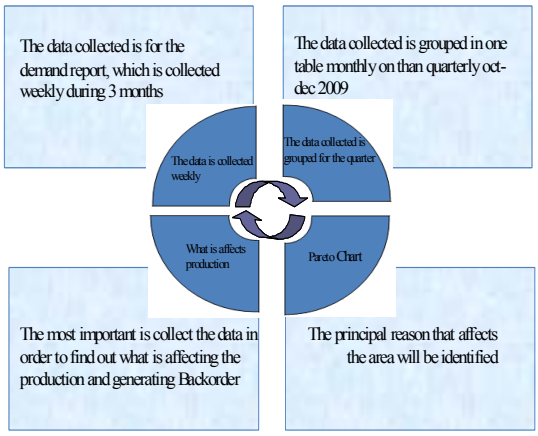

Figure 6
Data Collection Plan

- *Pareto Chart:* The Pareto Chart is a tool used to analyze the problems that affect the area, and grouped in vertical bars, arranged from the most important to the least important. It is referred to as the 80-20 principle since 20% of

the total causes cover the 80% of the total effects of the problem. This is the reason that Paretos were used to analyze the collected data, grouped monthly to find out the principal causes that affect the area of production, and the work that must be performed to solve them.

- Pareto Chart October 2009: During the month of October 2009 (Figure 7) the productivity was affected by the supplier of plastic parts, Molding Plant, and by the sub-assemblies which were not on time to complete the orders of the customers. Since the molding and sub-assemblies parts were not available, backorder of the products were generated. The products in backorder were mainly affected by the molding and sub-assemblies during the month of October 2009 (Figure 8). We can see that molding affected the productivity by 39%, and the sub-assemblies by 27%.

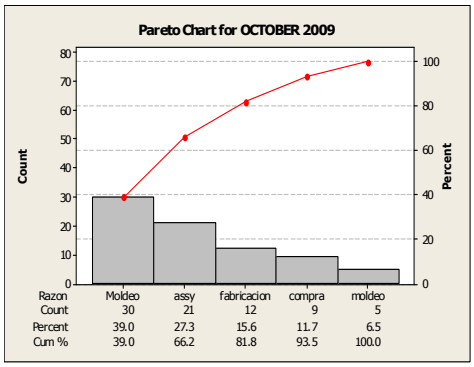

Figure 7
Pareto Chart for October 2009

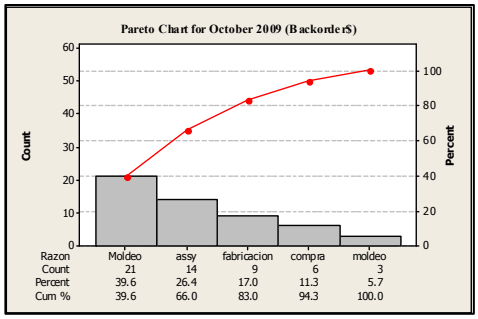

Figure 8
Pareto Chart for October 2009 (Backorder)

- *Pareto Chart November 2009:* During the month of November 2009 (Figure 9), the productivity was also affected by the supplier of plastic parts, Molding Plant, and the supplier of raw parts, the Fabrication Plant. Similarly, the orders in backorder were caused by the non- availability of these internal suppliers (Figure 10). Both components, plastics and metal parts, were not ready on time to complete the orders of the customer. The molding supplier affected the productivity by 11%.

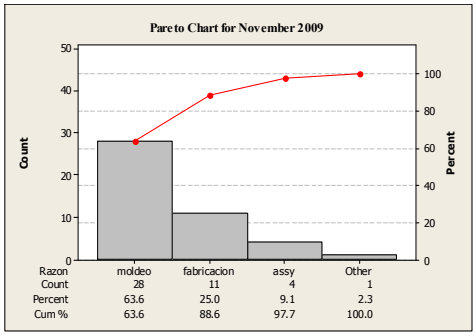

Figure 9
Pareto Chart for November 200

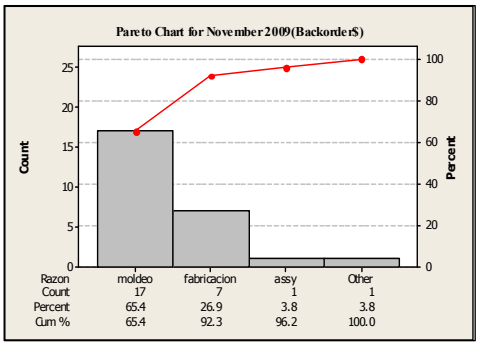

Figure 10
Pareto Chart for November 2009 (Backorder)

- *Pareto Chart December 2009:* During the month of December 2009 (Figure 11), the major offender to the productivity were the parts coming from the internal supplier of plastic parts from the Molding Plant. Similarly to the month of October 2009, the next offender was the sub-assemblies. This was also true of the orders in backorder, which were caused by the lack of availability of the plastic parts, and the sub-assemblies (Figure 12). The supplier of molding affected the productivity by 28%, and the sub-assemblies by 21%.

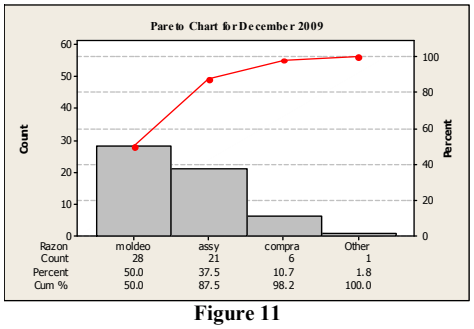

Figure 11
Pareto Chart for December 2009

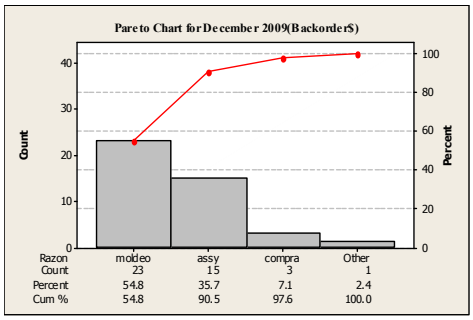

Figure 12
Pareto Chart for December 2009 (Backorder)

- *Pareto Chart Quarter October-December 2009:* These Paretos summarize the data collected during the quarter of October to December 2009. They show that the major offender for the orders of customers was the internal suppliers of molding (Figure 13), followed by the sub-assemblies of the area. The effect is proportional in that it is the regular orders that are affected, and in the same manner the area is affected by the backorders (Figure 13).

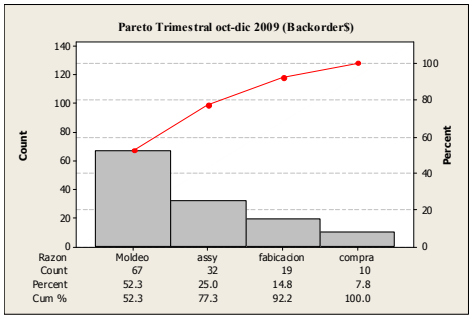

Figure 13
Pareto Chart for Quarter of Oct.-Dec. 2009 (Backorder$)

- *A Failure Mode and Effect Analysis (FMEA)*: FMEA (Failure Mode and Effect Analysis), is a tool that provides the guidance to properly identify and evaluate the potential failures of a product process. By the use of FMEA the process is evaluated step by step up to the final product. FMEA has three criteria: Severity, Occurrence, and Detentions. All three criteria are evaluated by assigning them values from 1-10, where 1 represents minor incidence, and 10 represents catastrophic event. The values of RPN (Risk Priority Numbers) are calculated as follows: RPN = (S)*(O)*(D), where the higher values represent that priority should be given to generating corrective action to prevent the failures. The next phase focuses on working on the molded parts that affect having the product on time, and also working with the sub-assemblies needed to complete the orders of the customers.

ANALYZE PHASE

In this phase the potential causes for the problem of productivity and products in backorder were selected as due to molded parts not complete on time, and the sub-assemblies of the product. The following (Figure 14), shows the relation that exists between the data collected in the past three months (Oct.-Dec. 2009) of the total demand, vs. the data collected of the products in backorder.

The sub-assemblies are not available since an inventory was not made, to determine its monthly usage, or calculated according to the demand of the product. The procedure was that when the order is reflected in the demand report, then the sub-assemblies are coordinated to be produced. Until it is produced in the area of the machines of sub-assemblies, the customer awaits for the product. If the machine breaks down, or there is no available machine, this increases the waiting time. Even though there is a rack of sub-assemblies, it is not supplied. The sub-assemblies that are left over from the order are placed there, by the machine operator that produced too many, or that the order was reduced. On occasions, these sub-assemblies surpluses placed in this rack have resulted in avoiding the product becomes a backorder.

The molded parts that are not available at this moment are due to different causes: problems with

the mold, the parts have not been placed on schedule in the molding area, or that the part has been rejected because of quality problems when it reaches the area. There is constant communication with the molding area, notifying which parts should be added to the schedule, and what parts have quality problems. When the parts are placed on scheduled, many times it is not placed with priority because the urgency to complete the backorder is not known.

It is important to point out that the products identified by the analysis were affected by the molded parts and the sub-assemblies. They generate an additional cost to the company, who is trying to reduce costs, with the intention of reducing them as close as possible to zero. The company not only incurs in additional cost (Backorder), but on occasions, the customer cancels the order even when the product has been completed. This is not beneficial to the company since it not only has an additional cost of the product, but it also loses a customer and now has a product in the central warehouse, which has no demand against itself.

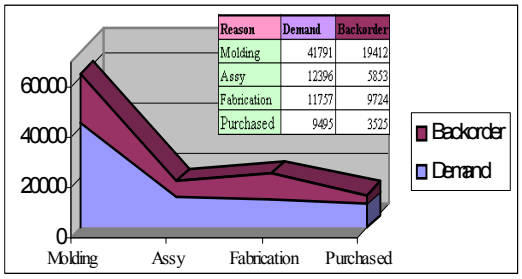

Figure 14
The relation of Data Collection to the Demand & Backorder

IMPROVE PHASE

In this phase the task was to improve the system of sub-assemblies so that they would be available when the order of the customer enters the system. The Coordination with the Internal Molding supplier must be improved also to avoid delays in receiving the plastics, and once they arrive at the area of production, that they have good quality so they wouldn't be rejected. With the information of sub-assemblies rack, the area was worked, using as a guide the tool 5'S. 5'S is a tool to create and maintain an organized work place, clean and of high yield. This tool, 5'S, generates an appropriate working atmosphere, which is indispensable for a perfect quality, stimulates visual control, helps to identify waste, places a high value on security, and promotes employee satisfaction. This tool ensures what is needed for the production of products in an organized fashion, and easy access for the material handles of the area.

The following photograph (Figure 15) shows how the sub-assemblies rack, how it looked before the concept of 5'S was applied. As can be seen in this photograph, the sub-assemblies rack is not in an orderly manner, the buckets are not appropriate for the quantity needed, and there are buckets of different sizes in the rack. The rack was cleaned; new labels were put with space to indicate the raw material of the sub-assemblies, the demand, comments, and the quantity of parts per bucket. The Supervisor of the area, and the Material Handler was informed of how the rack was organized, the importance of keeping the sub-assemblies rack organized for a greater response at the moment of assembling the order in the cell of production, as well as it being a visual aid to determine which sub-assemblies were needed or which raw material was needed for the sub-assemblies.

Figure 15
Rack sub-assemblies (Before-5'S)

The following photograph (Figure 16) shows the rack of sub-assemblies after applying the 5'S concepts.

Figure 16
Rack sub-assemblies (After-5'S)

To improve the availability of molded parts, the molds were matched with the parts since there are common molds between the products, and the number of parts that had quality problems during the quarter of Oct.-Dec. 2009.The backorders generated during the quarter of Oct.-Dec. 2009 was caused by 16 molds. Of these 16 moldings, 3 of them had problems of quality. The molds with problems of quality were: I447 with 584 pieces rejected, I462 with 176 pieces rejected, and I519 with 439 pieces rejected. The Molding Plant handles approximately 300 molds for 2,500 pieces. Upon investigation, it was found that the three molds above mentioned had no preventive maintenance. In fact, there is no program of preventive maintenance for molds. A request was made to have a record during this quarter of cleaning and maintenance, but this record is not related to the problem of quality that caused the rejection of the parts. It is important to point out that these 3 molds (I447, I462 and I519) affect a total of 19 catalogues. Nevertheless, that the parts were not available, or that the molds being in a condition to generate parts of good quality, affect 111 catalogues, since these 32 molds, correspond this number of molded plastics. There is a need to implement preventive maintenance program for each mold, but it is suggested to start with those with a documentation that show problems of quality. It is not advisable to wait for the molds to finally breaks, since this increases the time of delay of the plastic, while the customer waits for the product he ordered. The molded parts were not available for various principal reasons: that the mold has problems, that there is no resin or material to produce them (although this did not occur during the quarter studied, but is mentioned as a possible problem), or because they have not been placed on schedule. On occasions, even when scheduled, the production order has been placed in a position (on the schedule) which represents more than 60 hours before it is available.

CONTROL PHASE

A 5'S Audit was conducted in the area of production. To make sure that the improvements implemented in the area of sub-assemblies are maintained, after applying the 5'S tool in the rack of sub-assemblies, this rack has been included as part of the 5'S Audit. This will help to keep the sub-assemblies rack clean, organized, and with the buckets that are assigned for each sub-assembly. To make sure sub-assemblies rack is maintained functioning as it was left, the condition of the rack was made part of the evaluation included in the Audit. This will help to keep the rack in order. A suggestion was made to have the Production Planner of the area evaluate the demand of the sub assemblies on a monthly basis. The demand of the sub-assemblies should be verified, first with those that are part of the backorders of the area, and then with those that represent a high volume, so that the productivity of the area will not be affected. The rack is organized in such a way that it is able to absorb increases or decreases in the demand of the sub-assemblies.

A suggestion was made to the Quality Department that in order to ensure the maintenance of the molds to avoid quality problems in the molded parts, to submit as part of the Corrective Action, to submit, a verification of the molds that caused the defects. The practice has been that every time a part is rejected, the Quality Department generates a Nonconforming-Corrective Action Report (NCAR), to have a record of the part that was rejected, the reason it was rejected, and what Corrective Action is being requested to avoid the nonconforming. If the Quality Department identifies a constant problem with a molded part, the mold should be removed and taken for repairs to the shop for inspection and maintenance.

CONCLUSION

One of the objectives of this Project was to increase the productivity from an actual 87% to the 95% objective established by the company. Another of the objectives had to do with products in backorder, since they represent an added cost to the product. Initially, the costs in Backorder of the area studied were $26,000. The objective of the company is $0 in Backorder. The factors affecting backorder in the area of production studied –that is,

when the customer does not receive a timely response to the order he has placed in the system– were worked, and the objectives were reached. The factors that were affecting the area of production the most were the lack of availability of the sub-assemblies, which are produced in the area of production, and the lack of molded parts, which are provided by an internal plant. After working on these factors, the productivity was increased to 96.7% which was maintained as an average for the quarter of January-March 2010. On the other hand, the costs of products in Backorder are now $4,300, all due to molded parts not being available. None of these products were affected because of a lack of sub-assemblies. Of the 5 products in Backorder, 3 of them have no molded parts because of problems with the mold. But the $0 Backorder objective of the company was not reached mainly due to problems that exist with the supplier of molded parts.

There are limitations that hinder the possibility of integrating the other plants that participate in the final products. It is very possible that the $0 Backorder objective could have been reached if it had been possible to work directly with the plant that produces molded parts. There seems to be a concept that is unclear to the supplier of molded parts; that the plants of final products are their customers, and therefore, they owe a service so that a timely delivery can be made to the customers that placed the order initially. It is a chain, and if there are no molded parts, backorder costs will exist simply because there are no molded parts available. The result will be that customers will withdraw their orders, and in the worst of cases, look for another company of electrical products that will respond to their orders in a timely manner.

In this project recommendations have been mentioned that should help to solve the problem of the lack of molded parts being available when needed. It is important that these be implemented as part of the effort to achieve the $0 Backorder cost objective, and thus avoid the possibility of losing customers because the product they ordered was not completed on time. These recommendations were not implemented since it was beyond the scope of this project to implement improvements in other plants, even when the plant is an Internal Supplier of the area of production worked in this project. The Molding Schedule should be programmed based on priorities, giving precedence to those parts that are needed for a product in Backorder. It is considered very necessary to decrease the set up time of the molds in order to produce the molded parts by priority and volume. A preventive maintenance system for each mold should be implemented, starting with those which have a history of quality defects. Finally, the Quality Department should include as part of its corrective actions the proper maintenance of molds that produce parts with Quality problems.

REFERENCES

[1] Breyfogle, F.W. III (2003). Implementing Six Sigma Smarter Solutions using statistical Methods, Second Edition. USA: John Wiley and Sons, Inc.

[2] Pande, P. S., Holpp, L. (2003). ¿Que es Seis Sigma? España: McGraw-Hill Professional

[3] Electronic Reference (2010) ¿Que es DMAIC? Obtained in December 6, 2010 from Tech-Faq.com: http://www.tech-faq.com/dmaic.shtml

[4] Electronic Reference (2010) ¿Que es un Diagrama de Pareto? Obtained in March 19, 2010 from Infomioyme.com: http://www.infomipyme.com/Docs/GENERAL/Offline/GDE_03.htm