Reducing Variation at the Measuring Stage for a Quality Inspection Process in Material Handling Stations

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Abstract

We addressed the inspection process of a critical product in an industrial refrigeration company. Using DMAIC methodology and it's tools, through an integral proposal that included the implementation of new documentation, visual aids and training courses, it was expected to achieve the standardization of the inspection process as well as a better quality of it. Preliminary results shown a 125% increase in the Kappa index for agreement levels of an attribute Gage R&R (from weak to moderate), as well as a 10% reduction in type II error (using defective product) and a reduction of 75% in scrap after one implementation. A control plan was left with the company to maintain improvements, expecting savings of approximately $52,000 USD/year from the reduction of scrap.

Keywords
DMAIC, Lean Manufacturing, Six Sigma and Operational Excellence.

1. Introduction

Companies are constantly developing new techniques to improve current processes and in consequence, achieve operational excellence, which brings notable benefits to industries, such as increased revenue and long term savings of resources and time. A medium size company whose area of expertise is the production of refrigeration units is no exception. Even though they have been growing since they were established in 1994, becoming today's leader in the refrigeration market, they continue working to increase its overall efficiency and productivity. Therefore, a project was set in motion implementing Lean Six Sigma Methodology (L6). L6 consists of two different methodologies, the first one is *lean manufacturing,* a work philosophy whose main objectives are adding value to processes and eliminating waste. Secondly, *six sigma* whose main objective is to reduce variability and improve quality through statistic and strategic approaches.

Six Sigma is supported by DMAIC (Define, Measure, Analyze, Improve, Control) methodology, a set of cycled steps that allows to identify a problem in an existing process and analyze the critical reasons behind it, in order to implement solutions for a long term period. This methodology is supported by tools, each of them useful in each step of the DMAIC. For example, SIPOC diagram, VSM (Value Stream Mapping) and Project Charter in the Define stage; Data Collection Plan and Stakeholder Analysis in the Measure stage; Ishikawa Diagram and 5 Why's in Analysis; 5S, Visual Aids, FMEA (Failure Mode Effect Analysis) and SMED (Single Minute Exchange of Die) during the Improvement stage; and Control and Monitoring Plans for the Control phase. The implementation of some of these tools will be helpful for the development of this project.

Through the implementation of the DMAIC methodology and while observing the processes inside the company, it became clear that there is no standardized inspection method for quality control in a key area of the company. In this area, hairpins are inserted into coils, and it is through these hairpins that refrigerant flows, allowing the coil to cool. All hairpins need to be inspected before placing them in the coil looking for critical defects that may cause leaks and failures of the whole system if not detected. However, it was observed that the criteria used to evaluate hairpins was not in an agreement between departments (engineering and quality) which leads to using defective pieces on their products, as well as disposing functional ones, resulting in increased costs for reprocess pieces, customer complaints, guarantees and scrap. Therefore, the objective of the project was to validate the standardization of the evaluation of defects in hairpins by increasing the Kappa levels shown in a Gage R&R to at least 0.60 (The Kappa Index is the ratio of times operators agree to the proportion they could/should agree). Nowadays, a large amount of money is spent yearly due to customer complaints and two of the biggest causes of these complaints are caused by defective hairpins. After analyzing customer complaints of 2018, it was found that $340,000 USD were lost only due to damaged hairpins, either by leaks or dents. If the agreement level is good, then a decrease in the amount of customer complaints will be expected.

Two Gage R&R and another experiment consisting on the correct evaluation of hairpins were done, and all of them confirmed that the criteria used by people to evaluate hairpins was not standardized. In an effort to correct it, the team came up with several proposals for the solution of the problem. First, defining alongside quality and engineering departments the critical defects, characteristics in hairpins and the effect that it has on the functioning of the product, training personnel to standardize the evaluating criteria, implement graphic manuals in each workstation, as well as a board with masterpieces with samples of each defect.

With the implementation of these proposals, the standardization of the inspecting criteria began. A final Gage R&R was run to see improvements. Kappa levels went from poor and weak to moderate, however, operators have been working in a particular way for over 3 to 20 years so there is a slight resistance to change. Changing their criteria will take time in order to shape this new standard inspection method. A control plan was established in which every three months, operators will be evaluated through a Gage R&R. If the Kappa Index is below 0.60, then training will be imparted, until it reaches the desired value 0.60 which belong to a good agreement level. There might be a small room for variation but once on 0.60, monitoring should continue in order to maintain or restore this level if necessary.

2. Method

The following section will further explain each of the stages of the DMAIC methodology and how it was used to identify and solve a problem within areas related to hairpins. Several tools were used throughout the whole project to help achieve the objective. During the development, changes and adaptations were made to the initial project, constantly reforming and clarifying our objective as root problems were identified, resulting in the current objective of standardizing the inspection method of defects in hairpins. The metric was the Kappa index between operators and the standard, as well as the number of customer complaints due to defective hairpins.

2.1 Define

In this stage if the DMAIC methodology, it was realized that passing a defective hairpin increases the probability of failure of the assembled coil, either in the leak test, or once it is delivered to the final customer. Therefore, the amount of customer complaints is an important factor to consider. The data gathered from 2018 was organized in a pareto chart who, as shown in figure 1, 80% of the reclaims are caused primarily by four causes, and two of them are due to defects on hairpins (hits and leaks). Leaks can be caused by not welding the hairpin to the connection correctly, but this could be caused by having asymmetrical tails and many other defects. This shows that placing an incorrect hairpin to the coil could result on customer complaints due to malfunctioning of the coil.

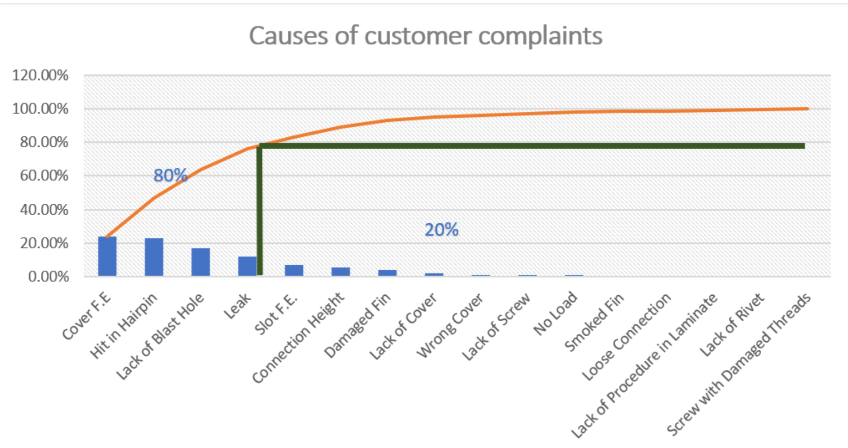

Figure 1. Pareto Chart with causes for customer complaints.

In order to verify that this was in fact a problem, a Gage R&R experiment was run. Along with the quality department, twenty hairpins were randomly selected and inspected, looking for which type of defect was present in the hairpin and with which frequency it appeared. The hairpins were randomly inspected by four operators of a certain assembly line. They needed to evaluate each hairpin three times. It was necessary to keep from the operators which hairpin was which, so they could evaluate them as different ones. Therefore, the study showed the agreement level the operators had within them, but also showed the agreement level between operator. What the agreement level shows is how consistent are operators evaluating each of the hairpins with themselves, meaning how many times the operator says that certain hairpins have certain number of defects, multiple times. And it also shows how consistent are the operators in identifying the same number of defects that the standard (set by the quality department and the team) has. The results are shown in table 1. As seen in the table, the agreement levels were between poor and weak, obtaining a Kappa Index of 0.2 in average.

Table 1. Kappa Index and percentage of accuracy Gage R&R.

Summary of the Gage R&R					
Evaluator	**Number of evaluated pieces**	**Compared with themselves**		**Compared to standard**	
		% of accuracy	**Kappa Index**	**% of accuracy**	**Kappa Index**
1	20	60%	0.37	20%	-0.002
2	20	50%	0.24	35%	0.25
3	20	55%	0.28	15%	0.02
4	20	80%	0.70	30%	0.12

Table 2. Interpretation of Kappa values

Interpretation of Kappa values	
Kappa value	**Agreement Strength**
< 0.20	Poor
0.21 - 0.40	Weak
0.41 - 0.60	Moderate
0.60 - 0.80	Good
0.81 - 1.00	Very good

As seen in table 1, most operators have a moderate level of accuracy with themselves, meaning they are consistent with what they identify as a defect. However, when compared to the standard, the level of accuracy is mostly poor, meaning that operators are consistent among themselves, but the criteria is not correct when compared to what the quality department establishes as a defect. This shows that the measuring system is inadequate, which results on defective hairpins used in coils, causing potential leaks. Or could also result in functional pieces are thrown away, increasing scrap percentage. Both mistakes result in increased costs and losses for the company.

During the evaluation, it was noticeable that operators only look for three main defects: hits in either wall or body, asymmetrical points and black tube. This showed that the accuracy level that operators have to identify specifically these details is greater than the ability they have to identify other details such as adjustment marks, trailing marks, asymmetrical points and marks by drops of water. This is something that was considered for a proposal because all defects should be identified equally. This is because in the end, any of the defects will cause customer complaints so none of them should be present of the client's product.

It was also seen that communication between and within departments was deficient, where not all information is passed on or if it was, it is sometimes wrong. This was noticeable when looking into the defects and the effect that it has on the correct functioning of the hairpin because the quality department established certain things as defects, but the engineering department had no knowledge of their existence. One example is the defect known as marks by drops of water. The quality department consider this as a defect, but the engineering department did not know of the existence of it.

Once the problem was identified, the objective was set: increase the agreement level given by the Kappa Index, among operators and according to the standard, to at least 0.60, by standardizing the criteria that operators have to inspect defects on hairpins, in an effort to reduce customer complaints by the end of the year 2019.

2.2 Measure

To determine the project's impact, it is necessary to establish the current situation (baseline) of the criteria used to inspect hairpins. To confirm the instability of the measurement system for defects in hairpins, a second Gage R&R was done under different conditions. This time, five operators from a different assembly line randomly inspected ten hairpins, looking and inspecting at each of the hairpins two times. Even though the result was developed under different conditions and with operators from other assembly lines, the conclusions were the same. Agreement levels in the assembly line showed a low Kappa Index, proving that this problem does not affect a single line, but all the areas related to hairpins.

Table 3. Kappa Index and percentage of accuracy of the Resulting Gage R&R.

Summary of the Gage R&R					
Evaluator	**Number of evaluated pieces**	**Compared with themselves**		**Compared to standard**	
		% of accuracy	**Kappa Index**	**% of accuracy**	**Kappa Index**
1	10	40%	0.28	20%	0.29
2	10	50%	0.38	0%	-0.14
3	10	30%	0.18	20%	0.22
4	10	40%	0.28	30%	0.31
5	10	40%	0.32	20%	0.33

However, in this assembly line, the accuracy level of operators with themselves was a little bit greater (highest value up to 50%), while towards the standard remained mostly poor and weak. This means that operators will require training to shape their own criteria, as well as towards the standard.

Another type of experiment was done in order to sustain the initial suspicion of no standardization in the inspection system used to evaluate hairpins. It was done along with the quality department. For every coil assembly line (standard, 3/8H, special) the experiment was run for bought hairpins and once for produced ones. It was important to consider these two types of hairpins because the tendency of the company is to outsource the production of hairpins. Nowadays, only a small percentage of the hairpins have been outsourced but it is expected that during the next year, the whole process will be outsourced.

The experiment consisted of the following: fifty hairpins of the same type were randomly selected from the container. All hairpins were numbered and inspected along with the quality department, and together determined if the hairpins passed as good, or were damaged enough to not be placed in the coil. Afterwards, hairpins were taken to the correspondent assembly line. There, operators were supposed to inspect them as they usually do, expecting from them to take out damaged hairpins and placing correct ones in the coil. To do so, a data collection sheet was designed, defects were listed in order to register those found according to quality department, and compare to those found by operators (Documents can be found in the Appendix 1).

Results were not surprising. The following graph represents the results from the experiment mentioned above. When the dot has a small diamond inside it, it means that the operators classified hairpins the same way the quality department did before, meaning they were in an agreement. However, when the dot is by itself, it means that the operator classified the hairpin differently than what the quality department stated before, meaning there was a non conformance on the evaluation of the hairpin. The results can be seen in figure 2. Out of the 50 pieces, 16% were marked incorrectly, with 8% defective being used, and 8% functional hairpins sent to scrap. This, as the result shown in the Gage R&R, shows that there is a large and considerable amount of hairpins being wrongly classified.

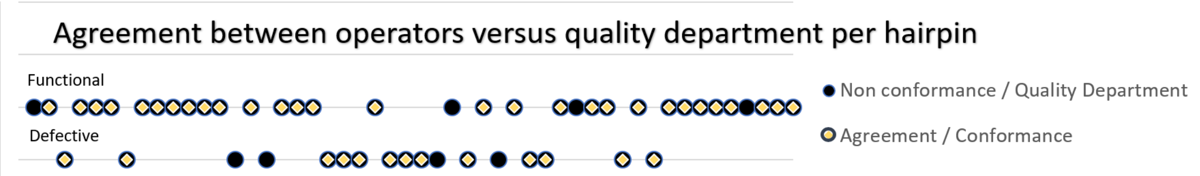

Figure 2. Agreement between operator and quality department when inspecting hairpins

2.3 Analyze

To determine the root causes of the non-standardization of the inspection method for hairpins, a collaborative session was arranged along with operators and supervisors from the area. Participants were to brainstorm 5 reasons why they believed damaged hairpins are placed inside coils and correct ones thrown to scrap. Ideas were then arranged in an Ishikawa Diagram shown below.

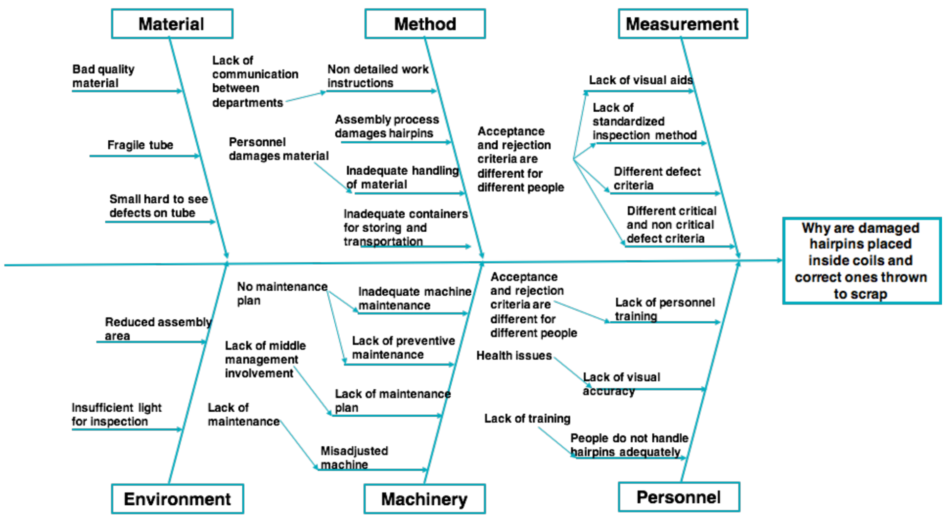

Figure 3. Ishikawa Diagram for use of misclassified hairpins

After building the Ishikawa with the results from the Brainstorming session, and keeping in mind that the company plans to outsource the process of building up hairpins, the team realized that proposals made for machinery and material were not going to be very transcendent. When looking at environment, there are only two causes which do not relate directly to the poor inspection of hairpins. Therefore, the most important categories in which the proposals were built where method, personnel and measurement, which are all related because operators measure defects according to a set method.

When looking at the causes of each of these three categories, the team, along with the participants of the Brainstorming determined that the criteria used to inspect hairpins is not standardized because every person inspects hairpins according to their own criteria. They know generally what the defects are, but do not know how to correctly determine if that means the hairpin is defective or functional. This results on not having an accurate inspecting system on how to differentiate defects. To obtain further information and complement the root causes found in the Ishikawa Diagram, the 5 why's tool was implemented.

Table 4. 5 Why's to find root causes

5 Why's	
Why are damaged hairpins placed inside coils and correct ones thrown to scrap?	Because hairpins are not inspected adequately.
Why are hairpins no inspected adequately?	Because operators do not know how to correctly evaluate hairpins.
Why do operators not know how to correctly evaluate hairpins	Because they don't know all the existing defects as well as the effect it has on the product.
Why don't they know all the existing defects as well as the effect it has on the product?	Because they haven't been trained about such defects.
Why haven't they been trained about such defects?	**Because operators are only given one training when they get to their job, and no continuous training and update of defects is given to them.**

When a new operator is hired, a small training is given where the company explains what their job should be. It was observed that there are certain defects that are more frequent than others, such as hits or bumps, black tube or bent hairpins. Yet other defects such as trailing marks, marks by water drops, or cracked hairpins are not that common. This led the operator to look mainly for those common defects and forget about the rest of them. The fact that only one training was given to them, and they have been working in the company for more that three years, increases the probability that the criteria these people have to evaluate hairpins has been deteriorated over time due to lack of tracking. Complementary to this, the fact that there are differences between departments on which marks on the hairpins are defects, lead to confusion among operators, leading them to focus only in those who are common between departments, which happen to be the most common defects.

To statistically prove that nowadays, the criteria used to evaluate hairpins is inadequate, the results of the Gage R&R (Kappa Index) were interpreted through a hypothesis testing. A comparison of a single mean to a specified value with a 95% confidence interval was done. Due to lack of time, the size of the sample is not enough to ensure that the whole population behaves the same way as the sample. But using this data, the objective was to see if the people from sample had Kappa levels below 0.60. Results are shown below:

Table 5. Results of hypothesis test within themselves

Hypothesis test: variance with themselves								
N	**Mean**	**Standard Deviation**	**H_0**	**H_1**	**T Value**	**P Value**	**Error**	**µ´s upper limit for a 95% confidence interval**
4	0.398	0.209	μ=0.60	μ<0.60	-1.94	.074	0.104	0.643

Table 6. Results of hypothesis test with standard

Hypothesis test: variance with standard								
N	**Mean**	**Standard Deviation**	**H_0**	**H_1**	**T Value**	**P Value**	**Error**	**µ´s upper limit for a 95% confidence interval**
4	0.097	0.115	μ=0.60	μ<0.60	-8.75	.002	0.0575	0.2323

We can conclude that there is enough statistical evidence to claim that the agreement level of operators compared to standard is below 0.6, as P-value is lower than the value of alpha (0.05), being the value of the sample 0.23 at a mean level criteria. Whereas there is not enough statistical evidence to claim that operators have an agreement level of at least 0.60 with themselves. This means that in both cases, operators do not have the correct knowledge on how to evaluate hairpins. Not only towards their own criteria, but towards the criteria established by the quality department. This represents a danger to the company because the lack of a system to thoroughly inspect hairpins results on high costs to the company when they pay for guarantees to clients complaining from defective product.

To determine the risks of not having a correct and standardized evaluating method for defect in hairpins, a FMEA (Failure Mode and Effect Analysis) was made. (See Appendix 2). In it, it was determined that the most important component that should be monitored along time is the criteria that the operators have to evaluate defects. Therefore, a control plan was established to monitor the training and agreement level operators have towards the satraization of defects that the quality department should have.

2.4 Improve

After analyzing the information provided by the above mentioned tools, several ideas emerged that could be used to impact directly on the standardization of methodology used to inspect defects and the number of customer complaints due to defects on hairpins. The proposals are the following: document with defined defects, periodical training for personnel, handbooks in every workstation, marterpieces board, pariodica Gage R&R and a gage for asymmetrical tails defect.

The first proposal was to establish a document along with the quality department, the engineering department and the manufacturing department, in which all the existing defects are stated as well as the effect that these defects have on the malfunctioning of the coil. This document was approved by the plant manager and by the responsibles from the quality department, in an effort to standardize and have an agreement on what defects the operator need to be aware at the time of inspecting the hairpin. (See the Document in Appendix 3). Knowing and transmitting the effect that a damaged hairpin has on the functioning of the coil is of great importance because it works as a backup to understand and present to other departments why are certain characteristics classified as defects. Besides, it will help to standardize the inspection of defects of hairpins throughout the whole plant and among all departments by stating what should operator look for while inspecting hairpins.

Once the existing defects were established by the above mentioned document, the information needed to be transmitted to the operators. Therefore, trainings were given to all operators in charge of inspecting hairpins at some point in the production process. Besides sharing with the operators all the defects they should identify while inspecting the hairpins, the objective of these trainings is to increase the Kappa Index within operator and between operators to at least 0.60. This value ensures that the agreement level from the operator to the standar and from operator to themselves will be good. As a consequence to this, it is expected that the amount of damaged hairpins in coils will reduce, impacting directly on a decrease of customer reclaims due to hairpin matters. During the training, operators looked that pictures from all the existing defects, and looked at the contrast between a functional piece and a defective one. (See example of the pictures in Appendix 4.1). They were also given physical pieces so they could identify the defects better. After the explanation was given, operators were submitted to a small test to identify if the information was helpful. They were given five hairpins to evaluate them and say which defect was present in which hairpin. The results were not perfect, but operators identified a large amount of the defects established. On average, operators identified 5 to 6 defects out of 9 they were supposed to identified.

To complement trainings, the team designed two visual elements, so they could be implemented in and close to workstations so workers could come and look at them in case they had any doubts while inspecting hairpins. The first one is a board where examples of physical pieces with all the defects called masterpieces were placed. Each one of the masterpieces contain one of the twelve defects established in the previously mentioned document and they are correctly labeled, as well as one correct hairpin. They were pasted to the board with magnets so the operators can take them, examine them, and then put them back in the board. Two boards were made. One was placed inside the area where hairpins are placed inside the coil, visible and available to anyone who requires its help. The second was placed in the reception warehouse so when the incoming hairpins are inspected, operators could take the visual aid as a reference to correctly decide if the hairpins fulfil the requirement. It is expected that if it is well cared by the operators, the board will last years in great conditions, the only changes that will need are if more defects are added, then the board will have to be modified. Otherwise, it is expected to help for many years. (See Masterpiece Board on Appendix 5).

The second visual aid implemented were handbooks. (See example of handbook in Appendix 6). Each of the handbooks contained visual aid in how to distinguish between a defective and a functional hairpin. Information about the twelve defects is presented containing pictures about how the hairpin should look, and how it should not. These handbooks were placed in the workstations so workers could use them while inspecting hairpins, in an effort to help them have a better judgment as they inspect all hairpins. To be able to place the handbooks inside the production area, a document according to the ISO 9001 needed to be filled out and approved by the company. (See document in Appendix 7).

One of the twelve defects is when the tails of the hairpins are asymmetrical. This means that one of them is larger than the other one. This is one of the hardest defects to identify because the difference between tails must be smaller than 0.032 in, a difference hard to detect only by looking at the tails. If the difference is bigger, then the hairpin is defective and needs to be discarded. Initially, operators only trashed away those hairpins in which the difference was really evident, but they placed many other whose difference was not that evident but was greater than the accepted one. In order to avoid this situation, a gage was created. The objective is to place the largest tail in the cavity without groove, so the shorter one will go in the cavity containing the groove. In the cavity for the shorter hairpin, the groove determines the 0.032 in tolerance. If the end of the shorter tail is inside that marked area, then the hairpin is functional, but if it is below the limit, then it should be sent to scrap.

The implementation of this gage works a poka yoke because it will help the operator determine if it is functional or not. The identification of this defect is crucial because when the difference is greater than the permitted one, the welder´s job could not be optimal and cause leaks due to poor welding.

This gage was implemented in the lines where hairpins are made and in the reception area in the warehouse. These two positions are strategic because in the production line, when operator make adjustment to switch producing one type of hairpin to another, they need to verify and manually move the machine to make sure the tails of the hairpin are symmetrical. The implementation of the gage here will help the operator to identify faster if the difference in tails is acceptable or not, ensuring that the production of the whole batch will have acceptable difference in tails. The implementation of this gage in the reception area of the warehouse will be used by the quality inspector whose job is to make sure the whole batch fulfills the agreed requirements by evaluating a sample. The hairpins of the sample will go through the gage to make sure the difference in tails is acceptable, and if this and all requirements are fulfilled to determine that the hairpins in the sample meet the requirements, then the batch can be accepted. (See Appendix 8 for more detail of gage).

After implementing proposals, another Gage R&R was run to measure the impact of our proposed solutions. An improvement was seen in both cases, compared with themselves and to standard. In the first case (with themselves) a major impact was seen in most cases, with a percentage of accuracy above 70%, as well as an agreement level between moderate and very good, except for evaluator 1, who was sent to the examination but this is not her area of expertise. Compared to standard, an improvement was seen as well, where operator 3 showed the greatest development in both cases.

Table 7. Shows Kappa Index and percentage of accuracy of the Gage R&R

Summary of the Gage R&R					
Evaluator	**Number of evaluated pieces**	**Compared with themselves**		**Compared to standard**	
		% of accuracy	**Kappa Index**	**% of accuracy**	**Kappa Index**
1	10	10%	-0.10	10%	0.32
2	10	100%	1.00	10%	-0.05
3	10	80%	0.71	60%	0.57
4	10	70%	0.42	30%	0.18

Another experiment similar to the one made during measuring phase was repeated. Defective hairpins were marked and left in the workstation for the operator to evaluate them and identify those who were defective. In the previous experiment, 16% of hairpins were placed incorrectly. After training, this percentage went to only 6%, reducing significantly just after one session. It is expected that the more trainings are delivered to operators, this percentage will tend to decrease since they will evaluate hairpins better and they will get to a point where it will stabilize and remain constant.

2.5 Control

The final step of the DMAIC methodology is controlling and monitoring improvements made, making sure that they maintain results obtained during improve phase. As seen above, operators have been working at the company in the hairpin area between 3 and 20 years. Training requires more than one session to achieve the 0.60 goal. Employees have been working the same way for many years, teaching them a new method of doing something takes time to create a new culture of quality.

To achieve so, a control plan was established. Trainings are proposed to be done every 3 months which is long enough period of time for operators to put in practice the knowledge they acquired in them. These trainings should be taken by every person involved with hairpins so they can receive the information and be evaluated afterwards. For future training sessions, teaching material such as catalogues with defects, masterboard and interactive presentation/activity was left for use (see Appendix 8). Right after every training, a new Gage R&R must be done to measure impact, as well as progress made since the very first session. Since the objective has not been achieved, it is necessary to perform sessions of training before the study. Once the objective is achieved and maintained several months (at least two more sessions), then the Gage R&R can be done before the training every six months, in order to verify if the objective is still met. In case the results decrease to a Kappa Index below 0.61, the trainings should be done every three months until the numbers show again that the acceptance level is good.

To monitor Kappa levels in a more graphic way, after every evaluation, data collected should be graphed as shown in the figure below (figure 4.), where the value of Kappa is registered with a dot each session and for each operator, measuring in a visual way the progress made after each training. Two graphs are required, one for variance within operators and one for variance between operators and standard.

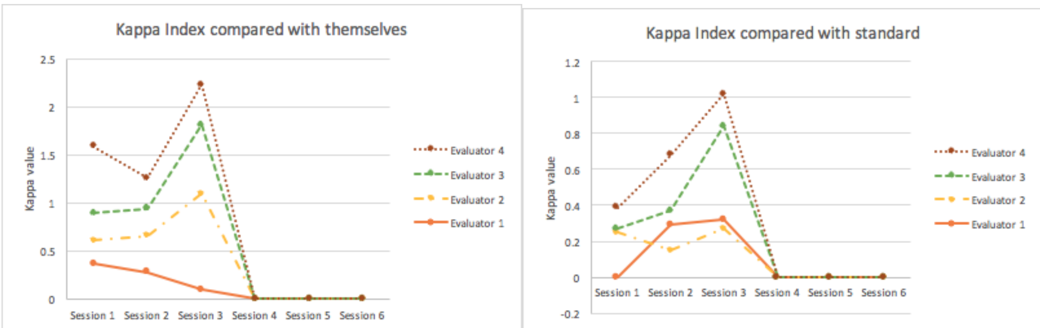

Figure 4. Control charts to monitor progress of accordance level.

Finally, to control visual aids (catalogues and boards), every 6 months, supervisors of all the corresponding areas where improvements were made (reception area, production area, quality department) must audit and verify that every document and board is where it should be, complete and in good conditions, reporting it to the coordinator, whom will keep register. In case something is missing, incomplete or damaged, it must be reported and replaced immediately.

All documents and instructions for further trainings and all of our proposals will be left with the coordinator, in order to allow them to have the necessary material for future control. (See documents on Appendix 10) Also, the gage for asymmetric tails must be constantly evaluated (every 6 months) by metrology lab to make sure it still covers the 0.032 tolerance, and is still approved for use. If time and/or use have deteriorated such device, then using the CAD document left, a new one has to be manufactured, tested by metrology lab, approved and validated before using it.

3. Results

As mentioned above, when it comes to working with people, we encounter a higher level of difficulty regarding modifying any process, because human factors such as resisting change and being used to old habits can become hard to overcome obstacles. This is why our objective was set to be achieved by the end of the last trimester of the year, having enough time to keep working and training until this new quality culture is acquired by each employee.

This can be seen in the following graphs, where the progress made during the three gage sessions was registered for operators compared with themselves, as well as compared to the standard. Figure 5 shows the behaviour of operators after two repetitions. The level of agreement with themselves in the beginning was between poor and moderate, however, after training, levels increased in average to a good agreement strength.

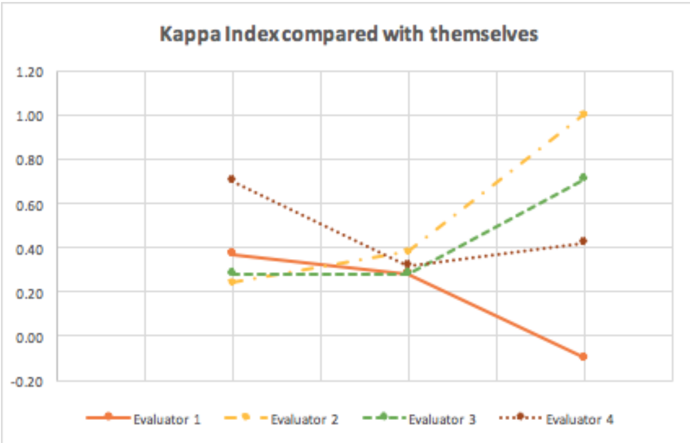

Figure 5. Kappa index compared with themselves

It can be seen that evaluator number 1 had a decrease in her agreement level, this was due to the fact that she was not the same employee tested in the first study, but instead was covering the original operator that was absent that day. The substitute was not familiar with the tasks done in that work station and was not familiar with defects and inspection method. This is why in this case, evaluator 1 shows a negative result, derived from the fact that it was not the same person as before and was not familiar with activities performed.

Furthermore, in terms of operators compared to standard, an improvement was seen as well, rising from poor and weak levels to a moderate agreement strength. The graph below shows the behavior of operators identifying the different types of defects found in each hairpin versus the evaluation made by the quality department. In this case, improvement was not as good as in the previous case, it was concluded that this was due to the resistance to change derived from working experience. Operators have been evaluating thousands of hairpins in a certain way, 8 hours every day for more than three years. It requires more than one session of training to create a culture of quality where operators are constantly trained and aware of the importance that a conscious inspection is required.

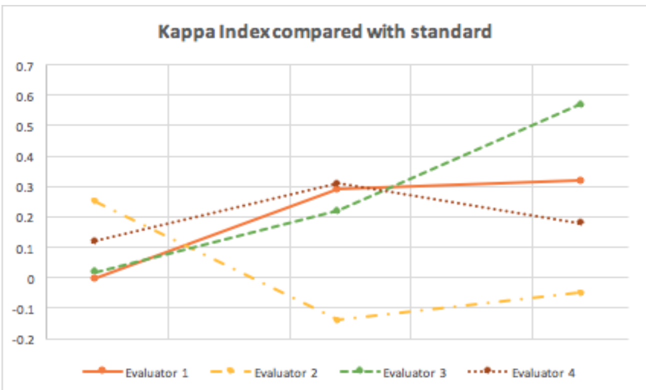

Figure 6. Kappa index compared with standard

The objective of the project was to increase the agreement level to at least 0.60, however, this can not be achieved in a short period of time. Since people have been doing the same evaluation for years, it will take several sessions to grow up this new method within each person. That is why an increase was observed, but the target was not yet achieved. With a continuous training and set of actions such as the ones proposed in section 2.4, it is expected that by the end of 2019, the objective should be achieved, and with further control, maintained or improved. In order to measure the impact on a population level, a second hypothesis test was made, results can be seen below:

Table 8. Hypothesis test within themselves after implementation

Hypothesis test: variance with themselves after implementation								
N	**Mean**	**Standard Deviation**	**H_0**	**H_1**	**T Value**	**P Value**	**Error**	**µ´s upper limit for a 95% confidence interval**
4	0.469	0.507	µ=0.60	µ<0.60	-0.52	0.321	0.254	1.066

Table 9. Hypothesis test with standard after implementation

Hypothesis test: variance with standard after implementation								
N	**Mean**	**Standard Deviation**	**H_0**	**H_1**	**T Value**	**P Value**	**Error**	**µ´s upper limit for a 95% confidence interval**
4	0.260	0.255	µ=0.60	µ<0.60	-2.67	0.038	0.128	0.560

It can be seen that for variance within themselves, our at least 0.60 desired value is within our confidence interval, while compared to standard, the upper limit of the confidence interval in the current situation is close to 0.60 (0.56). This proves that in fact, a notorious improvement was seen, however, it will require continuous effort to achieve our goal.It was observed that 75% of the time, asimetric tails defect was hard to identify due to the tolerance, consequently after the design and implementation of a gage, it is expected that this percentage will be reduced significantly since the gages were placed in strategic points in order to not produce hairpins with asimetric tails or not to accept supplier batches containing this defect.

Working along the manufacturing department, it was found that besides the impact made reducing customer complaints by not placing defective hairpins in coils, a reduction in levels of scrap would also occur. Currently, around $69,000.00 USD are spent on copper scrap due to hairpin manufacturing. Since hairpins will stop being manufactured but will be bought instead, scrap and waste will decrease . If a correct inspection is made when receiving hairpins with an adequate sampling plan following the Militar Standard 105E, only batches that cover quality requirements will be accepted, then no scrap will be absorbed by the company. This could result in savings of approximately $52,000.00 USD annually that come from selling 6 of the original 8 manufacturing hairpins machines, reducing over 75% the current levels of scrap. This data was taken and analyzed from historics of the first months of 2019.

4. Conclusion

Implementing Lean Six Sigma, specifically the DMAIC methodology, a project was made in a company whose objective was to increase the agreement level operator have when inspecting hairpins. 41% of the main objective was reached after the implementation of proposals, where operators were given training about all the defects they should take into account while inspecting, as well as providing them with visual aids (masterpiece board and defect catalogue), and the gage to ensure all hairpins fulfill the requirements of not having difference in tails of more than 0.032 in. With the kappa index increasing 125%, from 0.2 (weak level) to 0.45 (moderate level), a reduction of 10% of the error type II (defective pieces evaluated as functional) was observed. At the same time, the development of visual (list of defects) and physical aids (masterpiece board), lead us to a standardized inspection system of defects and the reduction of 75% of hairpins scrap.

There are several actions that need to be done to ensure that the impact remains along time. Training and Gage R&R should be imparted to operators constantly to ensure the criteria remains according to the ones set by the quality department. Audits should be done constantly to ensure that the material placed in the worksatios (masterpiece boards, gage and catalogues). To guarantee that this is done in a proper way, several documents and guidelines were left to supervisors with all the necessary instructions and material for them to execute these actions.

The development of the Six Sigma project was complex due to the multiple redesign of the project. It was observed that the DMAIC methodology is not linear because through the application of statistical models and quality core tools such as Pareto, Ishikawa diagram, hypothesis test, etc. the scope, limitations and restrictions needed to be changed in order to solve the vital few causes. Some restrictions and limitations were from the internal and cultural workflow of the company due the time workers have been doing the same procedure. Also the time given to develop the project was short compare to the expected results, that's why as a team we learn to identify the strenghts of each member and then hand out responsibilities and deadlines to deliver the project promptly.

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Biographies

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Juan Carlos Espinoza is an assistant professor at Tecnologico de Monterrey with graduate degrees from Engineering and Business Schools. His main area of expertise is in optimization models, particularly applying Linear and Mixed-Integer Programming to solve problems with uncertainty. Juan Carlos' research includes theoretical and practical contributions to the field of operations research in the areas of logistics and robust optimization. His research is mainly application driven, with special interest in location, scheduling, and transportation problems.