Cost of Quality Reduction in NEMA Coils Assembly Lines

Yari Babilonia Obregón
Master in Engineering Management
Dr. Héctor J. Cruzado
Graduate School
Polytechnic University of Puerto Rico

Abstract *— The Cost of Quality (COQ) is a proactive cost associated with a prevention investment needed to ensure requirements are met to avoid nonconformances. There are two components to ensure companies meet requirements: internal costs and external costs. The internal costs occur prior to delivery of goods and services, and external costs occur after delivery or shipment. In this paper, the focus is on COQ reduction for a production line in a manufacturing facility. The NEMA Coils area is one of the top assembly lines for the company. Improvement projects were needed in order to reduce recent influx in non-conformance and to accommodate high demands at both short-term and long-term horizons. Root cause analyses were carried out and, as a result, the top 5 defects were determined to be associated with incomplete molding, incomplete winding, wrong stamping, wire split, and bad winding. In addition, two of these defects contributed up to 50% of the total non-conformances found at these assembly lines. A time study was performed in NEMA coils and process changes were carried out which resulted in new assembly lines layout. After implementation line capacity increased by 25%, the downtime was reduced by 20%, and the COQ was reduced by 34%.*

Key Terms *— Cost of Quality; Root Cause Analysis; Nonconformance; Process Improvement*

INTRODUCTION

According to the American Society for Quality (ASQ), the Cost of Quality (COQ) is the total of the cost incurred by investing in the prevention of nonconformance to requirements, appraising a product or service for conformance to requirements and failing to meet requirements. Particularly, when taking into consideration the repercussions of failing to meet customer requirements, two additional factors are embedded in this, which are internal and external costs. The internal failure costs occur prior to delivery of shipments. Some of these costs are associated with scrapping, reworking, re-inspection, and re-testing. On other hand, the external failure occurs after delivery or distribution, which includes processing customer complaints, customer returns, warranty claims and product recalls.

In this paper, the topic is associated with the reduction in the Cost of Quality in the assembly lines of a manufacturing facility. In order to protect the company and follow its policies, for academic purposes, the name of the company will be Electrical YBO. The project was executed in the NEMA Coils area, one of the most demanding lines for the company. The NEMA Coils have different sizes and demand received for both short-term and long-term horizons are very high, thus management would like to ensure this is prioritized. In order to keep the production line with the highest performance, it was important to look for potential areas of improvements. After the recent influx in the number of non-conformances coming from these lines, further investigation was required to understand the ‘current’ state. After investigation, action plans were evaluated and subsequently implemented to meet the objectives.

OBJECTIVES

The objectives of this project were to:

- Maximize line capacity by 15% in NEMA Coils Assembly Lines by April 2022.
- Minimize downtime by 10% in NEMA Coils Assembly Lines by May 2022.
- Reduce COQ by 20% in NEMA Coils Assembly Lines by May 2022.

LITERATURE REVIEW

As companies launch new products in order to prevail in the marketplace, they must focus on how to improve current processes. In the case of manufacturing companies, the Lean Six Sigma philosophy helps to understand and determine where there are potential opportunities to improve current processes. In the circumstance of improving productivity, Nallusamy uses time studies to determine activities that do not add value to the customer [1]. After determining what those tasks are, he used other lean tools to modify the layout of the lines and improve productivity.

Another way to measure yield and performance is by analyzing the preventive aspect of the process. The preventive aspect includes what maintenance is but also how to be proactive in terms of product quality. There are studies that determine that there is a relationship between performance and preventive maintenance [2]. If companies invest in preventive maintenance before processes start to fail, at the end of the day they impact product performance and quality. This, in turn, translates into a reduction in production costs since it is not waiting for a process to fail to then fix it, which could sometimes be even more damaging since it can include downtime with a longer time than expected or even become an extensive investigation, recall of a product, among other situations.

On the other hand, the costs associated with the quality of the products are called cost of quality. There are different ways to address cost of quality, one is preventive, and the other is reactive. Naturally, it is of greater benefit to implement proactive measures, since when the event arises, the process is ready or much easier to resolve. In contrast, when actions are only taken reactively, it generally results in more time to resolve the situation or the failure.

In the event that proactive measures are still not enough and failures occur, there are several methods to determine the root cause of the situation. Better effectiveness is achieved when the fishbone diagram method is combined with the Five Whys technique [3]. When working on projects to find the root cause of nonconformances, the project can easily become gigantic, so the Five Whys techniques, together with the fishbone diagram, helps to maintain organization and guides to find the real root cause that will later be used to implement process changes, reduce nonconformances and increase productivity.

It is important to denote that when working to improve performance, there will not always be a direct or exact line to the solution. Not all concepts are applicable, but they can be leveraged to normalize and adjust to the industry in which the process is being carried out. When changes to processes are being considered, part of the decision-making must include the evaluation of the costs associated with these changes [4]. It is very important to implement a measure that is cost effective and meets the financial and departmental goals for projects of this magnitude.

METHODOLOGY

The first step was to segregate the scrap (non-conformances) by defects. Figure 2 shows the types of defects found in NEMA Coils Assembly lines Sizes 1 & 2. After completing this process, the major contribution to the scrap generation was the incomplete molding (IM) and incomplete winding (IW). On this project, the wrong stamping (WS) defect will not be considered because this was an unusual defect due to isolated events and it was investigated and addressed on a different project.

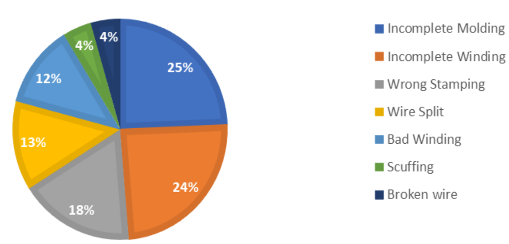


Figure 1
Type of defects found in Nema Coils Size 1 & 2

After selecting the main defects that contribute the most to the scrap generation, the fishbone diagram tool was very helpful to determine the root cause of the defects. In Figure 3 and Figure 4 are shown the fishbone diagrams generated for incomplete winding and incomplete molding respectively.

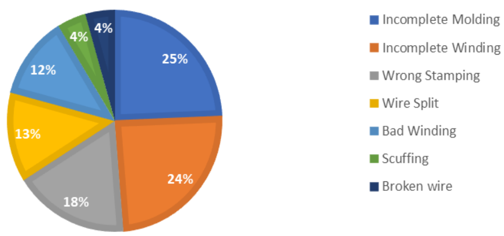


Figure 2
Type of defects found in Nema Coils Size 1 & 2

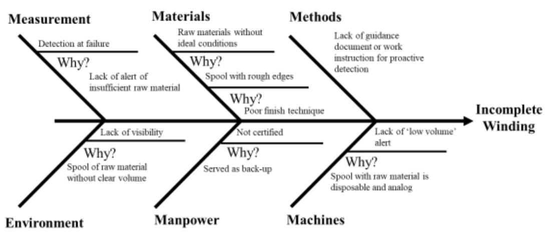


Figure 3
Fishbone for Incomplete Winding

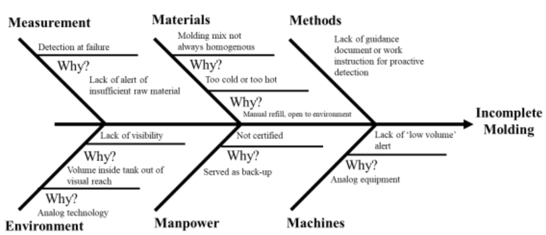
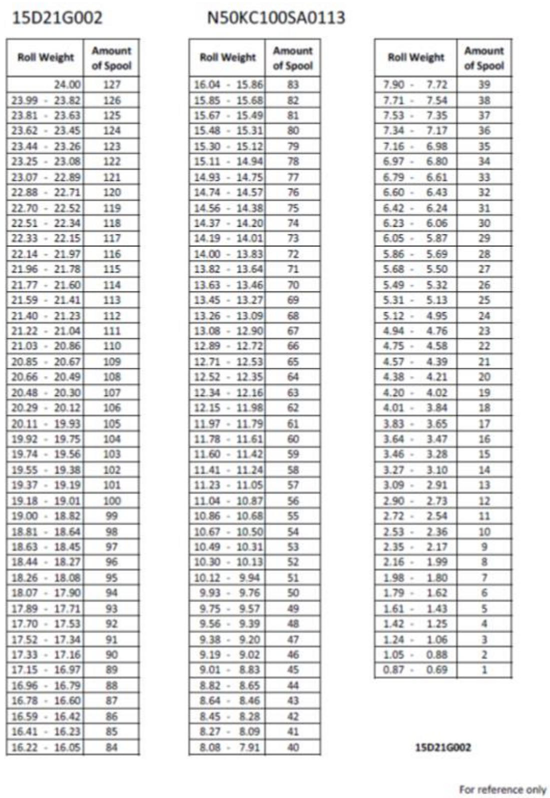


Figure 4
Fishbone for Incomplete Molding

For the incomplete winding defect, it is evident that scraps occur after failure and there is no alert or notice that raw material is running low until it completely fails. In addition to no standardized method that indicates how many spools can be made with a certain amount of wire. The first step was to investigate the amount of wire in the warehouse and if the suppliers would send a standardized amount of wire. Since each catalog uses a different type of wires with different number of turns, and due to the inconsistency of the supplied materials, another approach to solve this issue had to be designed. The solution was focused on the spool itself and measurements were taken to determine the empty spool weight which was 0.04 lbs. Then the spool weight was taken after the winding process. Fifty (50) samples were taken and then the average was calculated. After taking the initial samples, the team noticed that the weight did not vary, and then it was decided to take 10 samples for each catalog of the high runners. The high runners were determined using Pareto Principle also known as 80-20 rule. On this approach, 80% of sales come from 20% of products. In order to implement an effective method to reduce or eliminate the scrap for the Nema Coils Size 1, tables were designed containing two columns. The first column would indicate a roll weight and the second column would indicate the number of spools that could be made with that amount of wire. This approach was used for every catalog of the high runners.

To conclude implementation a weight scale was placed at the station and every time a new catalog and product was running, the new setup included having the operator weigh the roll of wire and look on the table the number of spools that could be produced with that roll. As operators keep track of the units produced, when the maximum number of spools are produced, the operator needs to remove the roll and place a new one. This new process was documented and validated, and operators are trained and certified to the new process. Figure 5 shows an example of the tables that were placed at the station for operators to have guidance of the number of units to be produced with the quantity of raw material available at the time of running new units.

Root cause analysis for incomplete molding showed that the main contributor for this defect was lack of work instruction for proactive detection and or alert that raw material is running low. In addition to zero to non-visibility in the tank that contains the molding mix. Once the mix is loaded in the tank, the machine does not provide an alert that triggers the operator to check the remaining volume. After further investigation, the team found a weight sensor that was able to fix the issue and easily detect or show the operator when the tank was running off molding mix, an issue that contributed to incomplete molding. The sensor was installed and now every time the tank is running low on mix, it will display a red light and a beep sound. The new process was documented and validated, and operators are trained and certified to the new process.



15D21G002

Roll Weight	Amount of Spool
24.00	127
23.99 - 23.82	126
23.81 - 23.63	125
23.62 - 23.45	124
23.44 - 23.26	123
23.25 - 23.08	122
23.07 - 22.89	121
22.88 - 22.71	120
22.70 - 22.52	119
22.51 - 22.34	118
22.33 - 22.15	117
22.14 - 21.97	116
21.96 - 21.78	115
21.77 - 21.60	114
21.59 - 21.41	113
21.40 - 21.23	112
21.22 - 21.04	111
21.03 - 20.86	110
20.85 - 20.67	109
20.66 - 20.49	108
20.48 - 20.30	107
20.29 - 20.12	106
20.11 - 19.93	105
19.92 - 19.75	104
19.74 - 19.56	103
19.55 - 19.38	102
19.37 - 19.19	101
19.18 - 19.01	100
19.00 - 18.82	99
18.81 - 18.64	98
18.63 - 18.45	97
18.44 - 18.27	96
18.26 - 18.08	95
18.07 - 17.90	94
17.89 - 17.71	93
17.70 - 17.53	92
17.52 - 17.34	91
17.33 - 17.16	90
17.15 - 16.97	89
16.96 - 16.79	88
16.78 - 16.60	87
16.59 - 16.42	86
16.41 - 16.23	85
16.22 - 16.05	84

N50KC100SA0113

Roll Weight	Amount of Spool
16.04 - 15.86	83
15.85 - 15.68	82
15.67 - 15.49	81
15.48 - 15.31	80
15.30 - 15.12	79
15.11 - 14.94	78
14.93 - 14.75	77
14.74 - 14.57	76
14.56 - 14.38	75
14.37 - 14.20	74
14.19 - 14.01	73
14.00 - 13.83	72
13.82 - 13.64	71
13.63 - 13.46	70
13.45 - 13.27	69
13.26 - 13.09	68
13.08 - 12.90	67
12.89 - 12.72	66
12.71 - 12.53	65
12.52 - 12.35	64
12.34 - 12.16	63
12.15 - 11.98	62
11.97 - 11.79	61
11.78 - 11.61	60
11.60 - 11.42	59
11.41 - 11.24	58
11.23 - 11.05	57
11.04 - 10.87	56
10.86 - 10.68	55
10.67 - 10.50	54
10.49 - 10.31	53
10.30 - 10.13	52
10.12 - 9.94	51
9.93 - 9.76	50
9.75 - 9.57	49
9.56 - 9.39	48
9.38 - 9.20	47
9.19 - 9.02	46
9.01 - 8.83	45
8.82 - 8.65	44
8.64 - 8.46	43
8.45 - 8.28	42
8.27 - 8.09	41
8.08 - 7.91	40

Roll Weight	Amount of Spool
7.90 - 7.72	39
7.71 - 7.54	38
7.53 - 7.35	37
7.34 - 7.17	36
7.16 - 6.98	35
6.97 - 6.80	34
6.79 - 6.61	33
6.60 - 6.43	32
6.42 - 6.24	31
6.23 - 6.06	30
6.05 - 5.87	29
5.86 - 5.69	28
5.68 - 5.50	27
5.49 - 5.32	26
5.31 - 5.13	25
5.12 - 4.95	24
4.94 - 4.76	23
4.75 - 4.58	22
4.57 - 4.39	21
4.38 - 4.21	20
4.20 - 4.02	19
4.01 - 3.84	18
3.83 - 3.65	17
3.64 - 3.47	16
3.46 - 3.28	15
3.27 - 3.10	14
3.09 - 2.91	13
2.90 - 2.73	12
2.72 - 2.54	11
2.53 - 2.36	10
2.35 - 2.17	9
2.16 - 1.99	8
1.98 - 1.80	7
1.79 - 1.62	6
1.61 - 1.43	5
1.42 - 1.25	4
1.24 - 1.06	3
1.05 - 0.88	2
0.87 - 0.69	1

15D21G002

For reference only

Figure 5
Table placed at the station that shows standardized number of spools per pounds of wire

Table 1 shows Running Time, Capacity and Downtime before the project and any process improvement effort. The overall available time per assembly line is 480 minutes and current capacity is between 70 to 80 percent, and the daily downtime is up to 28% for Size 5.

In Table 2 presents the time study performed in Nema Coils Assembly Line 1. Every step in the procedure is shown below and there are designated columns for Value Added (VA) and Non-Value Added (NVA) activities. There were additional time studies performed on other sizes that provided similar data with VA and NVA activities. The core team evaluated the waste and eliminated the NVA when possible. The approach included new layouts and required to update the work instruction and modification to workstations.

Table 1
Pre-Implementation state of assembly lines size 1 thru 5

Nema Coil Line	Available Time [minutes]	Daily Running Time [minutes]	Current Capacity [%]	Daily Downtime [%]
Size 1	480	390	81%	19%
Size 2	480	375	78%	22%
Size 3	480	375	78%	22%
Size 4	480	360	75%	25%
Size 5	480	345	72%	28%

Table 2
Results of Time Study Performed in Nema Coils Size 1

Step	Cycle Time [seconds]	Value Added [seconds]	Non-Value Added [seconds]
1	0:00:15	0:00:10	0:00:05
2	0:00:06	0:00:06	0:00:00
3	0:00:04	0:00:04	0:00:00
4A	0:00:31	0:00:31	0:00:00
4B	0:00:07	0:00:02	0:00:05
5	0:00:05	0:00:00	0:00:05
6	0:00:04	0:00:00	0:00:04
7A	0:00:10	0:00:10	0:00:00
7B	0:00:05	0:00:02	0:00:03
8	0:00:03	0:00:00	0:00:03
9	0:00:11	0:00:07	0:00:04
10	0:00:04	0:00:00	0:00:04
11	0:00:02	0:00:00	0:00:02

RESULTS

The updated work instruction for the winding process and the implementation of binders with tables at the workstations resulted in drastic improvement and the reduction of nonconformances due to incomplete winding. Before process improvement and pre-implementation, the NEMA Coil Assembly Line Size 1 and 2, was generating 24% of scraps, the action plans (AP) went from implementation to effectiveness monitoring (EM) phase and during this phase the count of nonconformances due to this defect is down to 0%.

Similarly for incomplete molding defects, the work instruction was updated, and a new sensor was installed at the workstation. Pre-implementation, the number of scraps due to this defect was 25%, the AP is now in EM phase and the number of nonconformances due to incomplete molding reduced by 15%. Combining both process changes the COQ for NEMA Coils assembly lines was reduced by 34%, which is 14% more than its initial target.

The line capacity before process changes was approximately 70% and the downtime was up to 25% depending on the assembly line size. After process improvements, which included the new layout, updated work instructions, and reduction in nonconformances, all of this contributed to a line capacity increased up to 95%, and the downtime was reduced on average to 5%. The daily output has increased which has increased coverage, days of supplies (DOS) and the stock equation.

CONCLUSIONS

The objectives of this project were accomplished. The NEMA Coils Assembly Lines COQ was reduced by 34% ($15K/annually). The line capacity was increased by 25%. The downtime was reduced by 20%. For root cause analysis, lean six sigma tools like the fishbone diagram and the Five Whys were helpful to determine the root cause for defects. In addition, time studies were supportive to determine VA and NVA activities. Also, the use of pareto principle supported the focus for selecting the high moving catalogs. For this project, the focus was particularly for two of the top five defects for NEMA Coils assembly line. However, the other defects will be revised and considered for future improvements projects.

The main benefit of this project was to understand the root cause for the recent influx in the number of nonconformances, which was achieved and resolved. Also, these assembly lines are considered the high runners or core lines, and the demand at both short-term and long-term horizons are very high. Since there are similarities between the core lines like Sizes 1 to 5, but also with larger sizes like Size 29, the work done for this project can be leveraged for future projects and to implement similar improvement ideas.

Key factor for effective execution was team collaboration and alignment with organizational goals. All departments worked together and contributed to this project. Their feedback, guidance, and execution were key to meet the deliverables at the timeline determined by management.

REFERENCES

[1] Nallusamy, S. (2016). Productivity Enhancement in a Small Scale Manufacturing Unit through Proposed Line Balancing and Cellular Layout. International Journal of Performability Engineering, 12(6), 523–534.

[2] Lazim, H. M., et. al. (2019). An Empirical Investigation of Preventive Maintenance Practices Among Manufacturing Organizations: Does Cost and Quality Matter? Global Business & Management Research, 11(2), 120–129.

[3] Mateos, M. C., & Place, K. W. (2021). Let’s Get Visual: Combine 5 whys and fishbone diagrams for better RCA. Lean & Six Sigma Review, 21(1), 28–31.

[4] Dean, B. R., Hand, S., & Kaye, M. (1997). A cost based strategy for assessing improvements in manufacturing processes. International Journal of Production Research, 35(4), 955–968.