Cost & Cycle Time Reduction and Increased Production on CNC Machines

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Abstract *— There are a lot of different types of manufacturing industries. Some of the similarities, in the majority, is the need to reduce cost, cycle tyme and consequently increase productivity. There are several methodologies or techniques that we can follow and implement that can help the industries to fulfill these needs. One of the type of manufacturing industries are the machining industries which works with CNC "Computer Numerical Control" programed machines. In these type of industries that use CNC program codes to machine there are a lot of ways to make that happen. In this article, it will be discussed how we can use lean manufacturing in the CNC codes programs. How we can use less expensives tools to machine without affecting the quality of the product. Finally we will manufacture the units with the expected quality, tooling cost reduction, decrease in cycle time and enhanced production. This execution was performed in: "Zimmer Manufacturing B.V. located at Ponce, Puerto Rico. Zimmer is a machining industries which produce different types of implants.*

Key Terms *— Computer Numerical Control (CNC) Programs, DMAIC, Efficiencies, Lean Six Sigma.*

BACKGROUND INFORMATION

This design project was conducted in Zimmer Manufacturing B.V., located at Ponce, Puerto Rico. Zimmer is a worldwide leader in musculoskeletal health care and has been since the founding more than 80 years ago. In 1993, Zimmer opened its manufacturing in Ponce. The manufacturing in Ponce is dedicated to create implants from: knee, Trauma, Hips and other areas. The project was conducted in the knee area. Inside the knee implants there are different areas and materials. In this case we will work on the Articular Surface area made with plastic. The Articular Surface Cell is one of the oldest cells inside the knee area. There are a several changes and new techniques that can be implemented in this cell, due to the lack of effort invested to this cell in the previous year. This cell is composed of four Makino CNC machines, 2 a51 and 2 a55, one CMM (Coordinate measure Machine) and one Mitutoyo.

NUM. OF MAHINE	DESCRIPTION
ZC01790	MAKINO A51
ZC01791	MAKINO A51
ZC01792	MAKINO A55
ZC01793	MAKINO A55

Figure 1
CNC Machining Machines

The four makino are the CNC programed machines that machines the plastic to create the articular surface implant. After the implant is created, there are different characteristic that are measured. These characteristics are measured following the MIS (measure instruction sheet). Some characteristics are measured in the CMM. The CMM use a program code to measure different dimensions of the unit. The mitutoyo is used to measure the roughness in some areas of the implants. There are other measures in the MIS that are measured with other tools or simply with only the use of the vision and characteristic can be executed. The makino machines are configured using two cubes, each cubes of four faces. There are 2 jaws per face in where we put the plastic material to be machined. There are a total of 8 units per cubes. The machines have 2 cubes but it works with one at a time. There are different tools that use the machine and it machines the units of one cube in the following way: Machining of the 1st unit of the 1st face using all the tools, then the second of the 1st face, then the 1st of the 3rd face, then the 2nd

of the 3rd face then the 2nd face and finally the 4th face. All this operation made a lot of tool changes. Also the tools that create the "Articular Surface" area of the units are really expensive. This tool is called condyle and it can cost from $500 to $1000 per set.

PROBLEM STATEMENT

The high consumption of the condyles and the delay in time per tooling changes is affecting the efficiency of the cell. The cell was experiencing high tooling cost and high cycle time. The problem in the high tooling cost is that the condyles tools were used to make the roughing and the final path operations of the machining of the units. The delay in cycle time was because there is not a lean sequence of tooling changes when machining the four parts in the cube.

Part Numbers	Condyles Part Numbers	Cycle Time (Current) Face #1 & 3	Cycle Time (Current) Face #2 & 4	Cycle Time (Current) Full Run
00-5962-030-10	25-4001-088/258-00	0:14:45	0:23:34	0:37:40
00-5962-030-12	25-4001-088/258-00	0:14:35	0:23:46	0:38:03
00-5962-030-14	25-4001-088/258-00	0:14:35	0:23:43	0:38:03
00-5962-030-17	25-4001-088/258-00	0:22:27	0:23:43	0:47:06
00-5962-030-20	25-4001-088/258-00	0:24:01	0:27:06	0:50:36
00-5962-030-23	25-4001-088/258-00	0:24:09	0:24:53	0:48:31

Figure 2
Cycle time per P/Ns

Figure 2 Shows the P/Ns, which were included in this design project. In the right of the P/Ns are the condyles tools that they use. The condyles are the more expensive tool used in the machining operation. The last three columns shows the cycle time per face one and 2, the cycle time per face two and four and finally the cycle time of the full run, remember that there are 4 face per cube that each one have 2 units to be machined. [1]

RESEARCH OBJECTIVE

The main objective of this design project is to show how to improve the manufacturing process related to the CNC program machining process. The improvements are focused on cost reduction and production increase. The cost reduction will be done using an alternate roughing tool. The production increase will be done reducing the cycle time using a lean way in the tool changing of the CNC program.

RESEARCH CONTRIBUTION

After the development and completion of this design project, it is expected to have a tool cost reduction as a main contribution. Also it is expected to have a production increase. This project supports the Company's goal to improve efficiencies, production and reduce costs. A time study will be excecuted in the articular surface cell. At this time no time study exists and this is really important when improvement initiatives need to be performed. Also, the scope of this project can be used to implement the same improvement effort in other areas. This project is an example of the company values, which ensure that every action taken in this assignment to accomplish its objectives is developed keeping in mind that quality is first.

LITERATURE REVIEW

The concept of *Lean Six Sigma* is an innovation concept of Six Sigma, this one was created to incorporate Lean Techniques into the Six Sigma tools. Many companies use Lean Six Sigma to achieve broad-based innovation and superior financial performance. Lean Six Sigma is a combination of Lean methods and Six Sigma approaches. In this way, Lean Six Sigma approach drives organization not just to do things better but to do betters things. This project will focus on the problem solving process proposed by Lean Six Sigma method, using the DMAIC tool to direct this project into its different steps. [2]

METHODOLOGY

In this project various tools will be used, but basically all are lean six sigma oriented. The DMAIC and statistical tools will be used as a lean six sigma methodology in the problem solving. These tools are used to reduce the tooling change and to found any way to reduce the tooling cost. DMAIC it is an acronym for the five-phase process of Define, Measure, Analyze, Improve and Control. [3]

Define Phase

In this phase the Lean Six Sigma project team identifies the objectives and the needs and requirements of the customer. Practitioners begin by defining the process. They ask who the customers are and what their problems are. They identify the key characteristics important to the customer along with the process that support those key characteristics. For this project we will use the business impact chart and other tool to understand the scope of the project. Various tools are used by companies, in this phase, that help to create a map of the process to be improved, with defined and measurable deliverables and goals.

Measure Phase

In this phase all types of data will be collected in order to understand and identify were the root cause for the costs and poorly productivity generated is located in the process. In the measure phase the team will assess the amount of variation within the variables. Teams are expected to identify and measure both input and output process variation. This phase is very important because if the data is not gathered, then one will likely end up with a lot of quick projects with short lived or disappointing results. At the same time if the data is collected erroneously then the entire project will be a failure. The measure tools used in this project were the Pareto Chart and the Time Study worksheet; both tools are an infusion between Lean Techniques and the Six Sigma method. These tools help you decide where your improvement effort will be concentrated and can be used only when the problem under study can be broken down into categories. In summary the measure phase is about understanding the current process, how the process is measured and its baseline performance.

Analyze Phase

The analyzing phase is about finding the top causes of the problem we are attacking. When executed, this phase starts with the team regarding potential causes. The objective of this phase is to make sense of all the information and data collected, where this data is used to confirm the source of the process variation, poor quality or other objectives. The challenge in this phase is to analyze properly the data and have a rational and neutral judgment about the analysis to make the correct improvement decisions around the root cause. There are a number of methods for exploring potentials causes, in the case a VSM- Value Added & Non Value Added Steps, Flowchart and Control Charts of the process was developed to analyze the manufacturing process. [4]

Improve Phase

The fourth step is to improve the process. Solutions to the problem are developed, and changes are made to the process. Results of process changes are seen in the measurements. In this step, the company can judge whether the changes are beneficial, or if another set of changes is necessary. This is the phase where all the work you have done so far in your project can come together and start to show some success. All the data mining and analysis that has been done will give you the right improvements to make to your processes. Sometimes this phase starts with the creation of an improvement implementation plan. In order to create the implementation plan, you need to gather up all the conclusions that have been formed through the analysis that you have done. Now that you know what improvements need to be made, you have to figure out what you need to do in order to implement them. For the improve phase we implement Lean tools to correct the problem exposed in this project. For the success of this stage it is important that the project team is aligned with the possible solutions to be used.

Control Phase

The Control Phase is the fifth and final phase of the Six Sigma methodology. This is the phase where you will see if the improvements that you have implemented are working. This phase unfortunately is one of the most overlooked phases in the methodology. One of the main reasons for improvements not showing any sustainability is because this phase has been overlooked. One of the big reasons of why Six Sigma programs fail is also because people get so excited after the improve phase, that they do not pay much attention to the control Phase - which leads to short-lived improvements. The key to the sustainability of the implemented action is the discipline and the continuing reviews of the actions taken. For this final phase we can implement the monitoring of different business metrics that impact directly the problem that was analyzed.

Results and Discussion

The final results were developed after the implementation of the Lean Six Sigma method integration. In this section we are going to discuss the analysis done before and after the implementation of DMAIC tool. In the problem statement chapter, the problem definition was presented and the time study was exposed through charts which was conducted to help us to have a better visualization of the problem. The time studies were developed in the measured phase. The data collected was analyzed through a Value Stream Mapping (VSM) and Control Charts, in this phase a flowchart was developed for a better to understanding of the opportunities, also the brainstorming techniques were implemented in the analyzed and improvement phase to find the root cause and possible solutions. To analyze the data and the process variation was developed a control charts for the before and after of each scenario to evaluating the process changes and improvements. The purpose of this tool is understand what causes that variation or waste to helps us decide what kinds of actions are most likely to lead to lasting improvement and work to minimize variation around a target. The following figures show the VSM for the machining manufacturing process. [5]

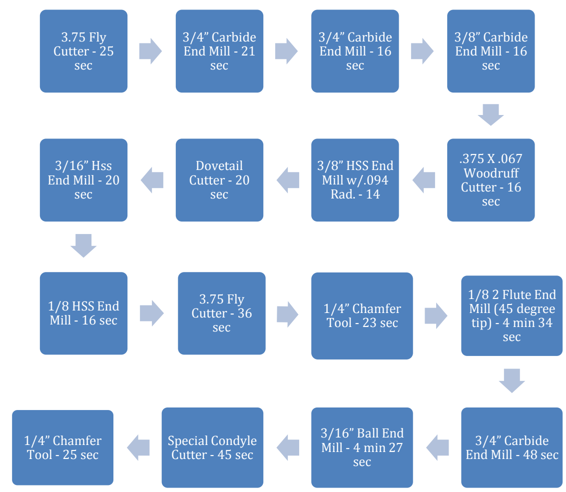

Figure 3

Product 00-5962-030-10-Before the VSM for the Machining Manufacturing Process

Figure 3, shows the Value Stream Map Exercise for the product 00-5962-030-10 before the improvement implementation. The total manufacture lead-time to machine one unit was 10 minutes with 59 second. The follow Figure 4, shows the Pareto Chart before the evaluate process.

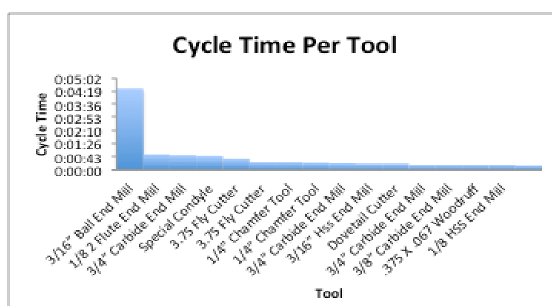

Figure 4

Product 00-5962-030-10-Before the VSM for the Machining Manufacturing Process

This figure shows the cycle time for each tool during the machining manufacturing process of this product. The tool we want to focus, given that is one of the most expensive, is the special condyle. This condyle is the fourth more used during the machining. The main idea is to found some way to reduce the use of this tool and make it one of the lowest used.

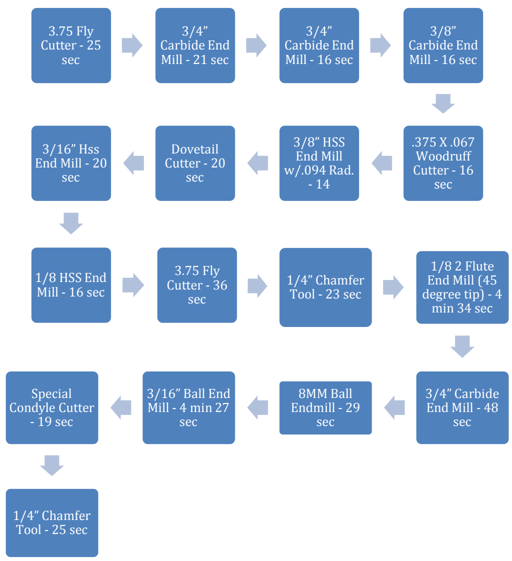

Figure 5

Product 00-5962-030-10-After the VSM for the Machining Manufacturing Process

This figure shows the VSM of the machining manufacturing process after the implementation of the DMAIC method. In the figure 5 it is showed a new tool, 8mm ball end mill. This is an inexpensive tool that is commonly used in other cells. This tool was chose for your availability and functionality. This tool in the new VSM it was showed that his specific cycle time is 29 seconds. This tool will reduce the effort and cycle time of the special condyles, I will make the roughing operation and the condyle only the final path. This new tool added will reduce (showed in the VSM) the cycle time of the condyles from 45 seconds to 19 seconds. In terms of percentage it will reduce 58% of the condyle tool usage.

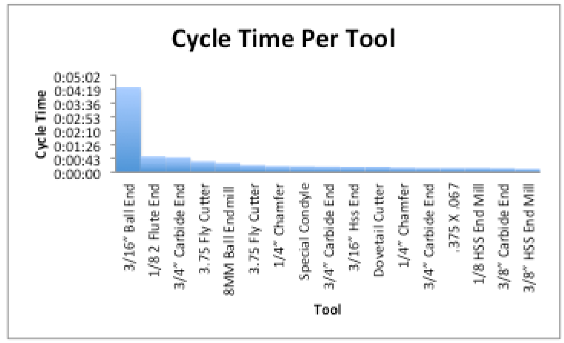

Figure 6

Product 00-5962-030-10-After the VSM for the Machining Manufacturing Process

This figure shows the cycle time per tool after the addition of the 8mm ball end mill tool. Showed in the Pareto, the condyle tool is in the 8th place of most tools used.

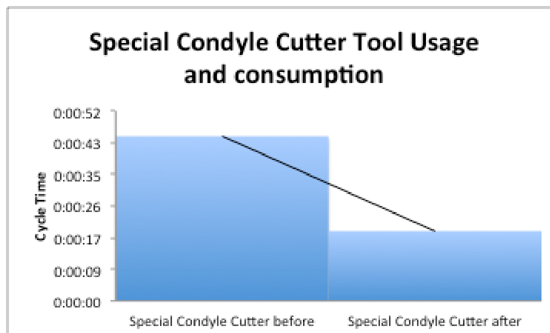

Figure 7

Condyles Pareto Chart, Tool Usage per Unit.

The figure 7 shows the cycle time of the special condyle before and after the implementation of the new tool. Due that the cycle time of the tool is directly proportional to the tool life, there will be a total approx. of 58% of tool consumption cost reduction when manufacturing this specific product.

The other improvement that was done and that will be explained is the tool changing. Exploring lean manufacturing and incorporating it in the tool changing sequence to void all waste, a new tool changing sequence will be incorporated.

Face#1_ 2 Parts Current Program		
CUTTING TIME	SPINDEL SPIN TIME	CYCLE TIME
0:04:03	0:06:21	0:07:18
Face#3_2 Parts Current Program		
CUTTING TIME	SPINDEL SPIN TIME	CYCLE TIME
0:04:03	0:06:21	0:07:18
Face#2_ 2 Parts Current Program		
CUTTING TIME	SPINDEL SPIN TIME	CYCLE TIME
0:10:25	0:11:28	0:11:51
Face#4_2 Parts Current Program		
CUTTING TIME	SPINDEL SPIN TIME	CYCLE TIME
0:10:25	0:11:28	0:11:51

Figure 8

Cycle Time of the Current Tooling Changing Sequence

Full Run 8 Parts Current Program		
CUTTING TIME	SPINDEL SPIN TIME	CYCLE TIME
0:28:06	0:35:02	0:38:18

Figure 9

Complete Cycle Time of the Current Tooling Changing Sequence

This figure shows the cycle time of each face of the machine cube before the new tool changing sequence was incorporated. Currently tool-changing sequence have the following order:

1. Part #1, face #1 – completed machined with all tools.
2. Part #2, face #1 – completed machined with all tools.
3. Part #1, face #3 – completed machined with all tools.
4. Part #2, face #3 – completed machined with all tools.
5. Part #1, face #2 – completed machined with all tools.
6. Part #2, face #2 – completed machined with all tools.
7. Part #1, face #4 – completed machined with all tools.
8. Part #1, face #4 – completed machined with all tools.

When this sequence was analyzed it was concluded that the machine waste a lot of time changing the tools. This waste is specific of the travel of the tool from the tool magazine to the unit to be machined and again to the tool magazine. To machine a full run there is a total of 64 tool changes per unit.

Face#1&3_ 4 Parts New Program with new sequences		
CUTTING TIME	SPINDEL SPIN TIME	CYCLE TIME
0:11:36	0:12:36	0:12:34
Face#2&4_ 4 Parts New Program with new sequences		
CUTTING TIME	SPINDEL SPIN TIME	CYCLE TIME
0:20:32	0:22:37	0:23:01

Figure 10

Cycle Time of the New Tooling Changing Sequence

Full Run 8 Parts New Program with new sequences		
CUTTING TIME	SPINDEL SPIN TIME	CYCLE TIME
0:027:29	0:33:20	0:34:31

Figure 11

Complete Cycle Time of the New Tooling Changing Sequence

This figure shows the cycle time of each face of the machine cube after the new tool changing sequence was incorporated. New tool-changing sequence has the following order:

1. Tool #1 will work on the 2 units of face #1 and with the 2 units of face #3.
2. Tool #2 will work on the 2 units of face #1 and with the 2 units of face #3.
3. Tool #3 will work on the 2 units of face #1 and with the 2 units of face #3.
4. Tool #4 will work on the 2 units of face #1 and with the 2 units of face #3.
5. Tool #5 will work on the 2 units of face #1 and with the 2 units of face #3.
6. Tool #6 will work on the 2 units of face #1 and with the 2 units of face #3.
7. Tool #7 will work on the 2 units of face #1 and with the 2 units of face #3.
8. Tool #8 will work on the 2 units of face #1 and with the 2 units of face #3.
9. Tool #9 will work on the 2 units of face #1 and with the 2 units of face #3.
10. Tool #10 will work on the 2 units of face #1 and with the 2 units of face #3.
11. Tool #11 will work on the 2 units of face #1 and with the 2 units of face #3.
12. Tool #12 will work on the 2 units of face #1 and with the 2 units of face #3.

13. Tool #13 will work on the 2 units of face #2 and with the 2 units of face #4.
14. Tool #14 will work on the 2 units of face #2 and with the 2 units of face #4.
15. Tool #15 will work on the 2 units of face #2 and with the 2 units of face #4.
16. Tool #16 will work on the 2 units of face #2 and with the 2 units of face #4.
17. Tool #17 will work on the 2 units of face #2 and with the 2 units of face #4.

With this tooling changing sequence configuration, there will be a total of 17 tooling changing. In terms of percentage it will reduce by 73% the tooling changing. This reduce in tooling changing will reduce the waste and let us to increase the manufacturing.

Finally when incorporating all changes the one full run cycle time will be reduced by 3 minutes 47 seconds.

Description	hh:mm:ss
Available time per shift	8:30:00
Less lunch time	0:20:00
Less break time	0:30:00
Set-up time	1:00:00
Allowance	0:10:00
Total Machining Time	6:30:00

Figure 12
Hours Worked per Shifts

Figure # 12 shows the hours worked per shifts. This time was used to make the time study and the following tables and data that will be showed in this paper.

Choice the part Number	Cycle Time (Current) Full Run	Cycle Time (New) Full Run	Improvement Time per full run
00-5962-030-10	38:18	34:31	03:47
00-5962-030-12	38:03	34:52	03:11
00-5962-030-14	38:03	34:33	03:30
00-5962-030-17	47:06	42:51	04:15
00-5962-030-20	50:36	46:41	03:55
00-5962-030-23	48:31	44:20	04:11

Figure 13
Improvement Time per Full Run

Figure # 13 shows current cycle time and the new cycle time after implementing all improvement. Finally in the last column it shows the improvement in all sizes of this specific product family.

Part Numbers	Run per shift current program	Run per shift new program	Quantity Parts per Shift current program	Quantity Parts per Shift New program
00-5962-030-10	10.2	11.3	40.7	45.2
00-5962-030-12	10.2	11.2	41.0	44.7
00-5962-030-14	10.2	11.3	41.0	45.2
00-5962-030-17	8.3	9.1	33.1	36.4
00-5962-030-20	7.7	8.4	30.8	33.4
00-5962-030-23	8.0	8.8	32.2	35.2

Figure 14
Production Before and After the Improvements

Figure # 14 shows in column two and three how many full runs can be done in one shift before and after the improvement. In column four and five it shows the production per shift before and after the improvement to the CNC program and tooling changing sequence.

Conclusion

After the DMAIC implementation as a Lean Six Sigma method the results were positive, reducing the tooling cost and cycle time and increasing the manufacturing production. After the implementation, operators were trained in the new changes. The results of this design project were presented to management. Finally management found this project very useful, and then they support the execution of this project in the other product family. Also, this project was presented to other areas to be analyzed and used as base to make other improvement in all the cells of Zimmer Manufacturing.

References

[1] Womack, J. P. and Jones, D., "Lean Thinking", *Simon & Schuster Inc.*, 2nd Edition.

[2] Byrne, G., Lubowe, D. & Blitz, A., "Driven operational innovation using Lean Six Sigma", *IBM Global Services*, Copyright IBM Corporation, 2007.

[3] Nave, D., "How to compare Six Sigma, Lean and the Theory of Constraints", *ASQ Organization*, March 2002.

[4] Xie, M., Goh, T. N. & Kuralmani, V., "Statistical Models and Control Charts for High Quality Processes", *Kluwer Academic Publisher*, 2002.

[5] Jones, D. and Womack, J. with Brunt, D. and Lovejoy, M., "Seeing the whole Value Stream", *Lean Enterprises Institute Inc.*, 2nd Edition, 2011.