ASEE AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Paper ID #44560

Strategies for Improving the Quality and Effectiveness of Education Courses

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Abstract:

The Manufacturing processes Lab (IENG 303) is one of the courses that is taught in the Industrial Engineering Department. The students perform several manufacturing processes in this course and for every one of these manufacturing processes, the students need to submit a project report. One of these manufacturing processes is a CNC turning process. The turning project of this course has historically had extensive average time for completion. As such, it was deemed necessary that a way to improve the quality of a turning project be generated. Industrial Quality Control (IENG 316) is also taught as part of the industrial engineering curriculum, and it was determined that the quality tools in this course should be used to evaluate the initial performance of the turning project. An executive activities sheet has been developed for this IENG 303 turning project to collect data about the time required to finish this project and to check if that was meeting the expectation or not. The turning projects of Spring 2021 and Fall 2021 semesters were evaluated by using several analysis techniques, such as Shewhart's control chart, the DMAIC process, check sheets, scatter diagrams, pareto charts, and fishbone diagrams. Several quality control tools were used to evaluate the length of time for the in-lab turning process and overall project completion. Several assignable causes were found and resolved to improve this project in the Spring 2022 semester. Then, the project was reevaluated by using quality control tools. Significant improvements were obtained from this evaluation which reduced the time to finish the turning machining process by 50% and reduced the errors and needed troubleshooting in the process and minimized the scrap material in the process which all led to improving the quality of the turning project.

Keywords:
Quality Improvement, Design for Quality, Manufacturing Processes, Turning Process, Reforming Curriculum

The Reason for Research

In The Manufacturing Processes Lab (IENG 303), there has been high variation among completion times for the turning project. Completion times ranged from 180 to 375 minutes. In addition to high variation, there has also been a high average completion time for the turning project as well. IENG 303 is a one credit hour course and should not demand an excessive amount of time to complete the turning process and the overall project. Further, it is beneficial to the teaching instructors if the in-lab time is minimal so that there is enough lab time for all of the students in the class. High turning process variation can make it difficult to effectively schedule students and teaching assistants to the lab and can ultimately cause students to not be able to complete the needed lab work for the course. It was deemed imperative that the turning process was put into control and that safeguards were implemented to mitigate high variation and overly long completion times.

Introduction

The present industrial environment is largely shaped by manufacturing processes, which make it possible to produce a vast range of items that are a part of everyday life. The Manufacturing Processes Lab is an important center where scholars, practitioners, and students come together to explore the complexities of state-of-the-art methods, encouraging creativity and productivity in manufacturing. An overview of the relevance of manufacturing processes, the role of laboratories in their investigation, and the value of practical experience in comprehending and mastering these processes are presented in this introduction. Industrialization is based on manufacturing processes, which convert raw resources into completed goods. They cover a wide range of approaches, from cutting-edge technologies to conventional ways. Kalpakjian and Schmid (2014) assert that "manufacturing processes are essential to the creation of products with desired shapes, properties, and performance characteristics." These procedures affect the cost, sustainability, and quality of products in a number of industries, including electronics, healthcare, and the automobile and aerospace sectors.

Professionals and students can bridge the gap between theory and practice in a unique setting offered by laboratories. Groover (2018) states that "Laboratories are instrumental in imparting hands-on experience, allowing individuals to understand the nuances of manufacturing processes beyond theoretical concepts." Students can develop a comprehensive understanding of production techniques by learning about material qualities, process parameters, and real-world difficulties in a manufacturing processes lab.

The quick development of technology means that production procedures are always changing. The lab transforms into a dynamic environment for investigating and testing state-of-the-art methods including smart manufacturing, sophisticated machining, and additive manufacturing. Cagliano & Spina (2000) have emphasized that "laboratories are essential for researching and developing new manufacturing processes that drive innovation in industry."

Sustaining elevated benchmarks for product and service excellence is crucial for the prosperity of organizations in the current competitive and ever-changing business landscape. Courses on quality control are essential for providing people with the information and abilities needed to maintain and improve quality standards in a variety of businesses. An overview of the importance of quality control education, the changing face of quality management, and the critical role these courses play in promoting an excellent culture are given in this introduction. Effective quality control has a significant impact on customer happiness, brand reputation, and overall operational efficiency, making it an essential element of corporate success. According to Juran and DeFeo (2010), "A well-crafted cultural environment produces quality. It must represent the organization's core values, not just a small portion of them." To remain competitive and relevant in the market, goods and services must either meet or surpass client expectations.

Since new techniques and technology have been included over time, the discipline of quality management has undergone tremendous evolution. A few examples of frameworks that have influenced modern quality control techniques are the ISO 9000 family of standards, Six Sigma, and Total Quality Management (TQM) (Dale et al., 2016). The goal of quality control courses is to give students a thorough understanding of these approaches and how to use them practically in various organizational settings.

An organized path for those looking to become experts in the concepts and procedures of quality management is provided by quality control courses. Numerous subjects are covered in these courses, including continuous improvement, risk management, quality assurance, and statistical process control. According to Besterfield (2013), "Education and training are essential components for building a skilled workforce capable of implementing effective quality control strategies.". New aspects of quality control have been brought about by the introduction of Industry 4.0 and the integration of digital technology. Digital quality management systems, artificial intelligence, and data analytics are frequently covered in quality management courses. This guarantees that experts are prepared to handle the intricacies of contemporary manufacturing and service provision (Souza et al., 2022).

The two courses of focus in this project are IENG 303, Manufacturing Processes Laboratory and IENG 316, Industrial Quality Control. IENG 303 is a 1-hour credit course that allows students to develop insight into various manufacturing processes. In this course, students are required to complete labs that involve creating designs within Autodesk Fusion, performing manufacturing processes in the lab, and completing project templates on their procedures and outcomes. Within each lab, the required tasks can be summarized into the following list: watch the project-specific instructional video that is created by the course instructor, create the design that meets the project specifications within Autodesk Fusion 360, create the tool path for the machine of focus, perform the machining in the lab, and create the project template for the project. The machine is overseen by teaching assistants who help students operate the machine, perform machine diagnostics, and ensure that students take the proper safety precautions.

IENG 316, Industrial Quality Control is a course that assists students in developing their statistical analysis abilities. Examples of tools that are taught within this course are control charts, histograms, cause and effect diagrams, check sheets, and scatter diagrams. The students learn how to calculate process mean and variance and to recognize when a process is out of control. Towards the end of the semester, when students have been taught the majority of the statistical and quality analysis tools, they are assigned a project to analyze a process to determine whether or not it is in control and if it is to propose recommendations on how to improve the process.

The turning project was analyzed and investigated within IENG 303 for the end-of-course project. The purpose of the project was to determine if the process was in control or not, identify the assignable causes, and to improve realistic recommendations that could be identified to reduce both overall mean completion time and process variation. These projects served two main purposes. First, the students in IENG 316 learned how to apply the tools they learned to real world scenarios. Secondly, the turning project was improved to allow for a more productive and less interrupted semester for the IENG 303 class.

Methodology

The two IENG 316 project groups that worked on the turning project in two different semesters (before and after the quality improvements) used a statistical approach to analyze the IENG 303 turning project process. The first step in the process was to collect data. This was done by extracting a sample size of executive reports (personal information removed) and recording the number of minutes the turning project took to complete along with capturing comments that were made by the IENG 303 students that provided insight into the reason behind the project duration. Figure 1 below shows an example of a partial turning project template. The section of executive schedule was used to collect the date to be analyzed by the quality control tools. Also, the conclusion and Follow-Up Actions section was utilized to find the assignable causes that made the process out of control.

Figure 1: Example of Turning Project Executive Report

Once the data was recorded, the team used a plethora of tools that are taught in IENG 316 to visualize the data and make useful inferences. The first tool that was used was the check sheet. When reviewing the data, the team recognized some thematic issues the IENG 303 students were experiencing. Two check sheets were created: one for the Spring 2021 semester and one for the Fall 2021 semester.

Table 1: Check sheet of Errors for Extended Turning Lab Times for Spring 2021

Check Sheet of "Errors"/Reasons Provided for Extended Turning Lab Times - Spring 2021		
Type of Error	**Count**	**Score**
Defined Axis on Part Incorrectly	I	1
Miscellaneous Problems	II	2
Toolpath Creation Issues	I	1
CNC Program/Machine Down - Operated Manually	IIIIIIIIIIIIIIIIIIII	20
	Total Errors	24

As seen in Table 1 , a significant number of prolonged turning lab times occurred because the CNC Program/Machine was down. It is important to note that type of errors was only able to be identified if the student explicitly wrote that they had experienced delay time for that specific type of error. The team also created a check sheet for Fall 2021 turning lab times as well.

Table 2: Check sheet of Errors for Extended Turning Lab Times for Fall 2021

Check Sheet of "Errors"/Reasons Provided for Extended Turning Lab Times - Fall 2021		
Type of Error	**Count**	**Score**
>1 Trip to Lab Required	I	1
Complicated Design	II	2
Dimension Difficulties	I	1
Surface Finish Quality Defect/Material Difficulties	II	2
Machine Cleaning Delays	I	1
CNC Program/Machine Down - Operated Manually	I	1
	Total Errors	8

The students in the Fall semester did not explicitly mention as many reasons for prolonged delays in their project. As seen in table 2, only 8 errors were counted with no specific category containing much more than any other. The teams statistically analyzed the processes for each semester separately. The first step of this procedure was calculating the sample mean, sample variation, and sample standard deviation for the processes by using equations 1, 2, and 3 respectively.

Equation 1: $\bar{x} = \frac{\sum x}{n}$

Equation 2: $s^2 = \frac{\sum(x-\bar{x})^2}{n-1}$

Equation 3. $s = \sqrt{\frac{\sum(x-\bar{x})^2}{n}}$

Once these numbers were obtained, the groups underwent the process of creating control charts. To do this, the center line and upper and lower control limits were calculated using the equations below:

Equation 4. $UCL = \bar{\bar{x}} + 3\sigma/\sqrt{n}$

Equation 5. $CL = \bar{\bar{x}}$

Equation 6. $LCL = \bar{\bar{x}} - 3\sigma/\sqrt{n}$

A control chart was created for the turning process itself and for the overall turning project for both the Spring 2021 and Fall 2021 semesters. The control charts can be seen below.

Figure 2 showcases the number of minutes spent on the turning process for each sample during Spring 2021.

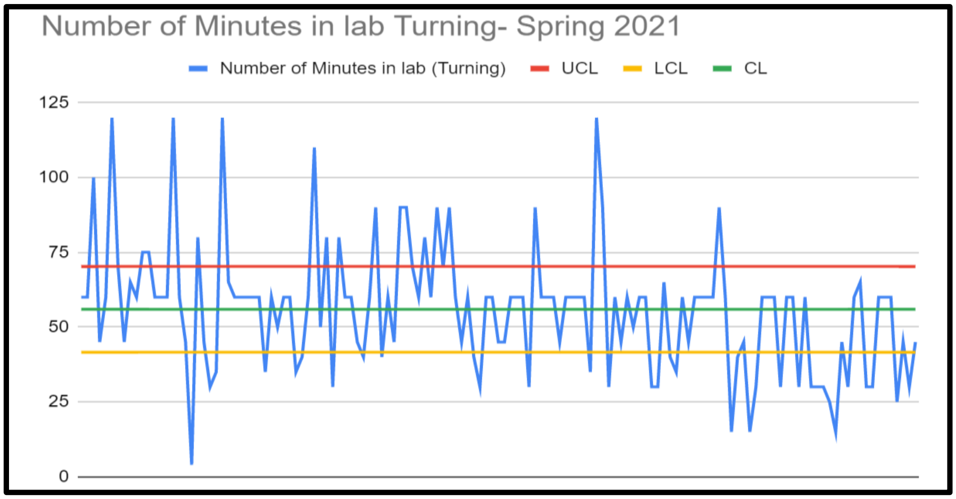

Figure 2: Time Spent in Lab Turning Spring 2021 Semester

Figure 3 below, shows time spent in minutes overall turning project for Spring of 2021.

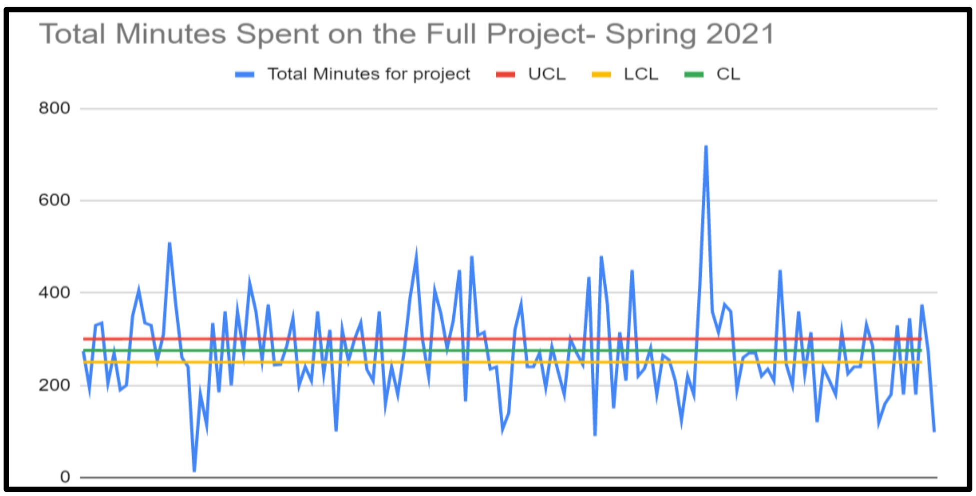

Figure 3: Total Time Spent on the Full Project Spring 2021 Semester

Figure 4 displays the time in minutes spent on the turning process for Fall of 2021.

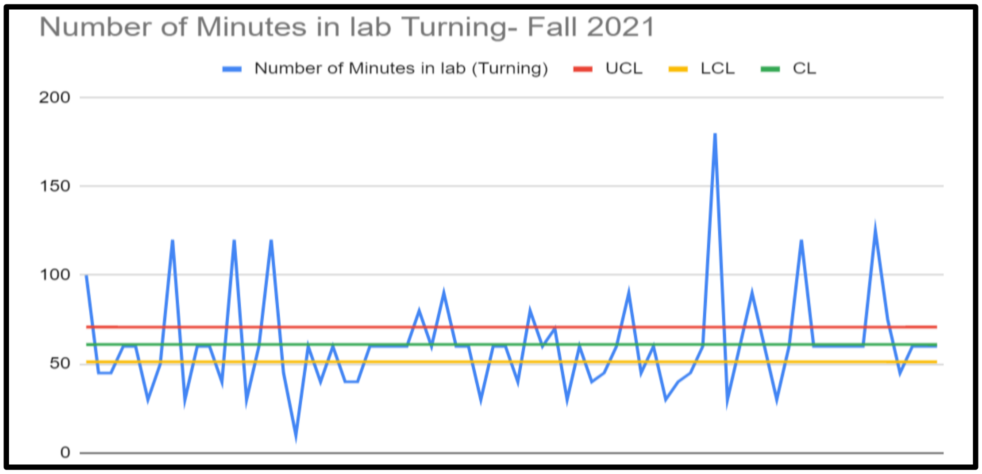

Figure 4: Time Spent in Lab Turning Fall 2021 Semester

Figure 5 showcases the number of minutes spent on the whole turning project for Fall 2021.

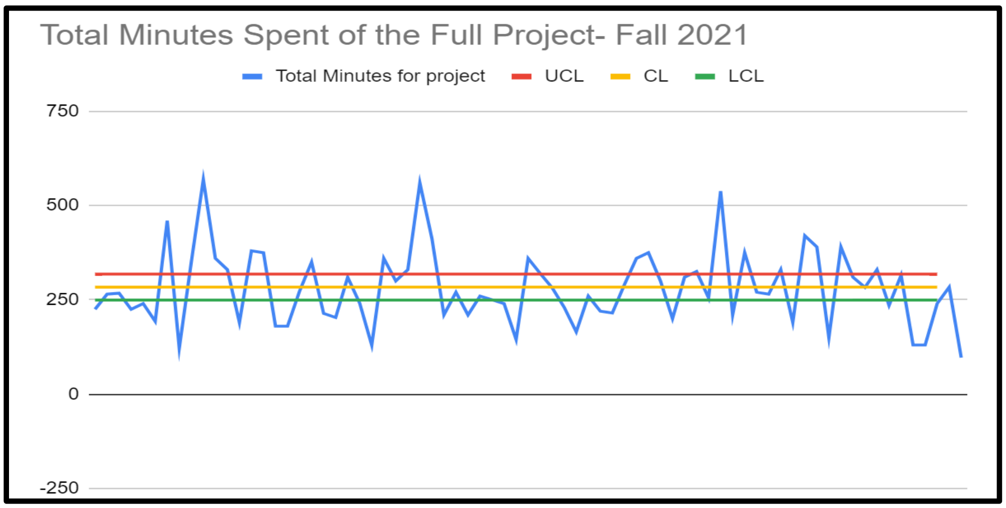

Figure 5: Total Time Spent on the Full Project Fall 2021 Semester

From the control charts, it was determined that both the turning process and the whole turning project were out of control. All four of the control charts have multiple points outside the control limits which indicate an out-of-control process.

In addition to creating control charts, a scatter diagram was created from the data for both Spring 2021 and Fall 2021 semesters. The team placed the turning process time of completion on the x axis and the time for completing the whole process on the y axis. The purpose of creating the chart was to calculate the correlation coefficient and to see if there was any visible correlation between the two data sets. Figure 6 displays the created scatter plot. The team found the correlation coefficient to be 0.367 which indicates a weak correlation between the data sets. As the correlation of the data becomes stronger, the value becomes closer to one. The calculated value of 0.367 is not close to 1 which shows that the data is not strongly correlated.

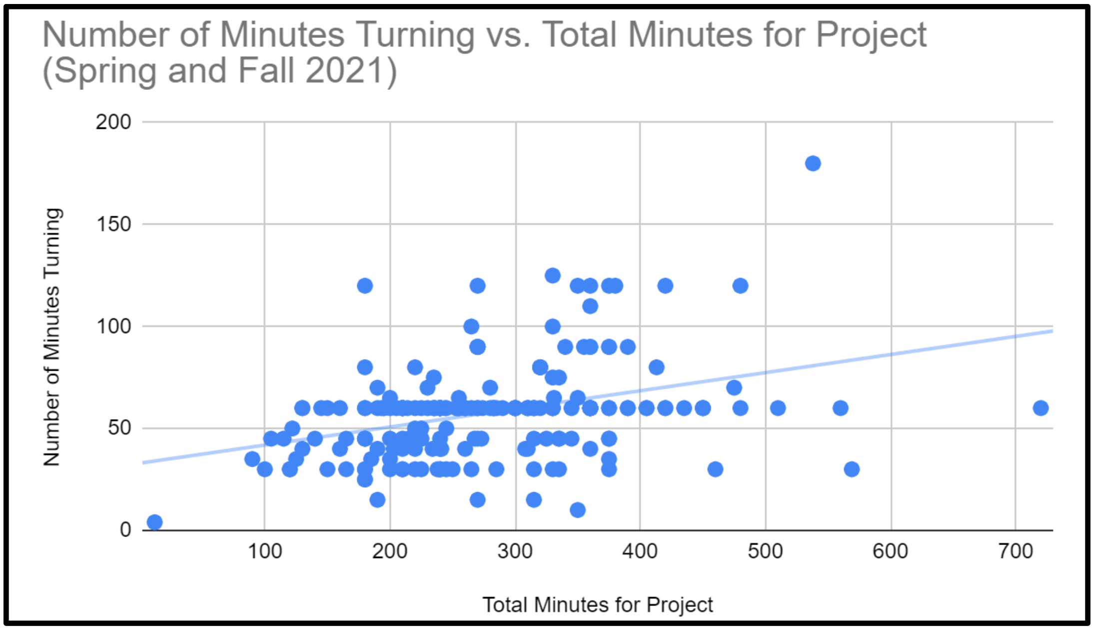

Figure 6: Scatter Plot of Time Spent Turning vs. Total Project Time

The team desired to identify the root causes of the high variation of completion times and high average completion times. As a result, the team created a fishbone diagram. Four main categories were identified in the analysis: extended time creating appropriate design, machine delays, part handling problems, and design flaws as seen in Figure 7.

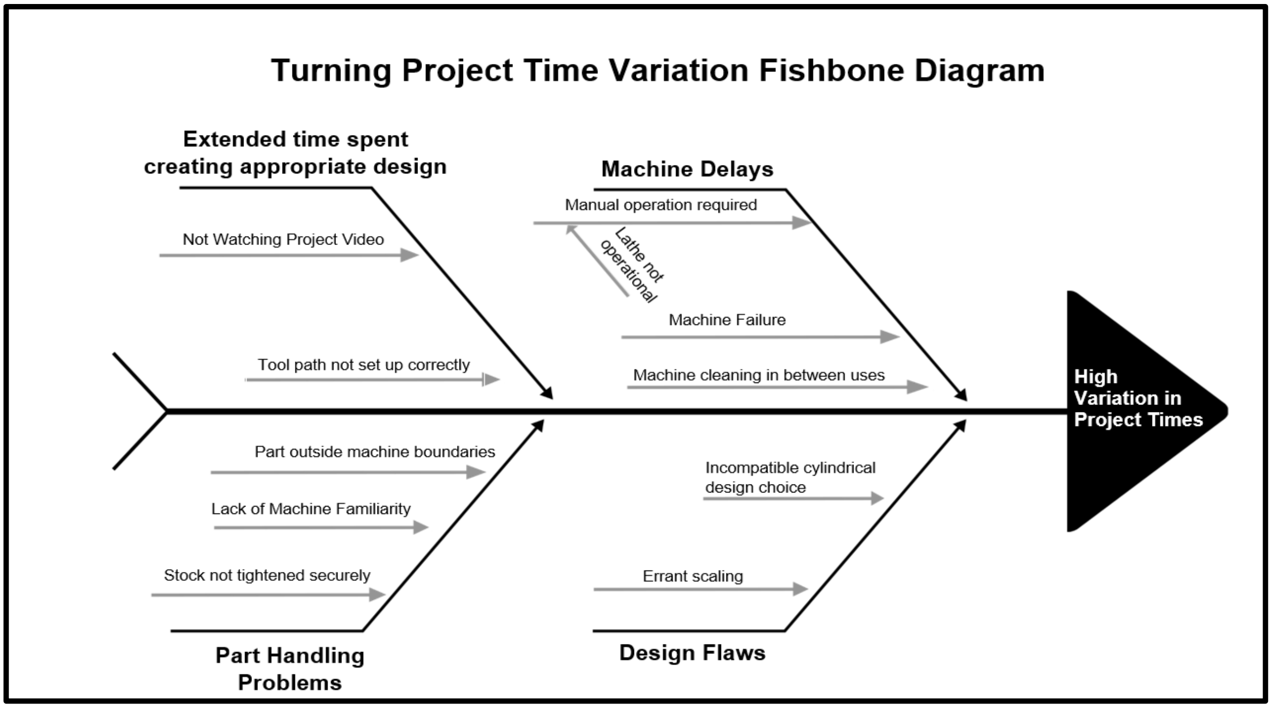

Figure 7: Fishbone Diagram of High Variation in Turning Project Completion Times

These four categories were gathered from the information the IENG 303 students provided in the conclusion section of the project templates. After the four main causes of the problem were identified, the sub causes were identified for each main category. This tool provided a systematic way to analyze the issue and drill down to the root problem.

To further analyze the process data, the UNTL and the LNTL were found using equations 7 and 8 as listed below.

Equation 7. UNTL = $\bar{\bar{x}} + 3\sigma$

Equation 8. LNTL = $\bar{\bar{x}} - 3\sigma$

Findings

After the analysis was performed on the process, the team identified the assignable causes of high variation and the subsequent out-of-control nature of the process. There were six main causes that were identified:

- Lack of knowledge of manual turning
- Machine not functioning sometimes
- Not watching the instructional videos
- Tool path troubleshooting needed

- Stock material wobbling
- Lack of knowledge about the project report requirements

An issue that caused large completion times and high variation in the process was that the students in IENG 303 had no prior experience turning before. Many students who went into the lab to perform the machining on their part did not know how to operate the machine and though there were TA's available to assist the students, additional time was needed in order to become accustomed to the process. In addition to the lack of prior experience, the machine itself proved to be faulty and required maintenance which inevitably led to longer completion times and increased variation as well.

To assist students with becoming familiar with the machining process and the turning project as a whole, the instructor of the class created and published instructional videos to be watched by the students. These videos provide instructions on how to set up the tool path, operate the machines, and provide insight into key things to look for when completing the project template. Occasionally, students do not watch these videos which greatly inhibits their ability to effectively machine their part and complete their whole project.

One other issue that caused prolonged completion times was troubleshooting faulty tool paths. Creating the tool path within Autodesk Fusion is a tedious process and requires attention to detail. If one misses even the smallest of steps, the tool can stop the mid process or even damage the part. Many students will unknowingly enter the lab with faulty tool paths which require assistance from the TA's to troubleshoot and ultimately remodify the problem. This corrective process requires much time and leads to extended lab completion time.

In addition to the tool path occasionally being faulty, the stock material that was used for the machining process caused issues. The material used was not conducive to the vibration of the machines which caused the material to wobble and required additional adjustments and overall, much more attention to complete.

Once the process was determined to be out of control, the IENG 316 project group brainstormed ways the turning process could be improved. The team recommended a series of improvements that would assist in lowering the high variation and large completion times of the turning project. The first of these improvements was the elimination of manual machining. Operating the machine manually proved to be a tedious process and one that did not significantly benefit the learning experience of the IENG 303 student. The project group recognized that IENG 303 students were having trouble with the stock material and proposed that better quality material be purchased for the process. The project group also suggested that quizzes should be assigned to the students to verify their understanding of the machining process, calculations, and project report requirements. These quizzes must be passed with an 80% or higher to be able to perform the machining process in the lab. The purpose of these quizzes was to ensure that students had watched the instructional videos and understood how to complete the key steps of the project. Listed below, are the summarized version of the identified assignable causes which contributed to the turning project being out of control in the Fall 2021 semester:

- Lack of knowledge about the manual turning
- Machine not functioning sometimes
- No watching the instructional videos
- Tool path troubleshooting needed
- Stock material wobbling

Implemented improvements

Using the DMAIC approach, the IENG 316 project team generated possible solutions that could be implemented to reduce the average duration of the turning project. The first of these solutions that were implemented was the elimination of manual machining. This allowed for more time for standard machining. Another solution that was implemented the stock materials replaced and centered. From the students below feedback, it could be seen that the stock material was a large issue contributing to the prolonged project completion time.

Samples of IENG 303 Students Comments – SEI Fall 2021 Before Improvements:

- “Many of the machines didn't work properly so maybe better machines”
- "More coverage on the machines”
- "Upgrade the machines. The machines break easily when they're used too much, so not everyone got to complete most of the labs”
- "I recommend changing the materials we use. It would have been nice to use steel or aluminum in one of the milling processes to see how they differ from plastic”

The IENG 303 instructor implemented quizzes for students to take to verify the students’ process understanding. These quizzes required students to review lab safety information as well as machine functionality. An additional requirement that the class instructor required was that quality check points were implemented for the process tool path. This did not create additional work for the student, but rather forced the student to focus on creating a correct tool path in a timely manner. To assist with creating a healthy, constructive lab environment, more teaching assistants were staffed for the lab part of the project. Further, the machine usage schedule process was improved to save time scheduling as well as optimize the in-lab machining time. An additional improvement that was made was that illustration project samples were provided to the students to ensure submission expectations were clear as well as maintaining standardization among student submissions.

The same quality control tools used in the initial evaluation for the fall 2021 and spring 2021 semesters, were used in evaluating the output of the CNC turning project for the spring 2022 semester.

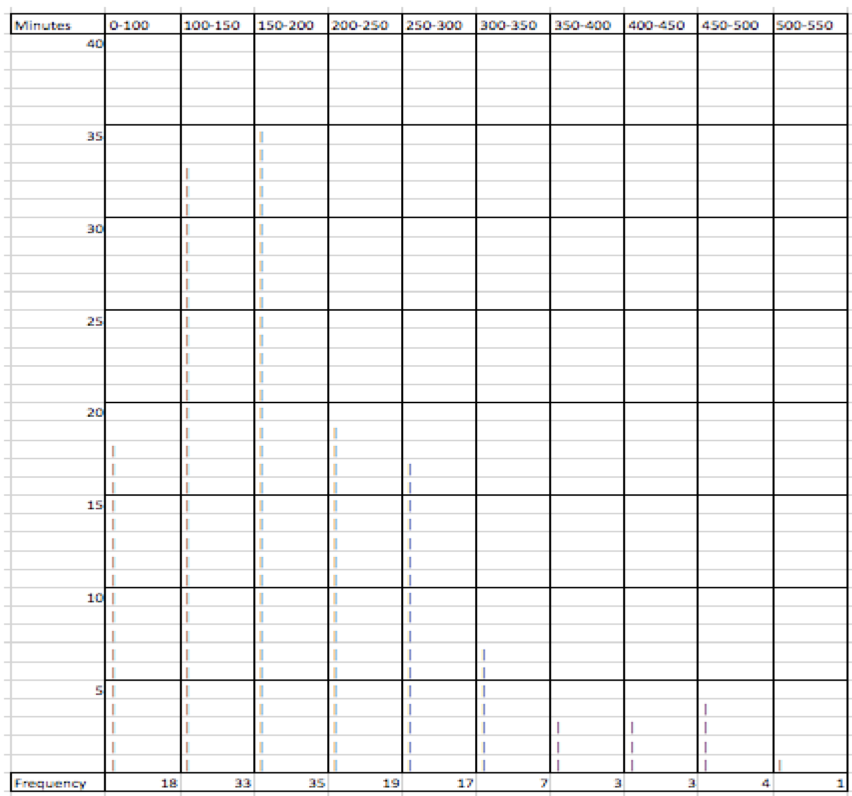

Figure 8: Project to Improvement Check Sheet– Spring 2022

Figure 9 below shows the data after applying the improvement in spring 2022 semester.

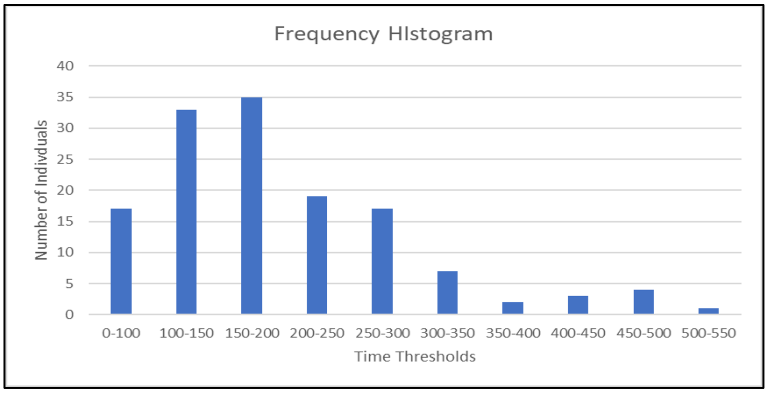

Figure 9: After Improvement Histogram– Spring 2022

The behavior of the data is shown in Figure 10 below:

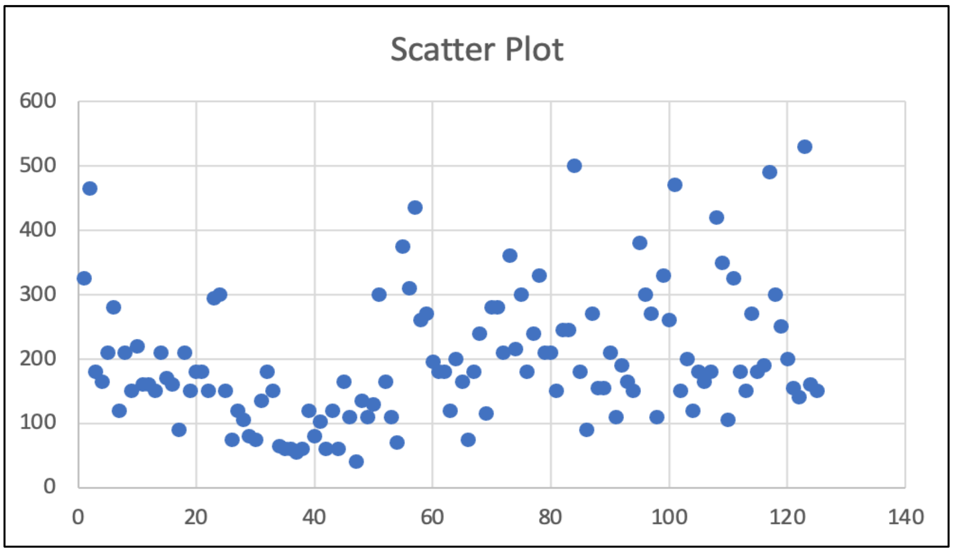

Figure 10: After Improvement Scatter diagram – Spring 2022

It can be clearly observed from the scatter diagram that the data is stationary and uncorrelated. This type of data is stable and doesn't have too much shifting in its sample means. From the data of the after applying the improvements the control X-bar and R control charts were created as shown in the figures 11 and 12 below:

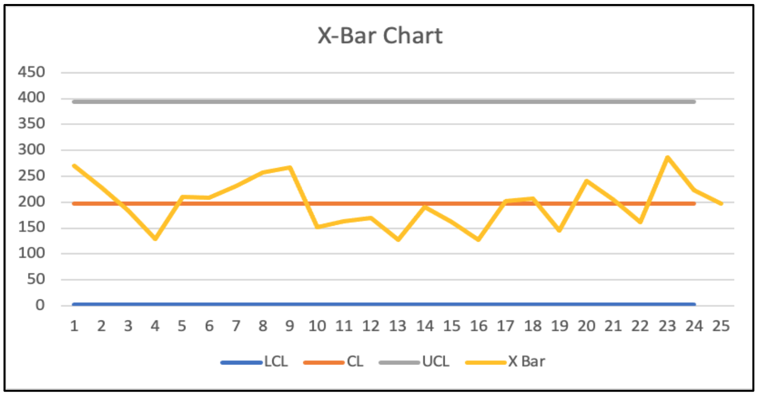

Figure 11: After Improvement X-bar Control Chart - Spring 2022

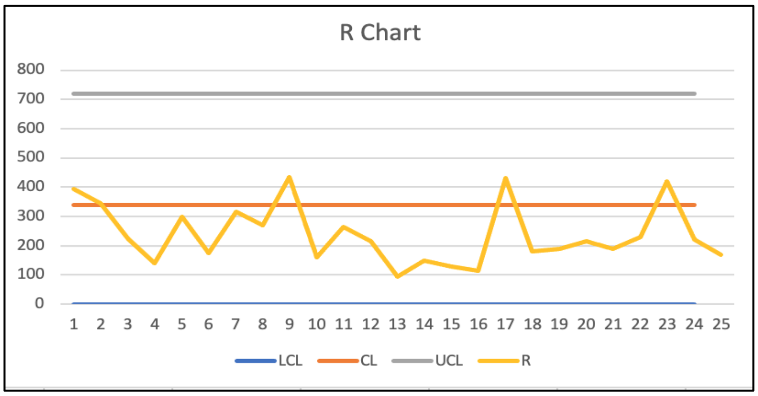

Figure 12: After Improvement R Control Chart - Spring 2022

We can see from the above control charts, the turning process was in-control for the spring 2022 semester. This was an indication that the applied improvements were useful to improve the turning project in the IENG 303 course. Moreover, the students' comments in the SEI for Spring 2022 semester positively reflected these improvements.

Samples of IENG 303 Students Comments – SEI Spring 2022 After Improvements:

- "The professor had videos for every lecture, which were step–by–step. This is extraordinarily helpful. As someone who has little experience with modeling software, the class was easy to understand because of this."
- "The creative freedom and structure of the projects was highly valuable. The TA's were also all very helpful."
- "The pre–project **quizzes** were the most helpful throughout the semester."

Results and Discussion

By using the Fishbone Diagram, it was found that there were four main categories that caused variation: measurement precision, skill capability, design, and machine. Then, by utilizing the Check Sheet, it was found that the main error in Fall 2021 was computer connection issues and students operating the turning machine manually in addition to lack of students' preparation. To evaluate the effect of the implemented improvements the professor turned to the SEI feedback from the students to identify what worked well and what needed to be improved. From the feedback, it was found that the quizzes had a tremendous, positive impact on the learning environment for the students as well as the instructional videos that the professor published. Overall, the feedback from the Spring 2022 semester was overwhelmingly positive.

Educational Impact

This project had a tremendous impact on the students in both IENG 316 and IENG 303. The students in IENG 316 were able to gain a deep insight into how to statistically analyze processes and use this analysis to drive real improvements. As part of the analysis process, the team used control charts, histograms, cause and effect diagrams, and other tools as well. Though the students had been taught these tools in lecture and tested on them as well, these tools were learned on a deeper level because of this project. Furthermore, the IENG 316 class obtained great experience with data collection and learned how to propose realistic recommendations in a convincing way.

This project had a tremendous positive impact on the IENG 303 learning experience as well. By implementing the improvements that the IENG 316 project group recommended, the IENG 303 class had a more learner-friendly, quicker turning project experience than previous semesters had. By improving the stock material, implementing a better scheduling process, and ensuring the TA's were optimally prepared, the students had shorter wait times in the lab and a clearer path to success for the project. Further, by implementing pre-lab quizzes, the students were forced to review the instruction material and have a baseline understanding of the equipment in the lab. These quizzes assisted with ensuring the project completion time was not extensive and provided an overall better experience for the IENG 303 student.

Suggested Future Improvements

To ensure that the turning project's average duration is kept at a reasonable level, the IENG 316 project group recommended that control measures be taken. The "Control" aspect of DMAIC is often overlooked, but is integral in ensuring that the effectiveness of implemented solutions is maintained. The IENG 316 project team recommended that quality control tools be used to monitor the turning project for future semesters just as they were used for the Fall and Spring semesters of 2021. Further, it was recommended that the IENG 303 professor continue to obtain feedback from students on what works well and what needs to be improved in regard to the turning project. This feedback can be gathered through SEI's as well as conversations with students.

The IENG 316 team in conjunction with the IENG 303 professor recommended that the project template be updated continuously. The project template should have clear instructions for each part the student is to fill out. This will ensure that standardization is achieved across project submissions as well as reducing the amount of time that is needed to fill it out. Machine problems were a cause of extended project completion time, and as such the IENG 316 team recommended that the turning machine be cleaned, checked, and calibrated regularly. Specifically, the machine should be calibrated every day that turing is to be done on it. It was found that the IENG 303's professor's project instructional videos were very instructive and current. However, as changes were made to the project and/or to the turning process in the lab in general, the videos will need to be updated accordingly. The IENG 316 project team identified the criticality of maintaining accurate up-to-date videos to ensure that the students are best supported.

As part of the analysis, it was found that students had issues with the stock material not interacting well with the machine. Troubleshooting and adjusting the stock material increased the time in the lab for some students and consequently raised the average time for the turning project. The project team recommended that a better stock material be chosen so that these problems would be eliminated. Lastly, it was suggested that all TA's are trained on the machines and equipment and the lab before assisting other students. Though the TA's had taken the IENG 303 class before, it was suggested that the TA's undergo training on how to upload the toolpath, operate the machine, as well as performing troubleshooting.

Another proposal was that if the lab turning time exceeded 60 minutes, the student record the specific reason for why that time was extensive in the project report. This will allow the professor and any individual(s) to identify specific causes for why the turning project's average duration was extensive. Also suggested for future consideration was that an executive schedule be made with the tasks pre-filled (and options for students to also add their own) for standardized reporting and comparison. Lastly, the IENG 316 project teams suggested that a sign-in/out sheet lab be made for precise turning time recordings. This would ensure that the data is accurate and keep the students accountable.

Conclusion

As a result of the improvements proposed by the IENG 316 project team, the IENG 303 turning project completion time was reduced by 50%. Also, there was less interruption and troubleshooting during the process because the students were better prepared before entering the lab. The scheduling process was improved to allow for more flexibility for students to perform their projects as well as reducing the amount of time to schedule. An additional positive result that was obtained from the implemented improvements was that the process failure rate was reduced and subsequently there was less material scrap. Overall, by creatively using tools taught in IENG 316, the learning experience in IENG 303 was improved tremendously. Simultaneously, the students in IENG 316 learned how to apply the lessons taught in lecture to assist with solving real issues that ultimately caused a significant improvement in the learning culture within the department.

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