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# Middle East Technical University

## IE 368 – Quality Planning and Control

# Case Study 2 – XYZ Shoes

**Spring 2023**


**Group Number 19**

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*"Academic integrity is expected of all students of METU at all times, whether in the presence or absence of members of the faculty. Understanding this, I declare that I shall not give, use, or receive unauthorized aid in this study."*

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## Introduction

'Doubt is a pain too lonely to know that faith is its twin brother'. It can clearly be seen that Khalid Gibran was not a quality control analyst, for when in doubt, statistical process control is the real twin brother. Shoes XYZ fall in sales is due to a specific sneaker, and the question of how to get it back on track will be answered by examining the available data and analyzing it using the proper tools, ratios, and graphs through statistical process control. This initial analysis will lead to a more specific, detailed data measurement to assess the accuracy of the preliminary analysis conducted on the production steps. Then a process monitoring system with a detailed action plan will be prescribed to the company in order to avoid future production and quality-related issues.

## Question 1

> ***Do you think that looking just at the total FTY is appropriate in assessing the quality level of the process, as the Quality Management Department claims?***

The first-time yield ($FTY$) takes into account the number of units going through a process and becoming defectives. It's formula is as follows, and the $FTY_i$ for each process $i$ is provided:

$$FTY_i = \frac{N_i - S_i}{N_i}$$

| Production Step | $FTY_i$ |
|---|---|
| Cutting | 0.999885 |
| Stitching | 0.99973997 |
| Sole Manufacturing | 0.999859947 |
| Assembly | 0.999419701 |

$$Total\ FTY\ (Total\ First\ Time\ Yield) = FTY_C * FTY_S * FTY_{SM} * FTY_A = 0.9989$$

Even though first-time yield can provide a clear view of the general quality of the firm's quality management in numbers, it does not provide specific info as $C$-charts or $P$-charts do. $FTY$ also does not include re-rolled or reworked units in its calculations and disregards them entirely.

> ***What can you say about the rolled throughput yield (RTY) of the process?***

First pass yield calculates the percentage of units that have passed through the process without becoming defectives or needing reworks:

$$FPY_i = \frac{N_i - R_i - S_i}{N_i}$$

| Production Step | FPY |
|---|---|
| Cutting | 0.999595 |
| Stitching | 0.999134901 |
| Sole Manufacturing | 0.999619857 |
| Assembly | 0.997803869 |

$$RTY\ (Rolled\ Throughput\ Yield) = FPY_C * FPY_S * FPY_{SM} * FPY_A = 0.99616$$

Rolled throughput yield is not looking great, but if the first pass yield of the stitching and assembly processes has been improved, then the $RTY$ can be increased.

***Which of the total FTY and RTY measures are more meaningful?***

It is better to include the reworks as well in the process of yield calculations because rework itself takes time and adds profit to the company. In addition, $RTY$ gives a better idea about costs, since a reworked part is more "expensive" than a part that has been processed once.

***Can you predict defects per unit (DPU) levels of the individual production steps besides FTY and first pass yield (FPY) of them?***

Under the assumption that the process follows Poisson distribution, it is possible to do that using the formula $DPU = -\ln FPY$. In order to figure out if the process does follow that distribution, center criteria need to be met:

- $DPO < 0.1$
- $m > 20$ where $m$ is the number of defect opportunities per unit
- $m \times DPO = DPU$

Verifying the conditions:

| Process | $DPO_i$ | $m_i$ | $m \times DPO = DPU$ |
|---|---|---|---|
| Cutting | $\frac{46}{400000} = 1.15 \times 10^{-4}$ | $< 20$ | True |
| Stitching | $\frac{104}{399954} = 2.6 \times 10^{-4}$ | $< 20$ | True |
| Sole Manufacturing | $1.4 \times 10^{-4}$ | $< 20$ | True |
| Assembly | $5.82 \times 10^{-4}$ | $< 20$ | True |

Since these conditions are met except for the second one, it may not be possible to calculate and predict the defects per unit levels of each process, individually. However, the formula will be used anyways and be compared with a more rigorous and precise method.

$$DPU_{i,estimated} = -\,ln(FPY_i)$$

| Production Step | $DPU_{i,estimated}$ |
|---|---|
| Cutting | 0.000405082 |
| Stitching | 0.000865474 |
| Sole Manufacturing | 0.000380215 |
| Assembly | 0.002198546 |

To calculate $DPU_{i,actual}$, the number of defects will be considered, mainly $S$ and $R$, and divided over the entire number of units that went through the process:

$$DPU_{i,actual} = \frac{Total\ number\ of\ defects\ in\ process}{Total\ number\ of\ units} = \frac{S_i + R_i}{N_i}$$

| Production Step | DPU (actual value) |
|---|---|
| Cutting | 0.000405 |
| Stitching | 0.000865099 |
| Sole Manufacturing | 0.000380143 |
| Assembly | 0.002196131 |

It is, however, seen that the values between the estimated and actual values are too close for comfort. According to Six Sigma Material (2022), the formula $DPU_i = -\ln FTY_i$ holds if the respective value of $DPU_i$ is small, where the smaller it is, the better of an estimate it is.

***What is the normalized yield (NY)?***

The normalized yield is the average yield of each process when considering a series of processes, of the formula: $NY = RTY^{\frac{1}{n}}$, with $n$ being the number of the processes that are in series. For XYZ Shoes, $n = 4$. The value of the normalized yield is $NY = 0.99616^{\frac{1}{4}} = 0.99904$

***Based on these measures, which production step should have the highest priority for improvement?***

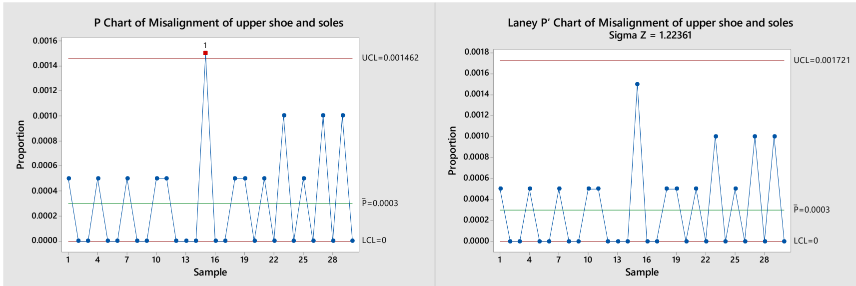
Even though the defective rates are low and the yields are high, some processes have better yield than others. Based on quantitative measurements it is clear that the assembly step, which is the last step in production of shoes, should be worked on the most, since it has the lowest yield and highest defect per unit amongst all the other steps.

## Question 2

*Before starting with the question, it is important to acknowledge that since the probability of each type of defective is constant and does not change, and the fact that it can be assumed that the probability of a defective occurring in a unit is independent from other units, the data can be estimated to a binomial distribution. This allows for use of $P$- and $C$-charts.*

***Based on these additional data, can you claim that each of the production steps in statistical control?***

Even though the firm boasts a small number of defectives per lot, it is not exempt from having its manufacturing processes fall out of control. With that being said, it seems that the data exhibits overdispersion sometimes, which is something to be expected, considering the large ($n = 2000$) sample size.

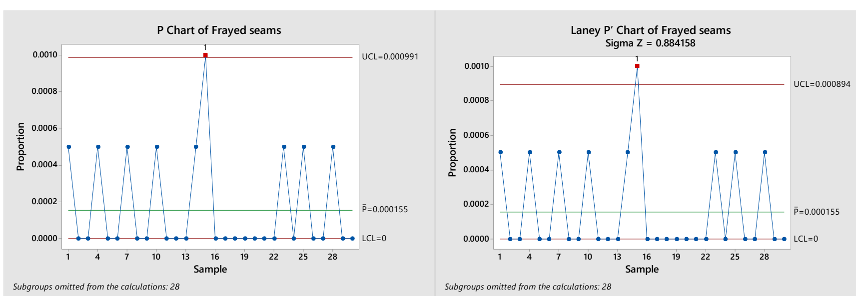



*Figures 1 and 2: P-chart and Laney P′-chart of misalignment of shoes and soles. Data shows overdispersion.*

After using the Laney $p'$-chart in order to catch dispersions, the $\sigma_z$ value is clearly higher than 1.1, meaning it exhibits overdispersion according to R manual (n.d.). After adjusting for overdispersion, the process is shown to be in-control, and has not fallen out of control like the traditional chart has suggested.

However, it seems that there may have been a shift after day 15, since it appears, at a first glance, that the misalignment issues had started to happen more frequently and at a higher frequency after day 15. After looking more into the issue, it does not appear that there could have been a shift occurring.

Even though the above charts do not display a possible special cause happening on day 15, the frayed seams charts do show that the stitching process fell out-of-control on day 15.




*Figures 3 and 4: P-chart and Laney P′-chart of frayed seams. Data shows under dispersion.*

The data sometimes also exhibits under dispersion in some cases. In the figures (3 and 4) above, an out-of-control point remained out of control even after checking the Laney $p'$-chart, since the latter's CL's actually narrowed down due to underdispersion of data.

Since day 15 marked the process as out-of-control, in this case it does not seem that the data following that data to be shifted, like in the misalignment charts above. To investigate whether this is related to the seemingly small shift in the misalignments chart, an EWMA chart is used, since it is not sensitive to non-normality (figure 5):

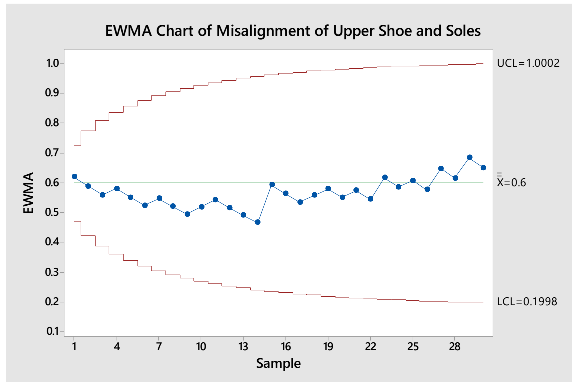
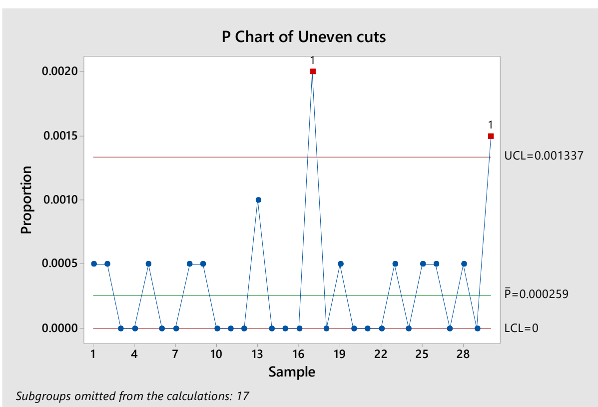
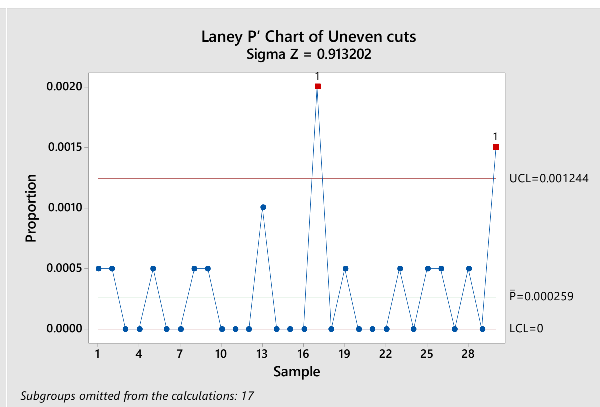



*Figure 5: EWMA Chart of Misalignment of upper shoe and soles.*

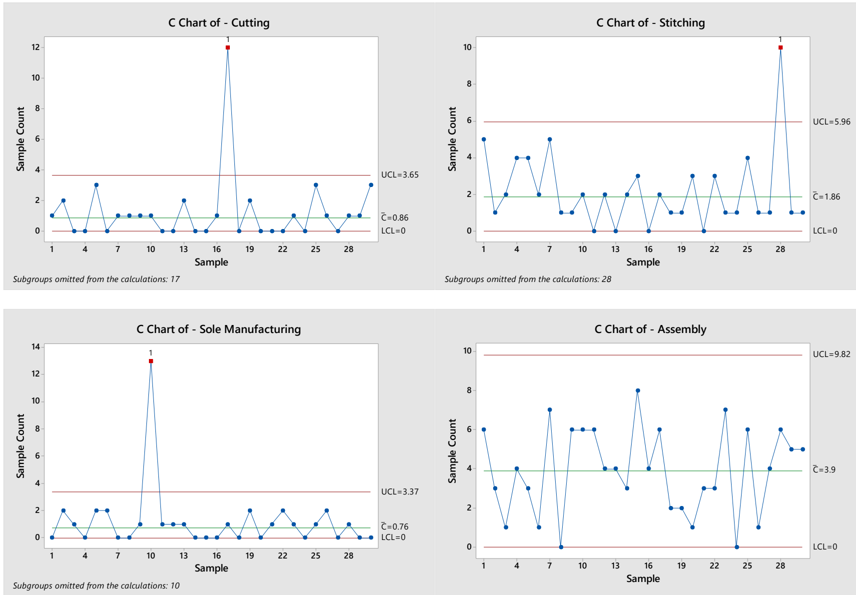
As seen, the data is very regular and no shifts are detected, so it can be safely assumed that no shift has occurred, yet, in the assembly process. However, the stitching process still seems to be out of control on day 15 in regard to frayed seams, and special causes must be investigated.




Since both the traditional and Laney $P'$-charts display an out-of-control point on day 30, it is safe to say that the cutting process has fallen out of control on that day in regard to uneven cuts, meaning XYZ Shoes need to inspect their cutting machines and blades to catch a possible special cause.

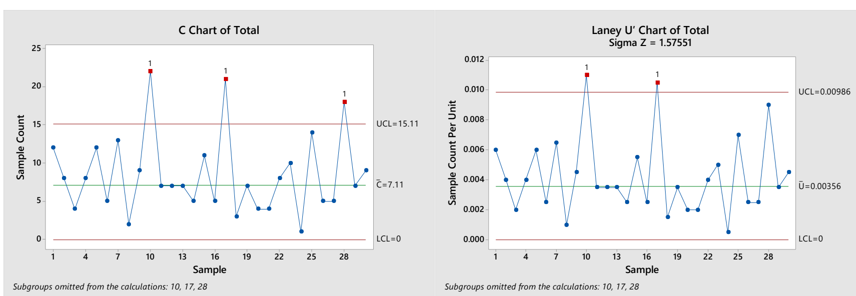
As far as the total number of defects goes per process, none of the four processes seem to be out-of-control, as seen by the following $C$-charts:




*Figures 6 through 10: C-charts of each manufacturing process.*

*Note: the rest of the charts and graphs are provided in appendix A.*

The entire process seems to be in-control when considering it as a whole, as seen in figures 11 and 12:




*Figures 11 and 12: C-chart and Laney $U'$-chart for total amount of defectives over the entire process. The data exhibits severe overdispersion.*

It is worth mentioning that $C$-charts and $U$-charts are similar, the values $C$ and $U$ are proportional to one another by some constant. This explains why the graphs look the same, barring the scales and the control limits, which were adjusted for overdispersion in the second figure.

One thing to note is that the Laney $U'$-chart did not catch day 28 as an out-of-control point. Meaning, that if the firm were using this chart to search for special causes, they could have missed the special cause entirely.

***What can you claim further about the capability of these process steps considering defect opportunities?***

After choosing a sample of 2000 shoes a day for 30 days per process, i.e., 60,000 shoes per process, the data shows that considering a total of 12 defects throughout the process making the total defect opportunities at a level of 720,000 or 12x60,000, a total defect counted at 246 defects is very low, out of 240,000 units. These processes are reliable, stable processes.

The cutting process has 2 types of defect opportunities that are uneven cuts, consisting of 15 defects throughout the month or an average of half a defect per day over a sample of 2000 shoe units with a $DPMO$ of 250, and 10 for the damaged material defect averaging at one third of a unit of damaged material daily with a $DPMO$ of 167.

As for the stitching process, it’s accountable for 62 defect units for 240000 defect opportunities the sole manufacturing 34 defects from 180,000 defect opportunities.

Assembly step accounts for the highest percentage of defects with the weakly attached closure defect, accounting for 93 defective units out of 246 total defects, it should be the process step to be improved as it's $DPMO$ is 695 defective parts per million.

***Considering the fact that a month is enough to observe special causes, can you comment on the long term and short-term sigma levels of these processes?***

The long-term sigma level (worst-case scenario) seems to be very healthy for XYZ shoes, which is almost $\sigma_z = 3.4$ for the whole process, considering that any value over 3 is good. As for the actual sigma level, the long-term is $\sigma_{LT} = \sigma_z \times \sigma = 9.06$, and the short-term level is $\sigma_{ST} = (\sigma_z + 1.5)\sigma = 13.07$. As for each process on its own, the $\sigma_z$ values are as follows:

| Production Step | Sigma-Z Levels |
|---|---|
| Cutting | 3.529296089 |
| Stitching | 3.471963454 |
| Sole Manufacturing | 3.555140071 |
| Assembly | 3.196950229 |

Every $\sigma_z$ value is above 3, which indicates a healthy, in-control, high quality process.

***Can you also estimate the DPU values of the process steps based on last month’s defect data?***

$$DPU_i = \frac{\#\ of\ defectives\ in\ process\ i}{\#\ of\ units\ that\ passed\ through\ process\ i}$$

| Production Step | DPU Per Process |
|---|---|
| Cutting | 0.000416667 |
| Stitching | 0.001033333 |
| Sole Manufacturing | 0.000566667 |
| Assembly | 0.002083333 |

Also, the $DPU$ for the entire process is 0.001025, (considering the samples from each process are different)

***Do these estimates agree with the DPU predictions based on the data in Table 1 collected in the previous month?***

Yes, from the very small differences between the DPU calculated and DPU from Table 1 seen above, it is obvious that the DPUs are indeed very close.

***What could be the sources of discrepancies?***

The values do not match exactly, because there are two layers of the problem. First, is that the DPU values in the first part takes into account ALL the units at once and gives the actual values on the DPU. However, in the second part, the data is based off of samples, which does not always represent the entire population, even if the size of the sample is large.

***Based on your analysis, which process step(s) should have priority for improvement?***

Even though assembly is the process with the highest $DPU$, it is a good candidate to be improved on, especially also considering that it is the last step. Meaning, the firm may pour cost into a unit just for it to a high chance of having it defect in the last step.

However, the cutting process seems to be out of control, so it is also worth considering checking for special causes and/or quality improvement. It is best to check for special causes in the cutting process before applying a quality improvement process for the assembly process.

All things considered; the cutting process must be prioritized first.

***Is your choice different from the one(s) you have made using the results of the yield analysis above?***

The yield analysis proved that the assembly process is the one that needs to be worked on the most, however, it could not show whether any of the processes were out of control. Hence, it is natural that the two choices are different.

## Question 3

***What can you recommend to the Quality Management Department for future monitoring and improvement of these steps? Comment on how factors such as external and internal quality costs and inspection errors that you might not have considered directly, could affect your selection of the production step for improvement.***

It would be recommended to use $C$-charts or $P$-charts. Between the two, it seems that $P$-charts did a better job at spotting out-of-control points, so if one is to be used, $P$-charts should be used. Laney $P'$-charts can help in accounting for overdispersion or under dispersion, but it may be difficult to use for a team that has little to no experience with quality control.

It's important to consider the external and internal quality costs associated with each production step. External quality costs include costs associated with customer complaints, warranty claims, and lost sales due to poor quality, while internal quality costs include costs associated with rework, scrap, and inspection. By analyzing these costs, the company can prioritize the production steps that have the highest impact on quality and profitability.

Another factor to consider is inspection errors, which can result in false alarms and type II errors. False alarms and type I errors lead to unnecessary rework or scrapping, while type II errors lead to customer complaints and warranty claims. To minimize inspection errors, the company should implement automated inspection tools or increase the frequency of manual inspections.

All in all, if the costs of improving the cutting process is much higher than that of assembly process, then it may be better to prioritize the assembly process momentarily, then observe customer feedback and see if any improvement in customer satisfaction is seen.

## Conclusion

Concludingly, it seems that the yield analysis suggests that the process is healthy and of high quality. On the other hand, the data analysis using quality control charts indicates that the cutting process is out of control and needs to be addressed.

The $DPU$ values from each type of analysis were remarkably similar, mostly due to the low $DPU$ values in the first place, making the estimates very close in value.

Moving forward, it is critical that the firm utilize some sort of quality control, preferably $P$-charts and Laney $P'$-charts later.

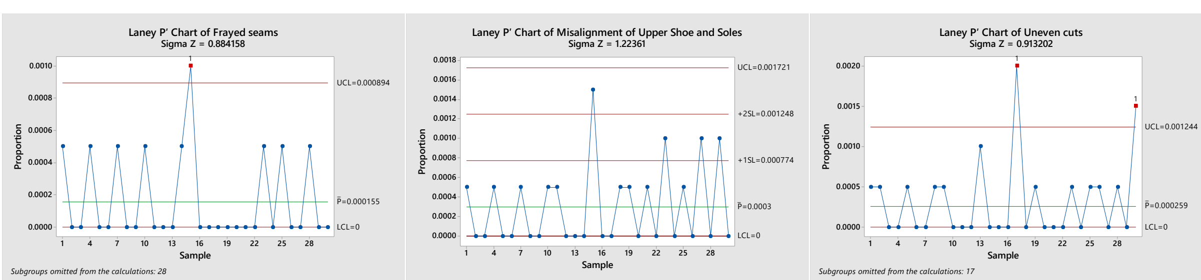
## References

*Rolled Throughput Yield (RTY).* (2022). Six Sigma Material. https://www.six-sigma-material.com/Rolled-Throughput-Yield.html

*Count Data And Overdispersion.* (n.d.). R-project. https://cran.r-project.org/web/packages/GlmSimulatoR/vignettes/count_data_and_overdispersion.html#:~:text=Over%20dispersion%20can%20be%20detected,or%20greater%20is%20considered%20large

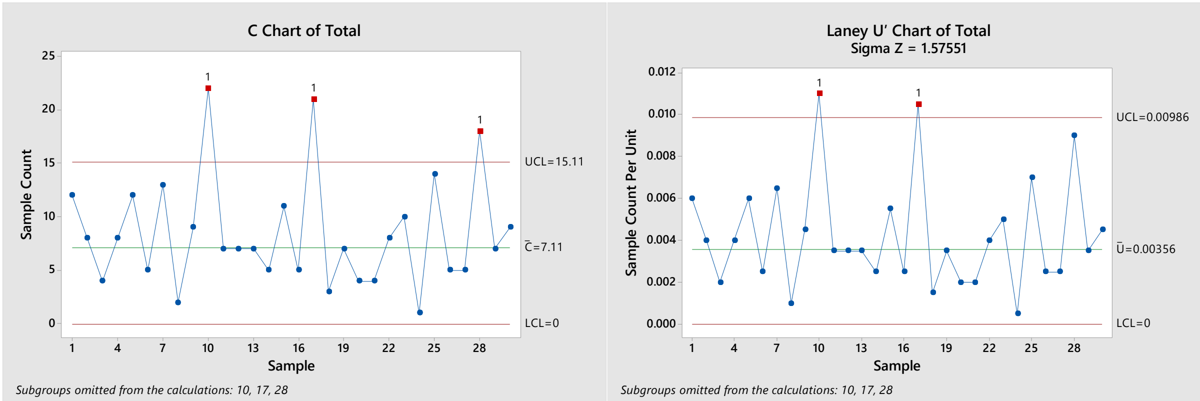
# Appendix


*Figures A1 through A12: P-charts of every type of defective.*

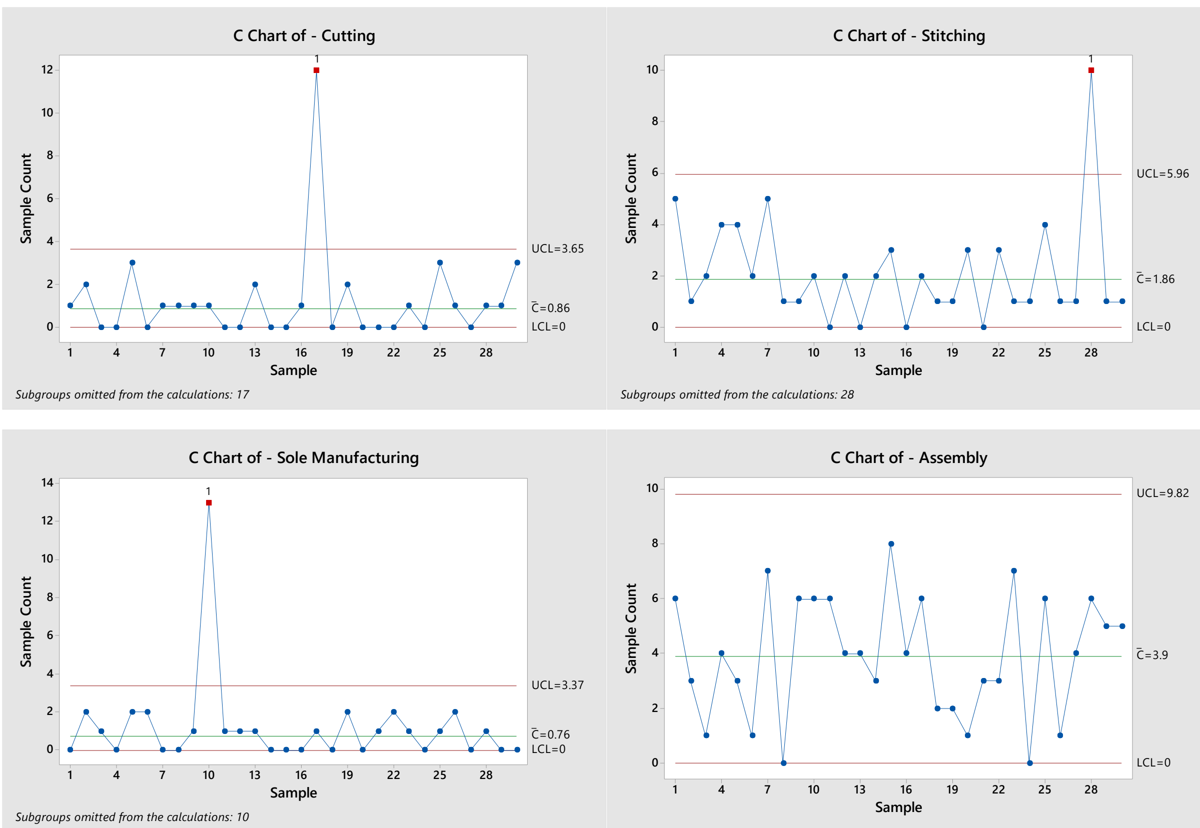



*Figures A13 through A15: Laney $P'$-chart of selected types of defectives.*

Note that Laney $P'$-chart has been used only when the necessity arises.




*Figures A16 and A17: C-chart and Laney U′-chart for total amount of defectives over the entire process. The data exhibits severe overdispersion.*




*Figures A18 through A21: C-chart of each individual process.*