Amy Kuang

PSTAT140

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New Factory Production of Office Chair

Introduction

In this case-study, we will discuss the production of office chairs. Office chairs have been around since the 19th century and evolved much since its first creation. With the COVID-19 pandemic, a good office chair has become a desirable essential for remote-work and learning during quarantine and lockdown for office personnel, students, and teachers.

In this case-study, our small company focuses on the production of office chairs from our company's new factory -- our company only has two factories. In this scenario, a proper office chair will be simplified to the following parts: backrest, arm rests, back support, seat shell, office chair mechanism, office chair gas cylinder, office chair base, and office chair wheels.

Basic Chair parts diagram for reference.
Source:
https://www.tincci.com/blog/post/office-chair-parts-diagram-guides-from-china-supplier.html

The company has received many complaints regarding the quality of our office chairs. There are several reports of quality problems with our office chair parts during at-home customer

self-assemblies. In this project, we utilize the DMAIC problem solving methodology to locate and resolve the source of reported assembly-quality problems.

Utilizing the DMAIC Process

Define.

Ever since starting production of office chairs at our newest factory, there has been a **problem** with an increase of negative reports with problems regarding at-home self-assembly from customers. The company believes that these reports are due to "non-standard compliant" products being produced in the new factory. While refunds and replacements of compliant office chairs have been shipped from the old factory, the problem with noncompliant products from the new factory is still unsolved.

Our **opportunity for improvement** is to inspect the manufacturing process of our office chair components, discover the assignable causes of our noncompliant chair problem, and resolve it.

The **goal** of this project is to successfully reduce future customer dissatisfaction by remedying the cause of customer noncompliant products from the new factory.

Internally, customers' requirements are having chair components manufactured with conforming measurements and quality.

Externally, customer requirements are complete and problem-free assembly of our office chair product.

Here is our **Project Charter**:

Focus ● This project supports the business quality goals to successfully reduce likelihood of future customer dissatisfaction by investigating the source of noncompliant products from the new factory.	Scope ● The scope of this project is the manufacturing process (production) of office chairs in the new factory from the creation of the first part to the last -- before packaging for out-ward shipping.
Direction ● This project seeks to inspect the manufacturing process of our office chair parts, discover the (assignable) causes of our noncompliant office chair problem, and resolve it.	Motivation ● The motivation for this project is to have fully compliant office chairs produced from the new factory. If the noncompliant office chair problem from this new factory is not resolved,

	the new factory will be closed until further notice -- loss in money.

Based on feedback from reviews, the **Voice of the customer (VoC)** that identify **critical to quality characteristics (CTQ)** can be summarized as:

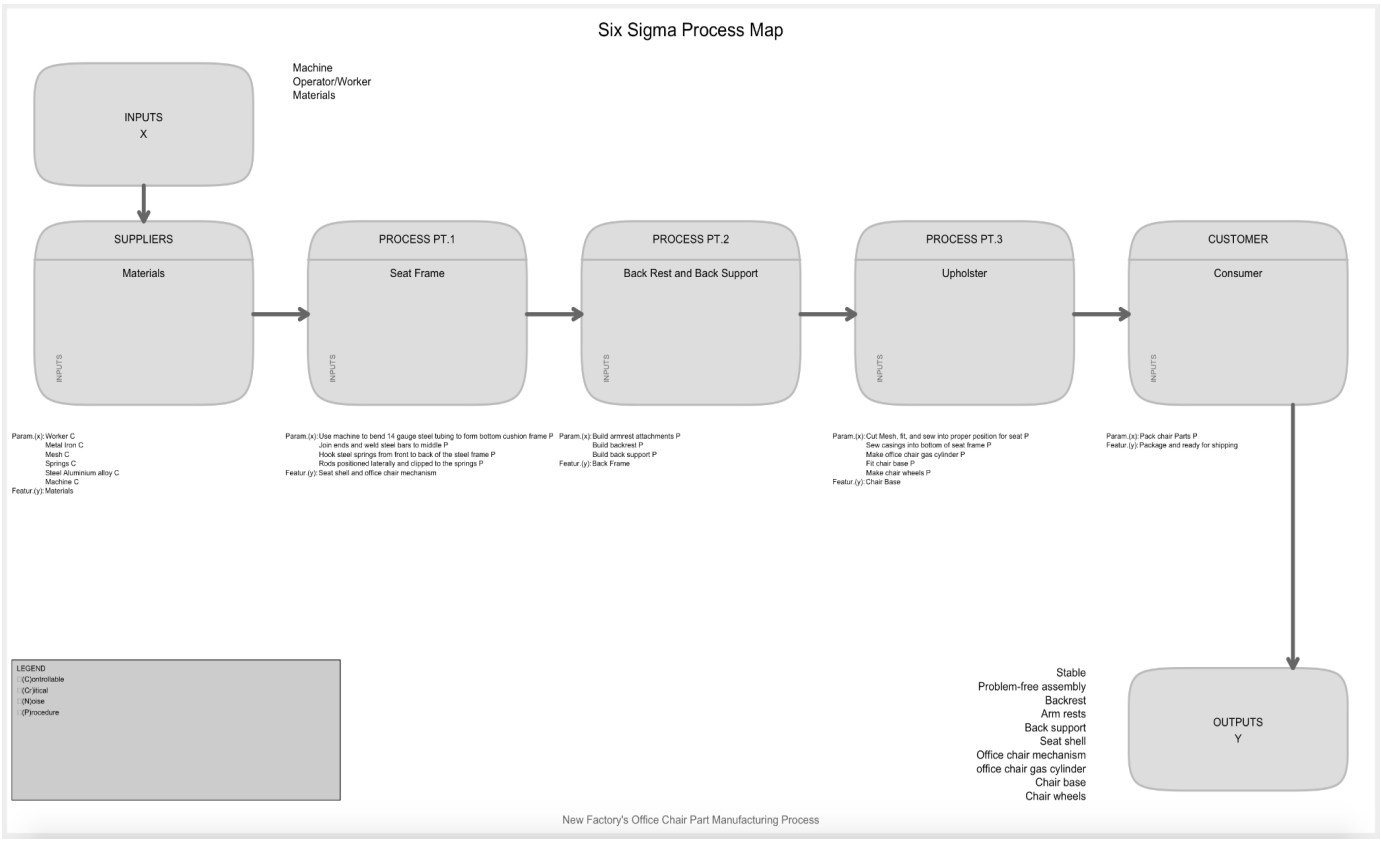
Good Quality:

- Assembly instructions: Included. Instructions are clear with pictures.
- Damage-free/non-faulty parts: All parts fit properly during assembly. All parts are included; no missing components.
- Stability: The final assembled office chair (product) is stable and safe to sit on as long as the consumer is within the weight limit noted in instructions. The office chair is stable and safe to sit on despite adjusting seat level and or leaning back.
- Durability: The final assembled product is safe and stable to sit on -- will not fall apart. The office chair (product) will last at least 3 years with no issues before showing signs of needing to be replaced.

Bad Quality:

- Missing assembly instructions
- Missing, damaged, or faulty components or office chair parts
- Unstable to sit on (despite successful customer assembly)
- Product is not durable. Shows signs of wear and or breaks within 1-10 months of purchase and assembly.

Here is a **SIPOC diagram** to illustrate the manufacture process (using the SixSigma package in RStudio):




```
library(SixSigma)

inputs.overall<-c("Machine", "Operator/Worker", "Materials")
outputs.overall<-c("Stable", "Problem-free assembly", "Backrest",
                   "Arm rests", "Back support", "Seat shell",
                   "Office chair mechanism", "office chair gas cylinder",
                   "Chair base",  "Chair wheels")
steps<-c("SUPPLIERS", "PROCESS PT.1", "PROCESS PT.2","PROCESS PT.3",
"CUSTOMER")

#Inputs of process "i" are inputs of process "i+1"
input.output<-vector(mode="list",length=length(steps))
input.output[1]<-list(c("Materials"))
input.output[2]<-list(c("Seat Frame"))
input.output[3]<-list(c("Back Rest and Back Support"))
input.output[4]<-list(c("Upholster"))
input.output[5]<-list(c("Consumer"))

#Parameters of each process
x.parameters<-vector(mode="list",length=length(steps))
```

```
x.parameters[1]<-list(c(list(c("Worker", "C")),list(c("Metal Iron", "C")),
                    list(c("Mesh", "C")),list(c("Springs", "C")),
                    list(c("Steel Aluminium alloy", "C")),
                    list(c("Machine", "C"))))
x.parameters[2]<-list(c(list(c("Use machine to bend 14 gauge steel tubing to form bottom
cushion frame", "P")),
                    list(c("Join ends and weld steel bars to middle", "P")),
                    list(c("Hook steel springs from front to back of the steel frame", "P")),
                    list(c("Rods positioned laterally and clipped to the springs", "P"))))
x.parameters[3]<-list(c(list(c("Build armrest attachments", "P")),
                    list(c("Build backrest", "P")),
                      list(c("Build back support", "P"))))
x.parameters[4]<-list(c(list(c("Cut Mesh, fit, and sew into proper position for seat", "P")),
                    list(c("Sew casings into bottom of seat frame", "P")),
                    list(c("Make office chair gas cylinder", "P")),
                    list(c("Fit chair base", "P")),
                    list(c("Make chair wheels", "P"))))
x.parameters[5]<-list(c(list(c("Pack chair Parts", "P"))))
x.parameters

#Features of each process
y.features<-vector(mode="list",length=length(steps))
y.features[1]<-list(c(list(c("Materials", "C"))))
y.features[2]<-list(c(list(c("Seat shell and office chair mechanism", "Cr"))))
y.features[3]<-list(c(list(c("Back Frame", "Cr"))))
y.features[4]<-list(c(list(c("Chair Base", "Cr"))))
y.features[5]<-list(c(list(c("Package and ready for shipping", "P"))))
y.features

ss.pMap(steps, inputs.overall, outputs.overall, input.output, x.parameters, y.features,
      sub="New Factory's Office Chair Part Manufacturing Process")
```

Credit: Process is taken from https://www.tincci.com/blog/post/office-chair-parts-diagram-guides-from-china-supplier.html, generalized, and uses aspects from https://officesolutionpro.com/how-office-chairs-are-made/.

Tollgate:

In our DEFINE step, we defined our problem statement to (somewhat) focus on the symptoms and the possible causes of the problem with the symptoms being an increase in negative reports on problems with at-home self-assembly. The believed cause is to be non-compliant product/parts produced from the new factory. We also identified the key stakeholders to be customers, company reputation, and company loss in investment and revenue. Evidence to

confirm the value opportunity represented by this project is that our company's office chair product has previously been well-received by customers in the past, prior to the shipment of products made from the recently opened new factory -- note, this is our only other factory. This indicates that this problem may be resolvable. The scope of this project is centered around a single new factory opened in 2020 -- the scope is not too large nor too small. A project charter and SIPOC diagram have been completed to illustrate the process of our office chair product production; there appears to be no barriers or obstacles to successful completion of the project. Next, the team has prepared a reasonable measure step of the DMAIC process.

Measure.

To begin, we identify the **key process input variables (KPIV)** and **key process output variables (KPOV)**.

The **key process input variables (KPIV)** are the parts to the office chair product. These parts are: backrest, arm rests, back support, seat shell, office chair mechanism, office chair gas cylinder, office chair base, and office chair wheels.

The **key process output variables (KPOV)** are the office chair product itself.

To understand the quality standards of the office chair products, important CTQs to reiterate in relation to KPIVs for a good quality KPOV is as follows:

Good quality pertains to:

- Damage-free/non-faulty parts: All parts fit properly during assembly. All parts are included; no missing components.
- Stability: The final assembled office chair (product) is stable and safe to sit on as long as the consumer is within the weight limit noted in instructions. The office chair is stable and safe to sit on despite adjusting seat level and or leaning back.
- Durability: The final assembled product is safe and stable to sit on -- will not fall apart. The office chair (product) will last at least 3 years with no issues before showing signs of needing to be replaced.

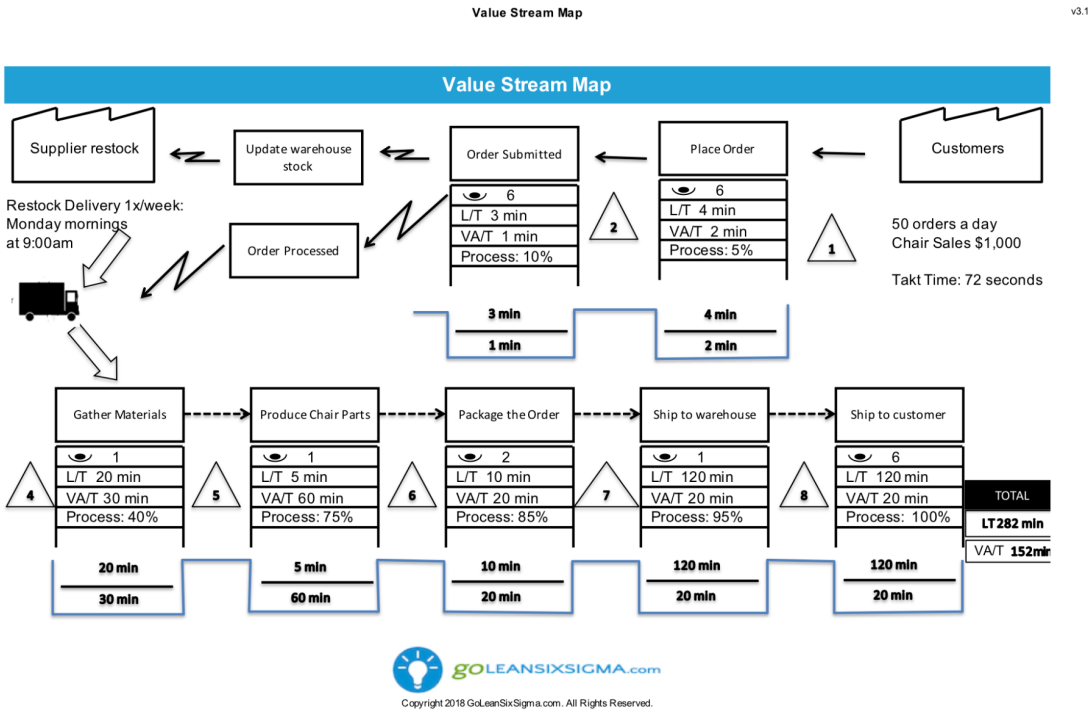
Bad quality pertains to:

- Missing, damaged, or faulty components or office chair parts
- Unstable to sit on (despite successful customer assembly)
- Product is not durable. Shows signs of wear and or breaks within 1-10 months of purchase and assembly.

Using the “good/bad quality” judgement standard based on previous customer feedback from products (not from the new factory), products that are deemed “good quality” with the standards above have been well-received by customers while products deemed “bad quality” with the standards above have been negatively-received by customers.

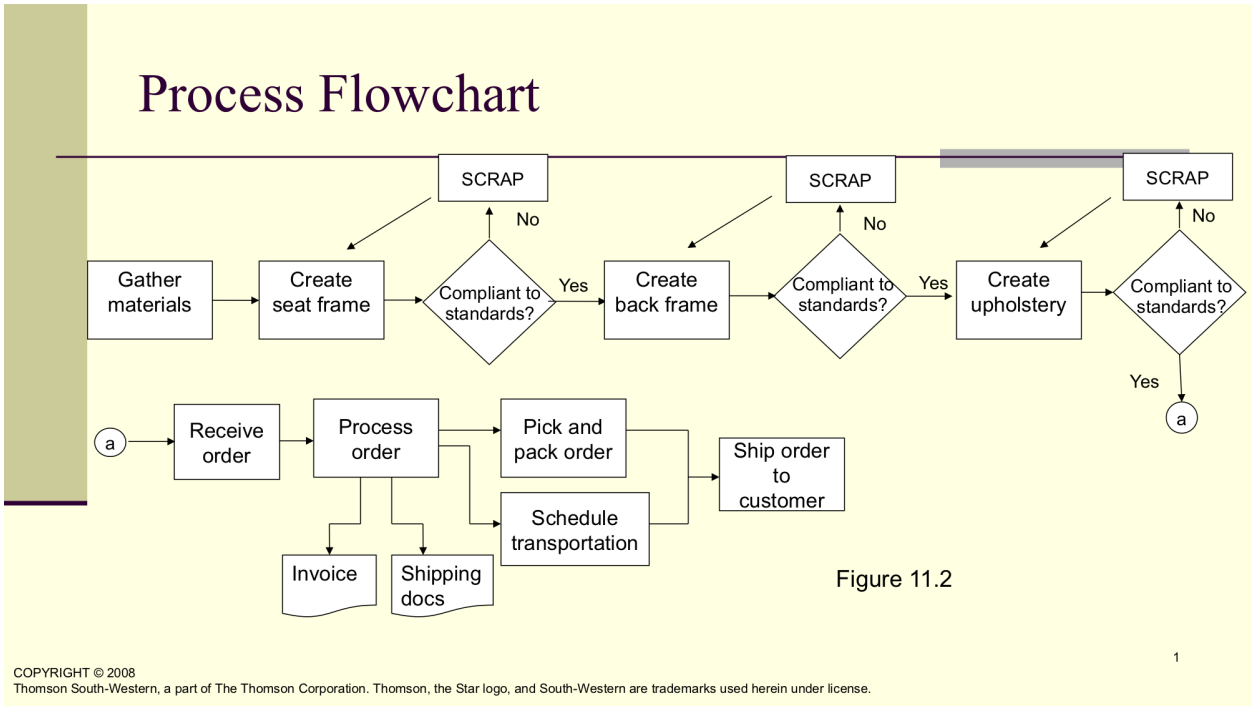
To understand the production process, we have a process flow chart and value stream map.

The order, production, and shipping process is as follows in the **value stream map** below:



According to the value stream map, the value-added features are the gathering and production of the chair parts. The non-value added features are mainly the packaging and shipping process. Steps where bottlenecks may occur are problems with placing order, delay in processing, restocking materials from suppliers, delayed production, and or delays in shipping.

Next, the general manufacturing process of the office chair product parts can be depicted in this **flowchart**:



In the general manufacturing process, the **value-added activities** are the creation of compliant seat frames, back frames, and upholstery. The **non-value added activities** are the short quality measurement standard checks to confirm that the parts conform to the correct measurements before proceeding to the next step.

Next, to investigate the cause of the non-compliant office chairs (our product), we collected 5 samples of each of the 8 office chair parts at random points in the day for 5 days. In our recorded defect data, we observe that 83 out of the 200 samples are deemed as 'defective' or non-compliant with company standards.

Below is a check sheet of the data collected on defects:

Check Sheet
Defect Data from New Factory 2020

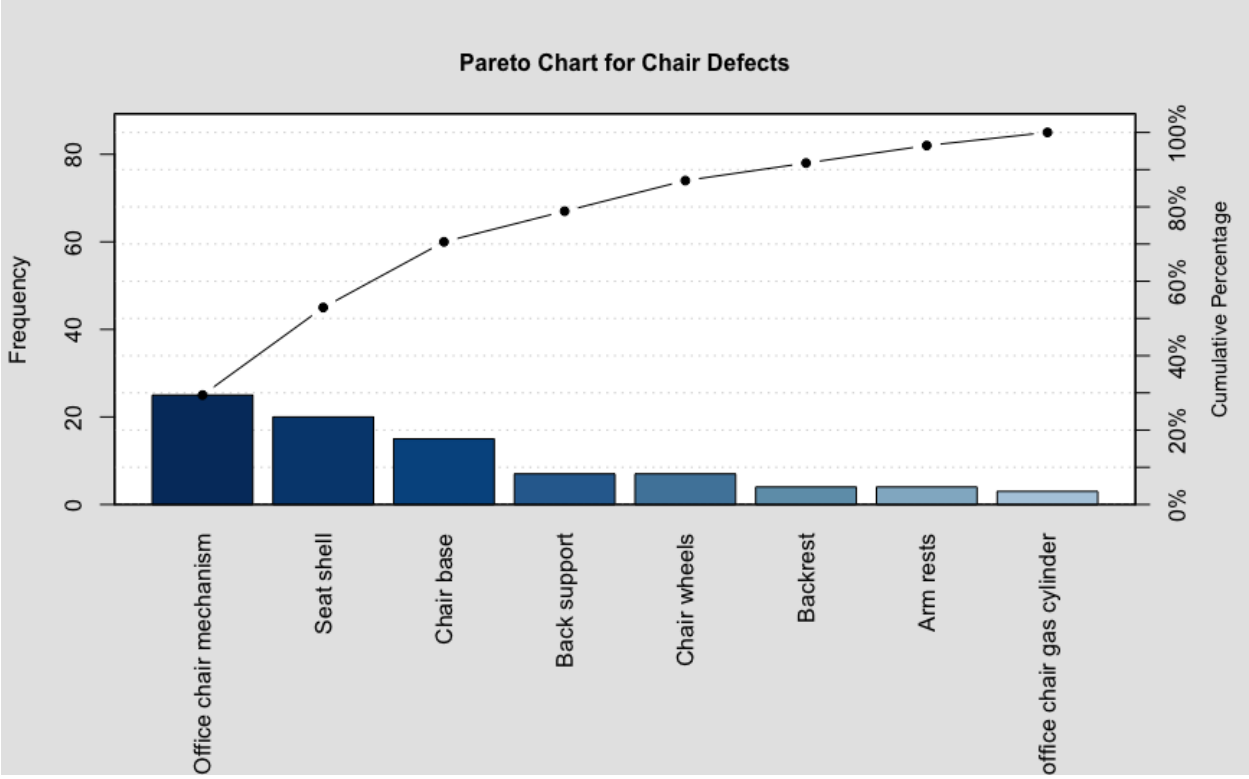
	Back rest	Arm rests	Back Support	Seat Shell	Office chair mecha	office chair gas cyl	office chair base	office chair wheels	Total:
Damaged	2	0	2	10	5	0	3	1	23
Faulty parts (quality issue)	2	0	3	4	4	3	6	5	27
Wrong components	0	4	0	2	4	0	2	0	12
Machine caused	0	0	2	2	12	0	4	1	21
Total:	4	4	7	20	25	3	15	7	83

Note:
Damaged parts can be due avoidable reasons during component assembly or damaged prior to part production.
Faulty parts may be due to non-conforming materials being passed through inspection on purpose/accident into manufacturing.
Wrong components can be due to human error during office chair part production assembly.
Machine caused defects may be due to machine problems or operator/worker errors.

	Defect
	Office Chair Part

Constructing a Pareto Chart with the data, we observe that: about 30% of the defects stem from problems with the office chair mechanism, about 25% of the defects stems from problems with the seat shell, about 18% of the non-compliant reports stems from problems with the chair base, and so on.

The **Pareto chart:**




```
# installed packages: qcc, qicharts2, ggplot2, dplyr, base, graphics,
# stats, datasets, tibble

# Create a vector of the defects
chair_defects <- c(4, 4, 7, 20, 25, 3, 15, 7)

names(chair_defects) <- c("Backrest",
                          "Arm rests", "Back support", "Seat shell",
                          "Office chair mechanism", "office chair gas cylinder",
                          "Chair base",  "Chair wheels")

# Create the Pareto chart
pareto.chart(chair_defects,
             ylab = "Frequency",
             ylab2 = "Cumulative Percentage",
             main = "Pareto Chart for Chair Defects",
             cumperc = seq(0, 100, by = 10))
```

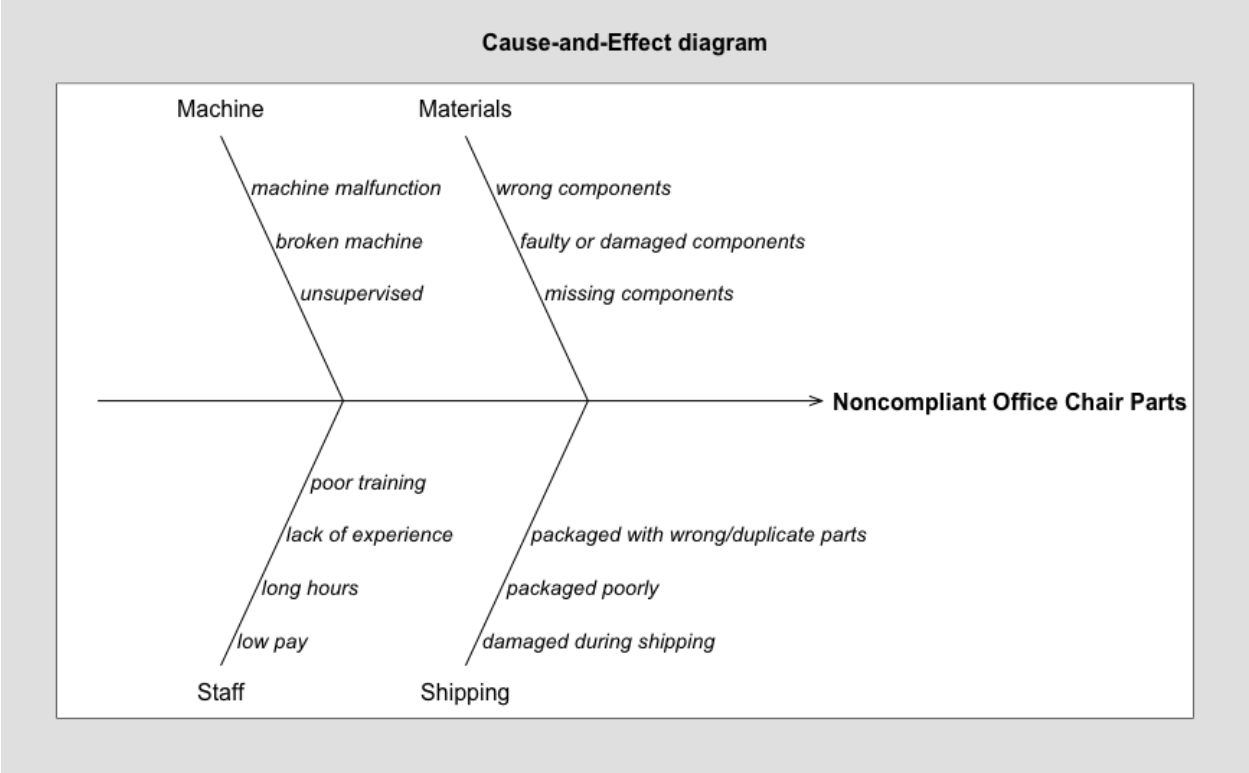
Tollgate:

In our measure step of DMAIC, we first identified the KPIVs and KPOVs and briefly summarized the KPIVs and KPOVs in relation to ‘good/bad’ quality judgement standards from the DEFINE step. We then created a value stream map and process flow chart to illustrate the production process. We also conducted a quality control check by sampling office chair parts from the production at the new factory. In the quality control check, we collected 5 samples of each of the 8 office chair parts at random points in the day for 5 days. The defect data was then recorded on a check sheet and analyzed in a Pareto chart. In the results, we noticed that 83 out of the 200 samples are deemed as ‘defective’ or non-compliant with company standards using a regular counting of defective parts by the whole. This blunt measurement system was decided on to ensure 100% fully complying parts without shortcutting to troubleshoot and reduce costs. Regarding deciding how to collect the data, the factory operates 5 days a week. For our quality control check, we chose a random week during the month after this project was opened to ensure that there is impartiality and no time to hide evidence of non-complying practices at the new factory. We believe that the data collected is enough to provide a reasonable picture of the process given the size of the product parts, time to inspect, and cost of doing this sampling.

Analyze.

To analyze our collected data from the measure step, we attempt to determine the causes and effect relationships.

To determine the potential causes, a **cause and effect diagram** is constructed below using qcc():




```
cause.and.effect(cause = list(Machine = c("machine malfunction", "broken machine",
"unsupervised"),
                    Materials = c("wrong components", "faulty or damaged components",
                          "missing components"),
                    Staff = c("low pay", "long hours","lack of experience", "poor training"),
              Shipping = c("damaged during shipping", "packaged poorly",
                    "packaged with wrong/duplicate parts")),
              effect = "Noncompliant Office Chair Parts")
```

With the cause-and-effect diagram, we can classify and determine which of the potential causes for our non-compliant product due to chance or assignable causes:

According to the cause and affect diagram, some possible sources of variability may be summarized as the following:

Chance cause (caused) that are natural and possible unavoidable:

- Machines and equipment used at the factory during production may have malfunctioned.
- Some material components may be poor quality.
- Staff may be tired and overworked -- human error.
- Product parts damaged during shipping during moving, weather, or general shipping.

Assignable causes (caused) that are avoidable and resolvable are:

- Machines and equipment used at the factory broke or was running unsupervised.
- Workers/Operators may have:
    - used wrong/faulty components during production.
    - forgotten to add certain components during production.
    - Misalignment/mis-assembly of components that make the chair parts
- Staff are overworked, underpaid, and or poorly trained.
- Product parts are not packaged properly, stored properly in the warehouse, and or mis-packaged with wrong/different parts.

Regardless of the non-compliant products being potentially due to chance and assignable causes, all of these causes lead to the same consequence of non-compliant final products sent to the customer. To reduce issues with problems arising from these specified chances and assignable causes the company can implement more frequent inspection checks with machine, equipment, and shipping. To address staff issues, the company can reduce each worker to normal amounts and hire more workers to balance out the overworking long hours.

Next, we then develop a **Demerit System** to identify and classify the severity of the product becoming non-compliant and considered defective: (Source: pg 330 in Statistical Quality Control by Douglas C. Mo.)

- Develop a Demerit System, identifying 2 defects for each class. Justify your choice of weights.
- **Class A Defects - Very Serious.** All office chairs are either completely unfit for service, or will fail in service in such a manner that cannot be corrected after shipped out, or will cause personal injury after the final product is assembled using this part.
- **Class B Defects - Serious.** Some office chair parts can arguably be used during assembly, but will likely require replacement for final product assembly to be possible. Product will likely be unsafe to use if assembly is somehow completed with these faulty parts.
- **Class C Defects—Moderately Serious.** All office chairs can be used during assembly, but the product is not as durable as promised, and in office chair products are slightly damaged/sturdiness is lacking.
- **Class D Defects - Minor.** All office chairs are fully functional. The office chair assembly and product may be perfectly working, but may have minor defects in either finish, appearance, texture, or show negligible damage from assembly or shipping.

Tollgate:

In our analyze step of DMAIC, we identified potential cause-and-effect relationships and created a demerit system to identify and classify the severity of non-standard-conforming office chair parts. In the improve step, we discuss the possibilities for improvement with the production

process by evaluating what can be done about the issues identified in the measure step and classifying them using components from the analyze step. Using the old factory's standards and previous customer feedback and reports, we consider possible solutions in the improve step to replicate the old factory's conforming product productions. As of this step, the project is still on track with respect to time and anticipated outcomes with no additional resources required.

Improve.

To begin, we take another look at the check sheet from the measure step.

Check sheet from before shown below:

Check Sheet
Defect Data from New Factory 2020

	Back rest	Arm rests	Back Support	Seat Shell	Office chair mecha	office chair gas cyl	office chair base	office chair wheels	Total:
Damaged	2	0	2	10	5	0	3	1	23
Faulty parts (quality issue)	2	0	3	4	4	3	6	5	27
Wrong components	0	4	0	2	4	0	2	0	12
Machine caused	0	0	2	2	12	0	4	1	21
Total:	4	4	7	20	25	3	15	7	83

Note:
Damaged parts can be due avoidable reasons during component assembly or damaged prior to part production.
Faulty parts may be due to non-conforming materials being passed through inspection on purpose/accident into manufacturing.
Wrong components can be due to human error during office chair part production assembly.
Machine caused defects may be due to machine problems or operator/worker errors.

	Defect
	Office Chair Part

Now, using the demerit system created in the analyze step, we attempt to classify the defects:

- According to the demerit system, damaged parts can potentially fall under Class A, B, C, and D Defects depending on the severity of the damage. For this problem, the proposed improvement as a solution is to scrap chair parts that cannot be reworked or repaired.
- For faulty parts pertaining to a quality issue responsible for 27/83 of product defects (the second highest defect), these defects would typically be classified as Class A or B Defects that should be scrapped if parts are found to be faulty. A proposed solution to improve this defect would be to begin a project to conduct routine material and machine operation checks to ensure that machines are fully functional and materials from suppliers are problem-free and are compliant with standards before beginning production.
- Regarding wrong components being used to produce the chair parts, these issues can be due to human error during office chair part assembly. Also classified under Class A or Class B (*very* arguably Class C), non-conforming parts created with wrong components should be recycled and reworked where possible to reduce waste. To improve this process, the factory can make changes to ordering by standardizing arrangement of office

chair part components. Informally, an assembly line can be set up with certain groups of workers/areas being responsible for certain components only to reduce mix-ups.

- Regarding machine caused defects, these parts produced can be classified as Class A or Class B as defective products from machines can pose safety concerns. An improvement to machine operation processes may be routine checks monthly to ensure that machines are fully functional. Another improvement would be to only allow fully-trained workers to operate the machines in order to reduce safety concerns during production and with the product itself.

Lastly, a final proposed solution is to implement the use of control charts to monitor the quality checks of office chair parts (and their components) in order to ensure conformance to standards.

Tollgate:

In the improve step, we evaluated the defects from the check-sheet by classifying the issue level severity with the demerit system. We then proposed possible improvements and or solutions to reduce errors in the production process identified in the project sampling conducted in this project. Regarding the risks and steps to initiate the proposed improvements and or solutions, further discussion and approval is needed with higher authority within the company due to the additional costs that may be incurred in order to implement the proposed improvements and solutions.

Control.

In our control step, we propose a **process control plan** of having routine quality inspection checks to ensure that office chair parts are all compliant with standards. Quality control inspection checks may follow taking five samples of each of the eight office chair product parts for consecutive or random X number of days depending on the amount of orders being processed. During time periods with many orders being processed, additional quality control checks should happen whereas time periods with fewer orders being processed may not need additional number quality control checks performed.

Further, surveys should be sent to be conducted after every purchase after 30-60 days of the time of purchase to receive customer feedback.

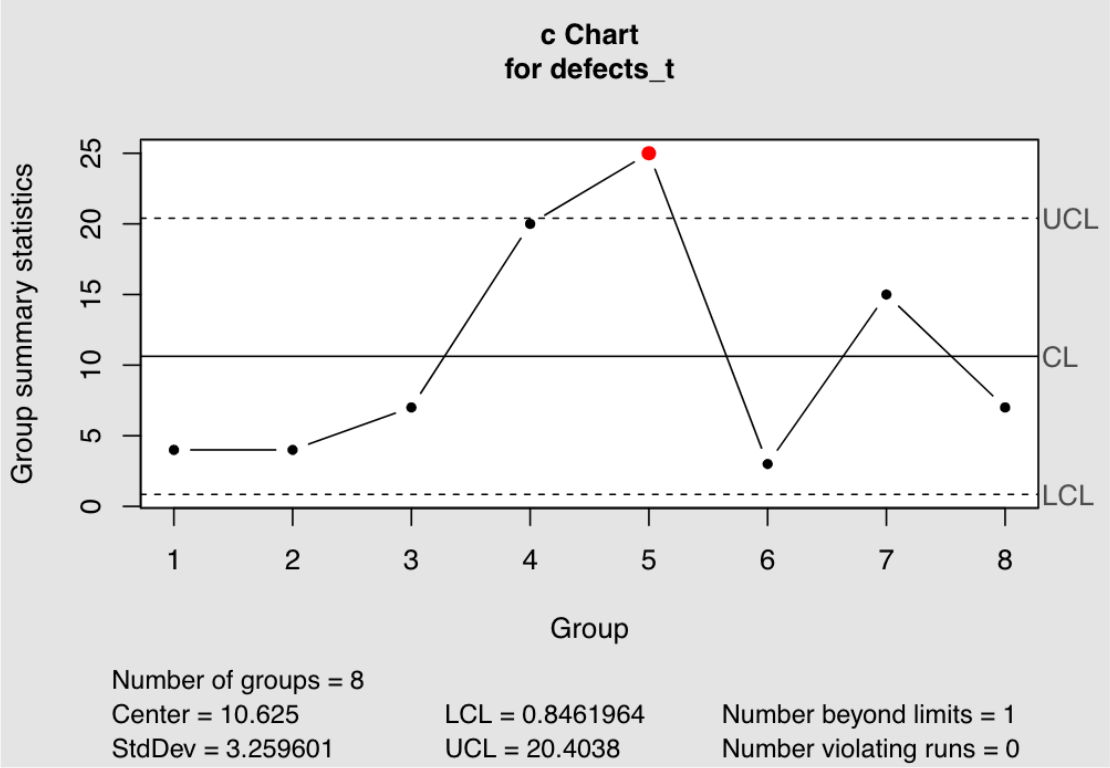
Regarding metrics for future audits, for now, standards and quality of products will remain unchanged but will be supplemented with more frequent quality control checks.

To prevent and or reduce future non-compliant product customer reports, full or partial returns are possible within 60 days of purchase with the following **out-of-control action plan**:

- Products returned classifying under Class A Defects may be either fully refunded or sent with a full replacement. The defective product will be shipped to a warehouse for inspection. Faulty/defective products or returns will be scrapped.
- Products returned classifying under Class B Defects may be either refunded or sent with a partial replacement for broken parts. These faulty/defective products or returns will be inspected to determine quality problems where damage is located for future manufacturing upgrades. Faulty/defective parts will be scrapped.
- Products returned classifying under Class C Defects may be issued a refund, and be scrapped or reworked if possible to reduce waste and costs. Un-reworkable parts will be scrapped.
- Products returned classifying under Class D defects may be issued a refund and reworked where possible to reduce waste. Products may also be inspected to locate where defects are occurring for future quality control improvements.

After implementing the proposed solutions in the improve step, there have been less defective parts and much fewer self-assembly problems reports from customers.

As a comparison with a before and after, below is a c-chart to depict our defect data before implementing the improvements from the improve step.

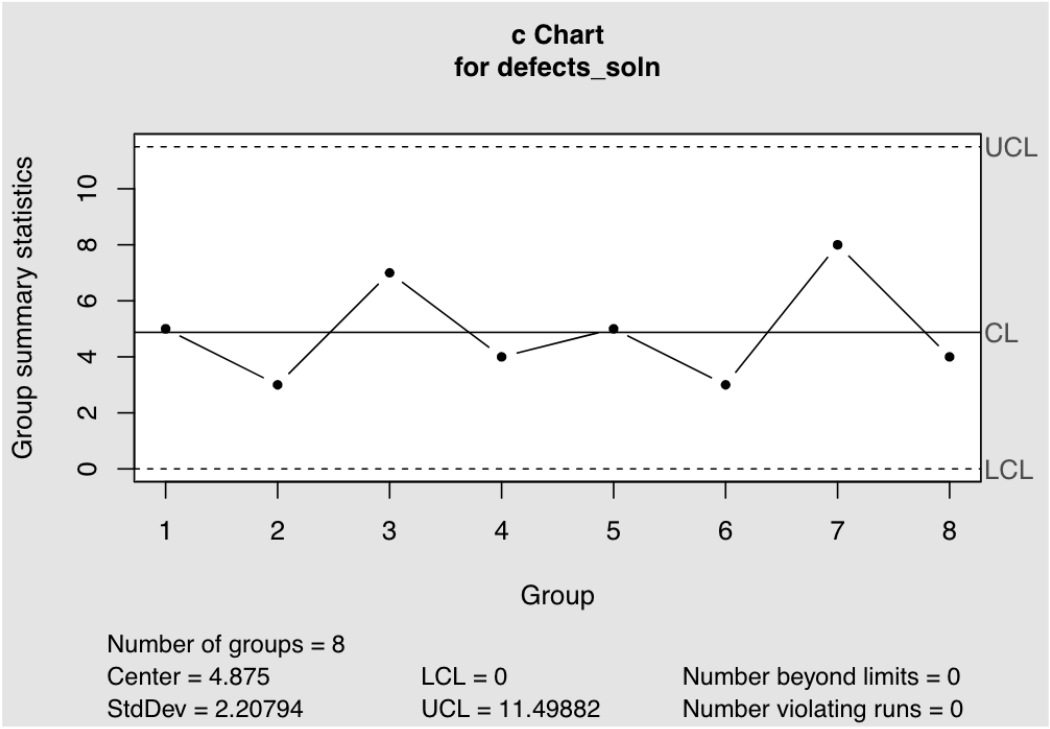



```
##
## Call:
## qcc(data = defects_t, type = "c", sizes = 8, plot = T)
##
## c chart for defects_t
##
## Summary of group statistics:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.000   4.000   7.000  10.625  16.250  25.000
##
## Group sample size:  8
## Number of groups:  8
## Center of group statistics:  10.625
## Standard deviation:  3.259601
##
## Control limits:
##        LCL     UCL
##  0.8461964 20.4038
```

defects_t <- tibble(chair_defects)
summary(qcc(defects_t, type="c", sizes=8, plot = T))

In this c-chart, we see point 4,5,6 appear to be abnormal subgroups in our defect sampling which supports our hypothesis that these defective parts in subgroup 4,5,6 may be results of assignable causes.

Now, here is a c-chart for our defect data collected using the same sampling method as before after the implementation of the improvements proposed in the improve step:




```
##
## Call:
## qcc(data = defects_soln, type = "c", sizes = 8, plot = T)
##
## c chart for defects_soln
##
## Summary of group statistics:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##   3.000   3.750   4.500   4.875   5.500   8.000
##
## Group sample size:  8
## Number of groups:  8
## Center of group statistics:  4.875
## Standard deviation:  2.20794
##
## Control limits:
##  LCL      UCL
##    0 11.49882
```

defects_soln <- tibble(c(5, 3, 7, 4, 5, 3, 8, 4)) # defect data after implementing improve step
summary(qcc(defects_soln, type="c", sizes=8, plot = T))

After implementing the proposed improvements and solutions from the improve step, we see the non-conforming production process appearing to be in statistical control which means that these non-conformities are less likely to be results of assignable causes.

For reference, this is the check-sheet collected on the defect data after implementing the proposed improvements.

Check Sheet 2
Defect Data from New Factory 2020

	Back rest	Arm rests	Back Support	Seat Shell	Office chair mecha	office chair gas cyl	office chair base	office chair wheels	Total:
Damaged	1	1	2	1	2	0	3	0	10
Faulty parts (quality issue)	2	1	4	1	3	3	3	4	21
Wrong components	2	1	0	1	0	0	0	0	4
Machine caused	0	0	1	1	0	0	2	0	4
Total:	5	3	7	4	5	3	8	4	39

Defect
Office Chair Part

While there are some significant improvements with fewer defects with certain parts, there are also some small increases in defects in parts that previously have had fewer issues. However, it does not warrant a huge concern in regards to this project's goal as the number of reports with problematic assembly have been greatly reduced to reasonable capacity.

Tollgate:

Defect data illustrating after results of implementing the proposed solutions appear to align and meet the project character goals as shown through the control charts in the control step. The process control plan is also complete.

As a summary, this project investigates the cause for an increase of negative reports with problems regarding at-home self-assembly from customers since the start of new factory produced shipments in 2020. With this project, we learned that many problematic office chair parts were the result of assignable causes such as lack of supervision, training, and strict policies during production. After implementing more accountability solutions, increasing supervision and training, and reduced hours, we have reported less defective parts and much fewer self-assembly problems from customers.

A future proposition and lesson that may be applied to other parts of the business should be a reasonable increase in supervision, reduced working hours -- to reduce human error, and increase training.