المعهد التكنولوجى لهندسة التشييد و الإدارة

Introduction to Six Sigma

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تقديم

يسعدنى أن أتقدم بخالص الشكر للسادة القائمين على المعهد التكنولوجى لهندسة التشييد و الإدارة بشركة المقاولين العرب لإتاحتهم الفرصة أن أشارك زملائى العاملين فى مجال الجودة بشركة المقاولين مفهوم الستة سيجما الذى ذاع فى الشركات فى الفترة الأخيرة و الذى حقق صعودا لنجم العديد من الشركات العالمية التى قامت بتطبيقه .

و لقد حرصت فى هذا التقديم البسيط لمفهوم الستة سيجما ان تصل الفكرة وراء فلسفتها و كيف تبنتها الشركات و استفادت منها بطريقة سهلة و بسيطة مع الكثير من الأمثلة العددية حتى يستشعر الدارس بمدى أهميتها ، ءاملا ان يستفيد كل الزملاء من هذه المادة العلمية على المستويات الشخصية و العملية.

و يسعدنى أن اتلقى اتصال كل من يرغب فى المزيد من المعلومات عن هذا الموضوع الهام.

القاهرة فى 29 مارس 2018

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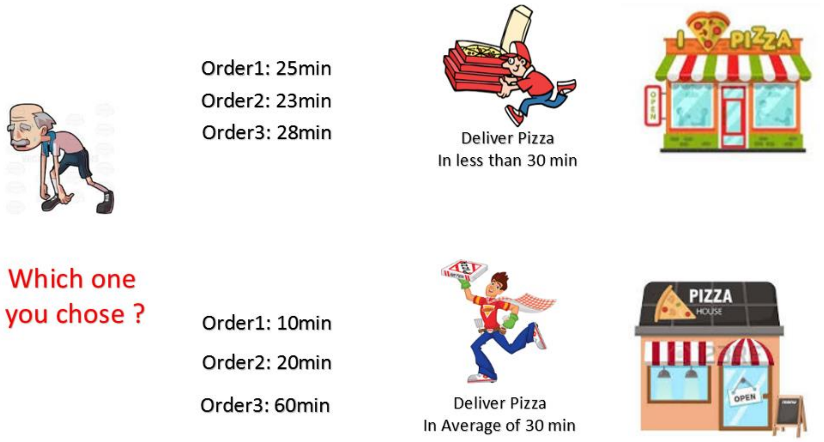
Chapter 1: Introduction

What you will learn in this chapter:

In this chapter, you will learn:

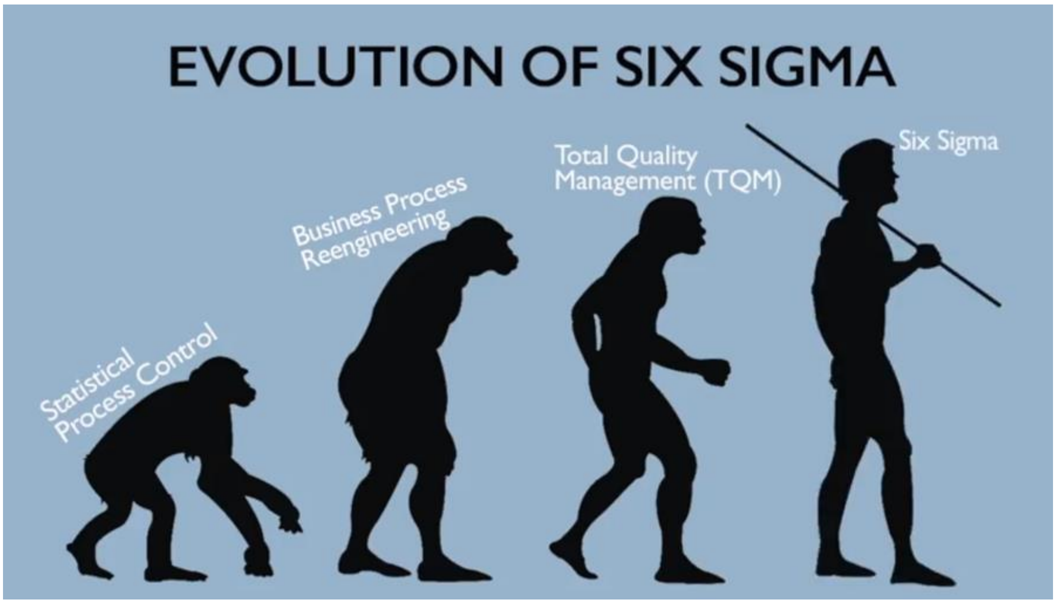
- How variation impact you.
- What is Quality?
- What does 99% defect free means?
- What does 99.99966% defect free means?

How Variation Impact you:



What is Quality?

Evolution of Six Sigma:



What is 99% defect free means:

The idea of Six Sigma is not new, and can be taken from statistical principles. In the past, organizations aimed for **99** percent defect free. Without realizing that this is the same as,

- At least 200000 wrong drug prescriptions each year.
- Too short or long landings at major airports each day,
- 5000 incorrect surgical procedures every week,
- 20000 lost articles of mail per hour,
- Unsafe drinking water for almost 15 minutes each day.
- And no electricity for almost seven hours every month.

This is 66,810 defects for every one million opportunities. From a cost and waste perspective, this is astonishing

What is 99.99966% defect free means:

Six Sigma aims us toward a goal of 99.99966 Percent defect free. This is 3.4 defects, for every one million opportunities. This can seem staggering and perhaps even difficult to reach and even sustain. But, the journey to this goal, reaps its own substantial rewards.

Once reaching Six Sigma, we can realize:

- 68 wrong drug prescriptions each year.

- One short or long landing at a major airport each five years,
- 1.7 incorrect surgical procedures every week,
- seven lost articles of mail per hour,
- One unsafe minute of drinking water every seven months. And,
- No electricity for almost seven hours every five years.

Imagine, the vast gains we can fulfill in defect reduction, waste reduction and customer service, as we journey toward a Six Sigma level of quality excellence

Chapter 2: Background and Meaning of Six Sigma

What you will learn in this chapter:

In this chapter, you will learn:

- Understand the origins of the Motorola Six Sigma methodology.
- List the six main themes of Six Sigma
- List the phases of the DMAIC process improvement cycle
- Understand the Six Sigma Roadmap and the problem solving strategy *Y(Critical-to-Quality Parameters) = f(key X-influencing parameters: x1, x2, x3)*

The Six Sigma System:

But, let's just step back and look at the big picture, the textbook; the "Six Sigma way" by "**Pande Neuman** and **Cavanagh**" explains, how the customer centric improvement driven Six Sigma approach achieved impressive benefits for companies, such as **General Electric** and **Motorola**.

The authors state that "the **Six Sigma system is a comprehensive and flexible system, for achieving, sustaining and maximizing business success**". The Six Sigma process strive to achieve this, by:

- Careful understanding of customer needs,
- use of facts through data collection and statistical analysis, and
- By managing, improving and re-engineering production, as well as business processes, to increase customer satisfaction and business excellence.

And hereby, business excellence we're talking about

- Cost Reduction,
- Productivity improvement,
- growth of market share,
- customer retention cycle,
- time reduction
- defect reduction and
- Change to quality culture, in new product and service development.

Six Sigma –Origin and development:

So, let's look a little bit at the origins, and the development of Six Sigma. In the late 1970s, Motorola started experimenting with problem solving, through statistical analysis and started using the Six Sigma approach in the 1980s, to achieve one of its top corporate goals of improving quality.

The engineer Bill Smith, called the father of Six Sigma is widely credited, with recognizing that a process mean, so the process centering could not be maintained exactly on target. And that for complex products, the product variability had to be controlled, to higher limits and was previously accepted.

With Dr. Mikel Harry, who was responsible for the development of the Six Sigma implementation strategy and deployment guidelines, Six Sigma was implemented at Motorola.

And in 1990, Dr. Harry founded and directed Motorola six Sigma Research Institute.

In 1987, though it was the official birth of the Six Sigma Motorola methodology in Motorola and this is for the communication sector uses an approach to track and compare performance, against the customer requirements and to achieve an ambitious target, target of near perfect Six Sigma quality in the products produced.

And what this means, and this is in key is that the defect rate for the production of each component, will not be more than three point four parts per million.

This Six Sigma process or systematic approach to process improvement, to attain the six metro quality, later spread throughout the company, with strong backing from the then chairman Robert Galvin.

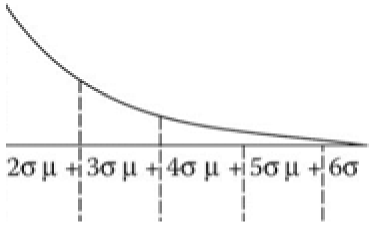
Now, in the late 1980s, this process helped the company to achieve enormous improvements in quality, for example

- tenfold improvement every two years and
- a hundredfold improvement in every four years.
- And two years after, they sat out of their Six Sigma journey, they received the prestigious national award, the Malcolm Baldrige award for Business Excellence in 1988.
- In the ten years between 1987 and 1997, the company increased its sales fivefold, saved 14 billion from Six Sigma projects, and saw its stock prices increase.

All this happened, to Motorola was facing tough competition from Japanese competitors and several other companies, have followed the Six Sigma process model and reported enormous successes.

Two important ones are of course, **General Electric** and **Allied signal** or **Honeywell**.

But, what does this 3.4 parts-per-billion mean, and here we can look at this, this is exactly what we'll be learning in this course and you're going to see this again, when we look at process capability, but if you want to know now, 3.4 parts per million we're roughly speaking about these tiny little tails in the diagram



Now, you will master this normal distribution and this type of probability and statistics will stand you in good stead, in any other areas including business analytics and management decision sciences.

Six Sigma Terminology:

Let's look at a few terms from Six Sigma, first of all, the term Sigma is used to designate the distribution or spread about the mean, the average of any process or procedure for process the Sigma capability, which we'll learn as z value, is a metric that indicates how well that process is performing.

The higher the Sigma capability, the better the process Sigma capability measures the capability of the process, to produce defect free outputs. And as we'll learn, a defect is anything that results in customer dissatisfaction, we are defining it as a defect occurs during any process step, when the outcome of the process step is not the expected outcome and that means that we have defined the expected outcome in advance.

Themes of Six Sigma

So, let's look now at the six main themes of Six Sigma.

Focus on the customer

The first major theme is focus on the customer, the Six Sigma process begins with a measurement of customer satisfaction on a dynamic basis. And Six Sigma improvements are then evaluated, based on how they impact the customer and the customer wants and needs.

First of all, the customer requirements are assessed and then the performance of the organization's product, is then evaluated against those requirements. Next any unmet needs or address through product or process change, customers get the highest priority in a Six Sigma organization.

Data and fact driven

The second major theme is data and fact driven management, the Six Sigma philosophy emphasizes a need for taking measurements. As you can see in this picture, for the candle example, we're taking measurements and proofs is performance. Product performance, satisfaction, the Six Sigma process has no room for decisions that are based on opinions or assumptions or just gut feelings. Process managers and problem solvers should decide, what information is needed and arrange to gather this information. The data should then be analyzed, using the appropriate tools, and the information generated must be used, to make decisions on process and product improvements.

This is a closed-loop system, in which measurements from the output are used to take corrective actions, to improve a process and is in a very important hallmark of the Six Sigma system.

Process focus

The third major theme is process focus; every product or service is created or produced by a process, whether it is designing a product for example, preparing an invoice, or answering a customer complaint. Any of these situations, these activities can be mapped as a process, involving a sequence of steps.

For example. When processes are mapped using charts on paper, they can be better understood and analyzed, improved and managed and so it's very important Six Sigma to analyze a process fully, then we are able to control it and improve it and this is a key precept in the success of leading to the success of Six Sigma systems.

Proactive management

The fourth theme is proactive management; proactive management involves setting ambitious goals and clear priorities, reviewing them frequently and implementing changes in the system, to prevent errors and defects from reaching the customer.

So, you can see here, with proactive management in Six Sigma, you need to have top management focus and support. If you wait for customer complaints, then you put your organization in a firefighting mode, so proactive management also means actively preventing the problems from occurring, and it's a lot cheaper and less time-consuming, than trying to solve them, after they have occurred.

Boundary-less collaboration

The fifth theme is then, boundary-less collaboration. And here, we need to have cross-functional teams with good communication among different functions. In the design or production stages and if you don't have this communication, you have delays, redesigns, rework, all of which cause wasted resources. You need teamwork across the functions, you need common goals towards customer satisfaction, and this has enormous potential for creating savings and customer confidence. The Six Sigma approach, emphasizes process improvement and process redesign, through these cross-functional teams and creates an environment in which people work together and support one another.

Driver for perfection

And finally, the last theme, the six theme is the driver for perfection; this is the most important theme of the Six Sigma process. We're driving toward near perfection and that is in our definition, not more than 3.4 defects per million opportunities.. Not more than 3.4 defects per million opportunities. In every process, this is achieve through diligent efforts in process analysis and process improvement repeated iterations on a never-ending basis we should say.

And this is the way to satisfy and then finally delight the customers and of course the customer standards usually keep changing and becoming more stringent. There may be occasional failures in driving toward perfection, but a Six Sigma organization will not be deterred by these, they'll learn from their failures and make progress towards perfection.

The DMAIC process improvement cycle.

The Six Sigma system recommends a five-step problem-solving methodology or five step roadmap, for organizations that want to become a Six Sigma organization. This process improvement cycle, uses the sequence **define**, **measure, analyze, improve and control**, which is abbreviated as **DMAIC**.

Now, we're going to go through the DMAIC flow in detail, in the next sections but in general:

Define

Define means to identify key customer requirements, what we call **the critical to quality parameters**. We want to set the goals for the Six Sigma project and form the project team. data, determine the current process performance and the current process capability.

Measure

In measure, you need to be able to map the process that we're studying. We want to collect. We measure influencing parameters, those that are likely to impact our critical to quality parameters.

Analyze

W we need to analyze all of the data, we need to confirm what we call - the vital few determinants of the performance. These are the key influencing parameters that affect our critical to quality outputs. We want to establish hypotheses for improvement and then,

Improve

You want to validate these hypotheses and you want to develop ideas to remove root causes, design and carry out experiments, to optimize the process, and finally, establish a solution for the process improvement.

Control

And then last but not least, in control; you establish a monitoring for your process, for these influencing parameters and you use generally statistical process control or SPC.

We now want to review the Six Sigma roadmap and the overall problem solving strategy used in Six Sigma. So we have our equation Y is a function of X, this is the fundamental equation behind the Six Sigma application strategy. The letter Y here, represents the output or critical to quality parameters of the customer values. Whereas the letter X, are the parameters of influence or affect the 'Y’s, the object is to move from the left side to the right side of the equation.

Our goal is to obtain knowledge about the ‘Y’s and the ‘X’s, as we move from process characterization, to process optimization and we achieve this goal, by following the road map. We take the project through the five phases; define, measure, analyze, improve and control.

Now, in define here, where we come up with our project charter, build our team, listen to the voice of the customer, understand what the critical to quality 'Y's are, then in measure; you're looking at measuring, mapping the process, measuring those parameters and starting at the top of our funnel. Looking at the overall capability of our process.

We then move through analyze; we narrow down these many ‘X’s to a vital few, we do cause and effect analysis, we identify the critical access and their influence on the Y with design of experiments or regression for example.

And finally, improve; we improve our process, test these improvements, And at the very end, under control; we put controls in place, for the critical influencing X variables using as we said, SPC.

Chapter 3: DMAIC Process Improvement Cycle

What you will learn in this chapter:

In this chapter, you will learn:

We're going to be reviewing the DMAIC process improvement cycle. The Six Sigma system recommends a five-step problem-solving methodology. And in this course, we're focusing on the process improvement strategy, which uses the sequence; define, measure, analyze, improve, and control. Abbreviated as DMAIC, and this five-step roadmap is recommended, for organizations that want to become a Six Sigma organization.

In a company, Six Sigma projects must be identified, and those selected or prioritized according to the prevailing situation. Once a given project is selected, the DMAIC flow for that particular project begins.

The Define Phase:

And in the first phase, the defined phase of the process improvement project; the project leader is responsible, for understanding the target customer expectations. Now, customer often refers to the end customer, which is the one purchasing the product.

But, this customer can also refer to an internal customer and the objective of this step, is to establish standards for the products produced, and the services provided, based on inputs from the customer so that, the process performance can be judged and its capabilities predicted. So important! It's important, not only needs to obtain the current customer, but also then to watch for the expected changes in this requirements over time. And, we call this then; listening to the voice of the customer or VOC.

The parameters which are then critical to quality, critical to achieve this; the customer needs or the voice of the customer, can then be identified, and the overall project goals can then be defined.

In the Six Sigma teams, comprises of top management, trained belts, who part or all of their work time have allocated the project. And in a full process improvement project of the project team, would be established to draw a formal project charter, including setting up a project timeline, cost estimations. And finally, the team, at the end of the defined phase, should be able to gain a basic understanding of the process flow, start basic maps of the core processes, and see what data is already available. And, this is of course all in preparation for the next step, which is measure.

Just a word about the special organizational structure that the Six Sigma system calls for, it also requires continuous and rigorous cooperation, among all the employees in the organization.

The key players in a Six Sigma organization and their roles are listed here as follows:

- **Executive leaders:** these are highly visible top-down commitment, they assume ownership of the Six Sigma process, and create vision and goals. They identify opportunities, importantly allocating resources and providing, you can call it inspired leadership.
- **The project sponsors:** sometimes called, the ***champion***, will be then the line manager or owner of the process, who identifies and prioritizes project opportunities. The project sponsor would then select projects, also help provide resources, participate in the project execution, and help to remove barriers.
- **The master black belt :**has an important role, this is someone who works full-time for Six Sigma implementation, and has the responsibility for planning and providing technical support for the entire organization.
  The master black belt, will train black belts, act as a coach and a mentor, and provide overall leadership in the Six Sigma implementation.
- **Black belts:** or people that have expert, or are experts on Six Sigma tools, they work full-time on Six Sigma projects, they train the green belts, lead teams and provide assistance, with Six Sigma tools.
  For example, the different improvement methods, diagnostic tools and statistical methods.
- **Green belts:** tend to work part-time on projects with the black belts and they integrate the Six Sigma methodology in their daily work, and lead smaller projects.
- **Yellow belts:** are projects are employees, who are trained in quality awareness and in Six Sigma basics, and our part-times participants in a team.
  They can contribute with precise expertise and finally, what's very important are
- **Financial representatives**: these are people independent of the project team, but are very important to help determine the project costs and savings, and report project benefits.

The measure phase

Here, we have these critical to quality outputs, these critical to quality parameters are identified from the defined phase, are defined. And here, we want to measure them, we want to check the baseline process performance, and see and evaluate it, against the needs of the customer - the voice of the customer, for the products and services created.

At the end of this step, we want to be able to have a baseline evaluation of process performance and person's capabilities, and this will be then known in a very quantifiable manner.

The project team, needs to understand the production processes in as much detail as possible, creating a measured, a detailed process map and this is in carefully reviewed, in order to identify the inputs in the process, which are likely to influence the critical to quality output parameters.

A data collection plan will be developed, and implemented for these parameters, and generally, a measurement system analysis or measurement system analysis, should be performed to make sure that the data we collect is correct. So for measure, we need to have a basic understanding of the statistics used for analyzing random variables. We need to know, how to map a process and how to design a sampling plan and collect data.

The analyze Phase:

In the analyze step of a project, the project team analyzes the data for the key process parameters, identified and measure, those which are likely to influence the critical to quality output parameters. In analyze, the objective is to develop causal hypotheses and to establish the key influencing factors, to improve the critical to quality characteristics, by confirming or not confirming the effect of these parameters, on the output.

This phase can include development, of course an effect diagrams, to identify potential causes. And here, the statistical background for hypothesis testing, correlation and regression are needed.

The Improve Phase:

In the improved phase of the DMAIC cycle, the priorities are established among opportunities for improvement. And the improvement projects, or the redesign projects are completed and validated. Here, we need to know how to design statistical experiments, and to evaluate the significance of inputs on outputs. This will then allow us to evaluate the impact of a process change on our product or process quality.

The Control Phase:

In the final phase, of the DMAIC process we have the control phase. Here, we assume here, we ensure that the obtained gains are maintained for the long horizon. We use standardized documentation, employee training and ongoing process monitoring with control charts and statistical process control and control charts then, are the key components, for the control phase.

So here, we see the entire cycle one more time, in a Six Sigma company, defining Six Sigma projects, we start with define, we define the voice of the customer, we setup our teams, we move to measure where we're looking for parameters, we're measuring our critical to quality parameters and identifying parameters, that will influence these critical to quality parameters. Then in analyze, we're actually looking at the data, to see if the effect of these influencing parameters on our outputs. Improve; we then look at different improvement projects, to achieve our voice of the customer, targets and finally, in control we try to maintain, we want to maintain and continually monitor our processes into the future.

Chapter 4: Impact of Defects / Measuring Defect Levels

What you will learn in this chapter:

In this chapter, you will learn:

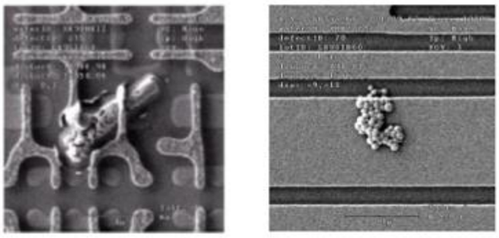
- Discuss the impact of defects in a process.
- Calculate process yield and ppm.
- Discuss the importance of a low fraction defective per part for complex products.
- Understand the difference between a defect and a defective part.
- Understand the terms DPU and DPMO and how DPMO differs from ppm.
- Discuss the importance of preventing defects.

Defects:

But first, what do we mean by the word defect? And so in this course, we're going to say that, a defect occurs during any process, **when the outcome of the process is not our expected outcome**.

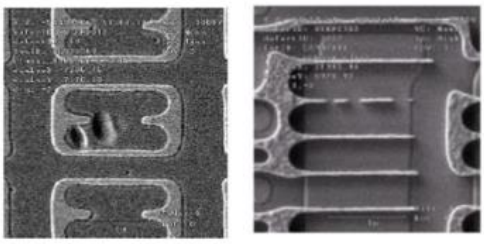
And what we mean by that, is that the expected outcome is the outcome that, we have specified in advance. It's what we want the process to produce and if a defect occurs then the outcome of the process will not be as we expected. In other words, a defect is a flaw or an error or a discrepancy.

And just to put this into a little more visual context, here are some defects from my former work. Here, we have some random defects, some particles not deposited on the semiconductor wafer, these could potentially cause the integrated circuit, the chip not to work.



Random Defects: unwanted particles

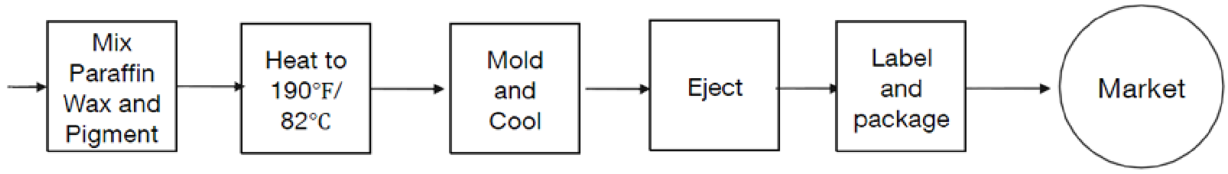
Here, we have also same thing, silicon wafers with here, and some systematic defects. Here, we have gouges for example, in the film or lines that are not printed correctly, they're also unwanted, and they're not part of the specified



Systematic Defects: process problem

outcome of the process. And then, could cause a defective part.

Now, let's look together at a simple process for making crayons:



The two basic ingredients for crayons are; paraffin wax and pigment color. These are then mixed and stored and heated gallon tanks and then they're heated. This is a storage facility, they're heated up very hot and melted and then, poured into a mold of crayon shaped holes, and a single mold can make over a thousand crowns at a time, for example.

You then cool the mold, and then an operator will use hydraulic pressure to eject the crayons, from the mold and then, they're labeled and packaged and so, a crayon manufacturer a big one could produce two to six millions crayons in a day, for example.

Now, why worry about a few defects? You're the manager of a crayon manufacturer, out of a hundred batches of paraffin wax and color pigment used for the crayons, an average of one batch does not match design specifications. When you find out about a bad batch, you need to scrap around 40 batches but you estimate that the scrap costs are very low. In fact, the scrap costs for this 40 batches is less than 0.05% of the cost of goods sold, extremely small. So you say, the problem is under control.

Now, from a quality perspective; are there any flaws in your thinking?

let's look at this together. So here, we see our crayon flow again, now, a defect is produced somewhere in our process. Let's just arbitrarily draw defect occurs and this leads to in my example, to a defective crayon, defective crayon, defective product or if we were service process, would be defective service.

Where are our costs here?

Now, before the defect occurs, you have costs due to the materials and we've said that's not so much in this example. Even though, we scrap the batches we know that it's a small amount of money. But, where else do we have costs?

well we have also the labor, that went into making that crayon. So the people that we've hired for our process for our process, they're there to make the products and we're paying them for making parts that we cannot sell. Now, the other interesting thing is, if we have a process where we have a high demand and we have a capacity constrained process, then we're using on both cases even if it's not capacity straight, we're using up capacity on machines, we're using up the energy costs for example, for heating up the mixture, the molding machine, we're molding products that could potentially not sell. So the capacity is being used up and this can be critical when we have a capacity constrained process, which means we need every single part of our capacity every minute of our capacity, we need to make good parts to meet the demand.

So these though, in this part of the factory, we've got internal failure costs. Which although they may be small, they're very real. Now the other problem is that, we have this defective crayon, I didn't write that right. Crayon and this defective crayon might end up getting out to the customer.

Now, the case of crayons maybe is not that critical depends if there's something toxic in it or something then it would be critical but you can think of this applied to something like to another product like our car or like some kind of medicine. That defective product gets out to the customer, we have for example, warranty cost, liability cost.

We could have even worse, recall cost, we could even worse have the loss of reputation and loss of reputation leads to things like lower prices; we're forced to sell our products at a lower price or even loss of market. The demand will drop and these are called then the external failure costs.

And these external failure costs are often underestimated, so even if you're arguing that the scrap or the material is not that much there's other things you need to think about, and one of the most important ones is what happens if that defective part gets out to the market.

And there's one more thing here, can you think of one more thing, one more problem. It's the idea that if you allow one batch of a hundred, so one match of a hundred looking at 1% of poor material, if you allow that you are creating a culture; **1% defective are ok**.

And what we're going to see very soon is that, even a small percentage of defectives can accumulate to very substantial failure rates for an entire process. And these are crayons, we just have a few parts, what if you have a very complex process? For example, we said before like a car

Process Yield:

Now let's look at the important concept of process yield, to measure the level of defects in a process. We'll use "p" to represent the number of defective units produced at a process step, divided by the total number of produced units going into the process step.

p = # of defective units produced at a process step / total number of produced units going into the process step ("*fraction defective*")

This is also known as:

- The fraction defective,
- the defect rate or
- the failure rate,

Because you hear those terms. And if you convert that into a percentage, then we get the **percentage defective**.

So, on the other hand, the yield at a process step which represents the number of good units produced at that step, divided by the total number of units going to that step, is going to be equal to (1 - p). So (1 - p) is the percentage of units that complete a sub process, or a part or a process step meeting quality guidelines, without being scrapped, retested or reworked.

Yield = # good units produced at a process step / # total units going into the process step

= ***1 – p***

So, if you have more than one process step or more than one part to make your product, where n is a number of process steps or parts then, the overall good units coming out of the entire process is going to be the process yield or the yield at each process step (1 - p) ^ n.

***n*:** number of process steps (or parts)

***1 - p*:** yield at each process step (all steps or parts have same yield)

Note: *here, we're going to use the term process yield, but this is also referred to as for example, first pass yield or first time yield or old throughput yield and* *these are sometimes used interchangeably. Although typically rule throughput yield is normally given as the probability of manufacturing a part or performing a service process, that you can perform all the required steps without any failures. Whereas, first-pass yield or does not normally consider that but, it it depends on the reference.*

We're going to call it process yield means, the yield at each step (1 - p) ^ n or n is the number of steps. And just one variation on that, is if you have different yields at the each process step, so yield at step one, we call 'a', yield at step two is called 'b', yield step three is called 'c' .

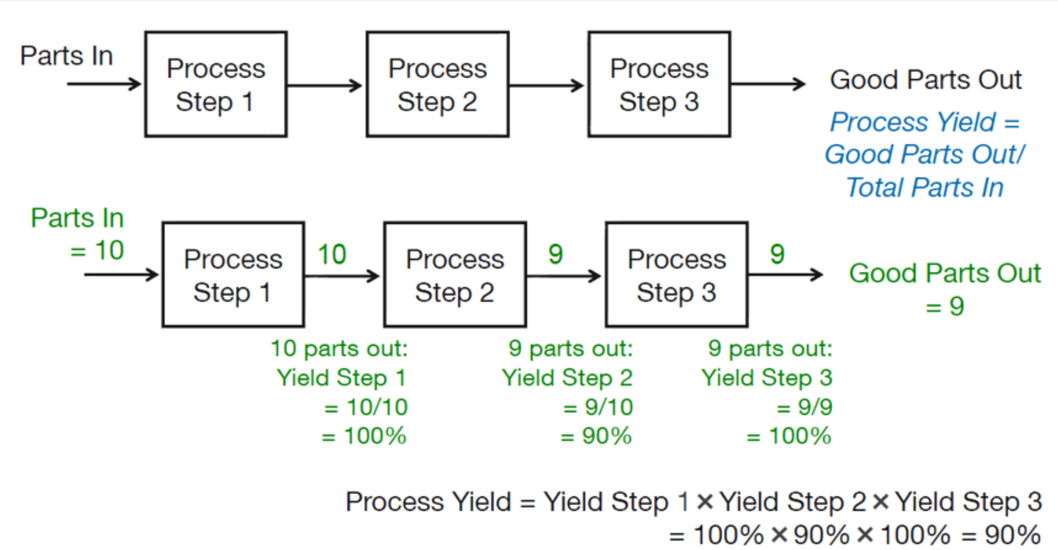
Process Yield* = $(1 - p)^n$

a: Yield at step 1, ***b***: Yield at step 2, ***c***: Yield at step 3…

Process Yield = *(a)(b)(c)*

You multiply all these three together to get the process yield.

So let's do some examples:



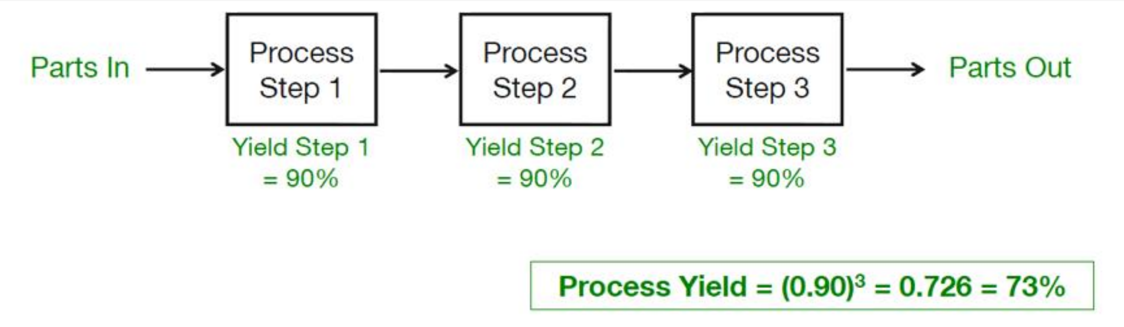
Here we, have a three step process and the process yield defined as a good parts out, divided by the total part in. So for example, if we start with ten parts into process up one, and get ten good parts out, then the yield is going to be 10 /10 or 100 % , for that per system.

For process step two, we get to have 10 parts going in and only nine out. So the process yield for step two is going to be 9 /10 or 90%.

For step three, those nine parts go in and nine parts come out, so here, we have process yield of 9 /9 also 100%.

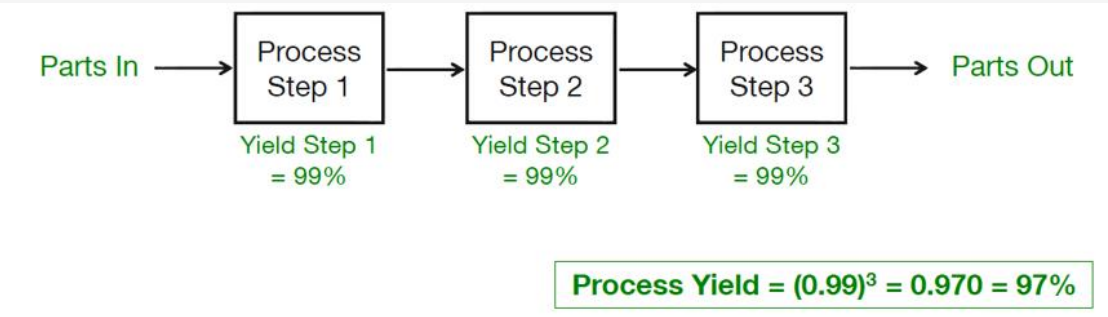
The total yield as we learned, we have to multiply all the yields together, so we have (100 * 90 * 100) and we end up then, with an overall yield of 90% , and we can also say, I've written over here - good parts out is 9, parts in is 10, 9 /10 is 90%, okay.

So, let's look at the three process step then with each 10% fraction defective and calculate our final process yield.



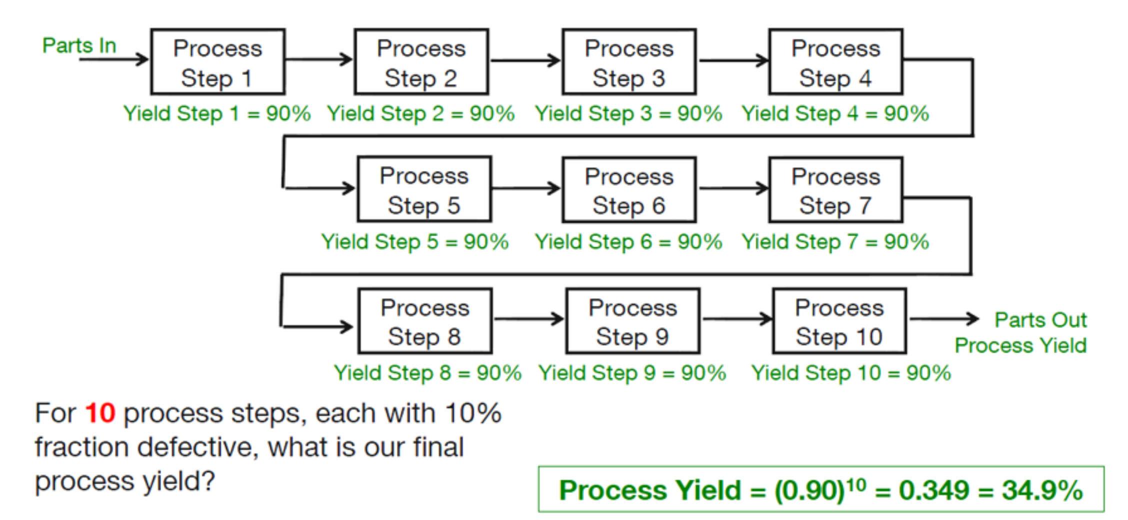
So, we said that the fraction defective is equal to P. So p is equal to 10% or 0.1 We have three process steps, n = 3 here, and this means then, we have fraction good parts coming out of each step is (1 - p) = (1 - 0.1) = 90% (0.9) and we can then calculate (0.9) ^ 3 to give us an overall process yield of 73%.

To another example, here we have a three process step with a fraction defective and each process step of 1% ,



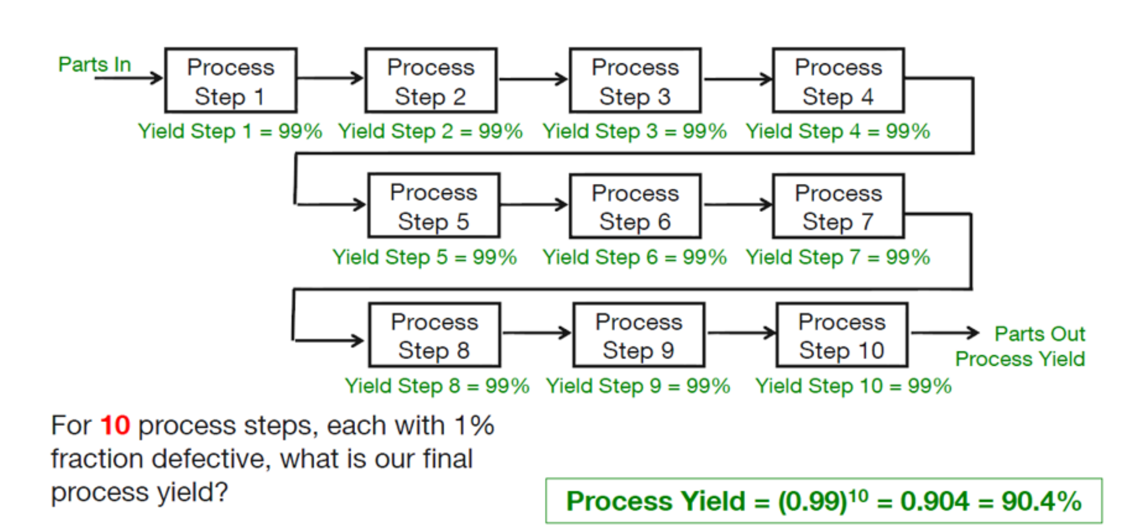
so since 1% of the production of each process step is defective, P = 0.01 and the yield again, we're going to have at each process step is (1 - p) or 99%. So, we calculate this is (0.99) ^ 3, and what do we get here? For our overall process yield, much better right? 97% better than 90% process yield at each step, or we only stuck with 73 percent out now we have 97 percent out.

So now, let's look at a ten step process; we have at each step 10 % fraction defective, so (P = 0.1) , (1 - p),



The yield at each step is equal to 0.9. How do we calculate this? Before (0.9) ^10, we end up with only 34.9 good parts coming out of our process.

You know what we're going next, right? we have 10 process steps, each with 1% fraction defective.



So, p =0.01, (1 - p) = 0.99. 99% effective at each process step. Now, we have (0.99) ^10 and we end up with, yes a better result, 90.4% yield overall process yield.

For 100 process steps, each with 1% fraction defective, what is your final princess yield?

For **100** process steps, each with 1% fraction defective what is our final process yield? *1 - p = 1 – 0.01 = 0.99 = 99% yield at each step.*

Process Yield = $(0.99)^{100}$ = 0.366 = 36.6%

So here, you have p= (0.99) ^ 100, only 36.6% good parts out.

For a 1000 process steps, each step with 0.99 (99%) yield, our overall process yield is 0.00432%

For **1000** process steps, each with 1% fraction defective what is our final process yield? *1 - p = 1 – 0.01 = 0.99 = 99% yield at each step.*

Process Yield = $(0.99)^{1000} = 4.32 \times 10^{-5}$ = 0.00432%

and what if we have 10000 process steps,?each with 99% defective, 1% fraction defective, 99% yield?

For **10000** process steps, each with 1% fraction defective what is our final process yield? *1 - p = 1 – 0.01 = 0.99 = 99% yield at each step.*

Process Yield = $(0.99)^{10000} = 2.25 \times 10^{-44}$ = pretty much zero!

pretty much zero and process yield. By the time you take (0.99) ^10000 you don't have any good parts out.

Now, why is this relevant? What could this be?

Well, assume a car consists of 10,000 parts or processes, let's look at this,

For **10000** process steps, each with 1% fraction defective what is our final process yield? *1 - p = 1 – 0.01 = 0.99 = 99% yield at each step.*

Process Yield = $(0.99)^{10000} = 2.25 \times 10^{-44}$ = pretty much zero!

for 10,000 process steps, each with 1% fraction defective, each with 99% yields, we just said, you don't get any cars out.

What can we do?

let's improve that fraction defective, let's make it 0.621%, so instead of 1% , we've improved the fraction defective to less than 1% (0.621)

For **10000** process steps, each with 0.621% fraction defective what is our final process yield? *1 - p = 1 – 0.00621 = 0.99379 = 99.379% yield at each step.*

Process Yield = $(0.99379)^{10000}$ = 8.84 × 10^{-28} = pretty much zero!

Well, if we do that, where do we end up? Well, pretty much zero (0)! Pretty much, nothing comes out of our process.

What happens if we go to extreme measures and each process step has only 3.4 * 10 ^(-4)% , fraction defects, does it mean that each process type has 99.99966% yield. What do we get?

For **10000** process steps, each with 3.4 × 10^{-4} % fraction defective what is our final process yield? *1 - p = 1 – 0.0000034 = 0.9999966 = 99.99966% yield at each step.*

Process Yield = $(0.9999966)^{10000}$ = 0.97 = 97% good parts!!

Well, if we do that, (0.9999966) ^10000, we end up with 97 good parts. What you're supposed to see here, these numbers are chosen purposefully, that you have to have a very very low fraction defective, when you have a complex product. In order to get a reasonably high yield and think about 97%

For BMWs, how much does each BMW sell for? And so if, out of every hundred, we only have ninety seven that are good, we're losing three percent of our production every time, for example.

Parts per million

So now we've talked about process yield, we'd also like to discuss three more ways of measuring defects. On the first one, is the parts per million or ppm.

Before we had denoted P as the number of defective units over the total number of produced units.

PPM is the number of defective units per million,

$\boldsymbol{p}$ = # of defective units / total number of produced units = "*fraction defective*"

$$ppm = \text{\# defective units} \times \text{million units}$$
$$= p \times 1 \text{ million}$$

so the number of defective units in one million produced, or can also write as the fraction defective 'p * 1' million. Now, you hear ppm typically used in scientific fields like chemistry, as a way of quantifying very small volumes, but you also hear it quite regularly in quality management.

So as an example:

For a 99.379% yield at each step what is the ppm?

$1 - p = 0.99379$

$p = 1 - 0.99379 = 0.0621$

$ppm = 0.0621 \times 1000000$

= 6210

for a 99.379% yield at each step, what is the ppm?

well we have the yield at each step is going to be then 0.99739 which is equal to our '1 - p', then p = 1 - 0.99739 = 0.0621.

So the parts per million as we said, will take that fraction defective p * 1 million and we end up with 6210 parts per million defective.

Another example then, if we have 99.99966% yield at each step, what is then the parts per million?

For a 99.99966% yield at each step what is the ppm?

$1 - p = 0.9999966$

$p = 1 - 0.9999966 = 0.0000034$

$ppm = 0.0000034 \times 1000000$

= 3.4

So again, the yield at each step is going to be 1 - 0.9999966, oh sorry! 1 - p = 0.9999966, p = 1 - 0.9999966 and here, we have 0.0000034 parts per million then, it's going to be 3.4 parts per million defective, so closely related of course.

Now, we have our car example, if we have a car consisting of ten thousand parts and production processes, and if we have six thousand two hundred and ten parts per million defective for each of those process step or for each part, this then means our overall process yield as we said before is going to be (0.99379) ^10000.

6210 ppm → 0.0062 fraction defective at each process step or part

→ **Process Yield = $(0.99379)^{10000}$ = 8.84×10^{-28} = all vehicles faulty**

So again, we took our fraction defective and we converted that then into the '1 - p' and all of our vehicles will be faulty.

On the other hand, if we have 3.4 parts per million, which translates into this 0.0000034 fraction defective at each process step or for each part, then the overall process yield of course is '1 - p' so it's going to be the (0.0000066) ^10000 or as we saw before 97% fault free vehicle's

3.4 ppm → 0.0000034 fraction defective at each step process step or part

→ **Process Yield = $(0.9999966)^{10000}$ = 0.97 = 97% !**

Good cars.

So, let's just make one point before we move on. There's a distinction we're making if you've not picked it up already between defects and defective products. And we said before, a defect occurs, when the outcome of a process or process step is not what we expect.

Defects vs defectives

Let's look at another example here, I produce pencils and I reduce high-precision drills, if I produce 1 million pencils on 1 million drills and my pencils have 30 defective units, then my parts per million since I produced a million is going to be 30 parts per million defective. My drills have 3000 defective units, defective drills, I'm going to have a ppm of 3 thousand parts per million defective. The question is, are my drills worse than my pencils?

I produce

1. pencils
2. high precision drills

If I produce 1 million pencils and 1 million drills,

and my pencils have 30 defective units → ppm = 30

and my drills have 3000 defective units → ppm = 3000

So here, I've written it again, let's look at our yield, so the yield for the pencils. So we knew that the parts per million divided by 1 million (ppm/1 million) is going to be 'p' so the yield is '1 - p' and we end up with 99.997% yield for our pencils. The drills on the other hand, again this is 'p' , we end up with 99.7% yield and so clearly this is higher, clearly the yield for the pencils is higher but, our drills worse than the pencils.

Process Yield Pencils = (1 - ppm/1 million) = (1 - 30/1000000)
= 0.99997 = 99.997%

Process Yield Drills = (1 - ppm/1 million) = (1 - 3000/1000000)
= 0.997 = 99.7%

DPU and DPMO

And now, we come to the concept of DPU and DPMO. if the drills have many more opportunities for defect creation, then the defect per million opportunities measure, can actually be the same or even better for the drills.

Let's have a look, the first of all defects versus defective; a defect occurs during any process when the outcome of the process is not our expected outcome. It's a flaw, an error or discrepancy. There can however be multiple opportunities for a defect and so, an item is only said to be defective when there's a decision made, that the item is not acceptable. And this can be based on one characteristic or the accumulation of multiple defect, making our characteristics unacceptable.

To take this into account, we can use, we define additional measures:

- **The DPU** :or defect per unit, which is the average number of defects per unit of product and
- **The DPMO:** or defects per million opportunities.

The DPU metric is a measure of capability for discrete or attribute, we'll learn later data defined by the following: the total number of defects divided by the total number of units.

$$\text{DPU} = \frac{\text{Total \# of Defects}}{\text{Total \# of Units}}$$

So you count the number of defects produced and this could be for example, the pencil could have defects such as the length; it could be too short or too long, it could be the diameter; could be too thick to thin, blemishes on the paint for example, the eraser is fitted too tightly or too loosely, we can count these defects. We count them up and we divide that by the total number of pencils to get the DPU.

The DPMO or defect per million opportunities is a metric with differentiates between products with many defect opportunities, like our drill and those very few defect opportunities which is our pencil in this example.

$$\text{DPMO} = \frac{\text{DPU} \times 1000000}{\text{Total Opportunities for a Defect in One Unit}}$$

$$= \frac{\text{Total \# of Defects} \times 1000000}{\text{Total \# of Units} \times \text{Total Opportunities for a Defect in One Unit}}$$

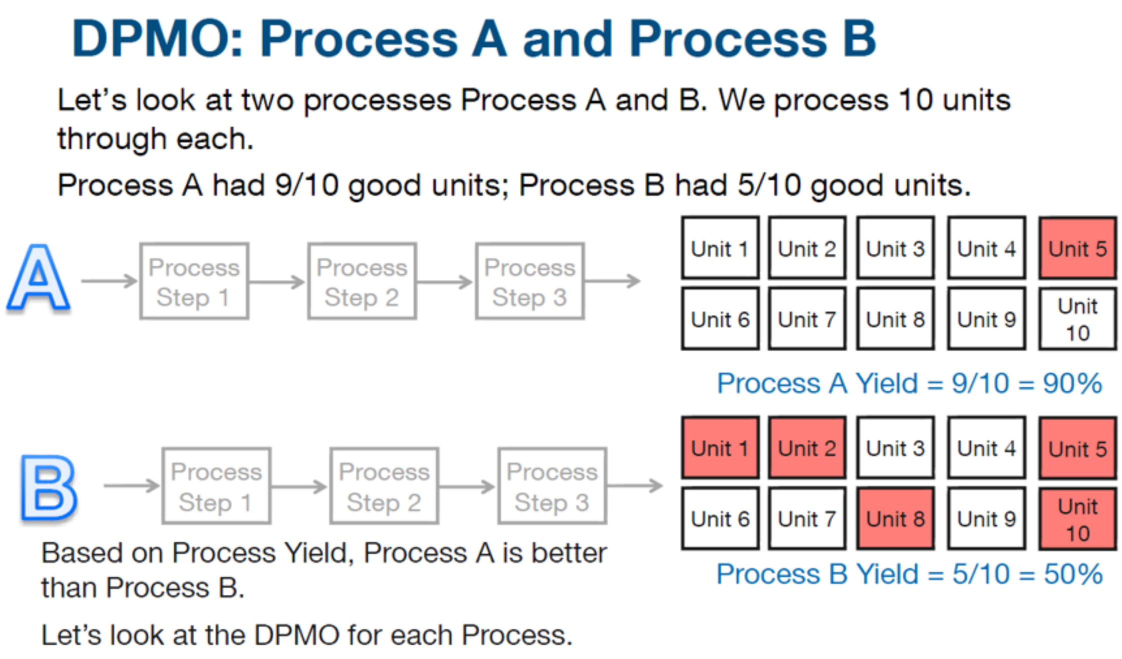
if each unit has several opportunities per unit of critical to quality characteristics, to be defective then, we can talk about DPMO as the defect per million opportunities, equal to our DPU times a million divided by the total opportunities for defect in one unit. And that then, translates into the total number of units, the total number defects divided by the total number of units, which is here then equal to our DPU.

Now, how do you make this decision of, how many opportunities we have for defects in a unit? And this is where the softer side of quality comes in, your team decides. How many defect opportunities do you have in a pencil? how many defect opportunities do we have in a drill? what happens then if your team selects more than one opportunity for defects?

So clearly, if you think from between pencils, excuse me pencils and drills, this number will change, this is the decision here. If you think your drill has more opportunities, then this DPMO number will be reduced compared to pencils. We're going to look at an example of this.

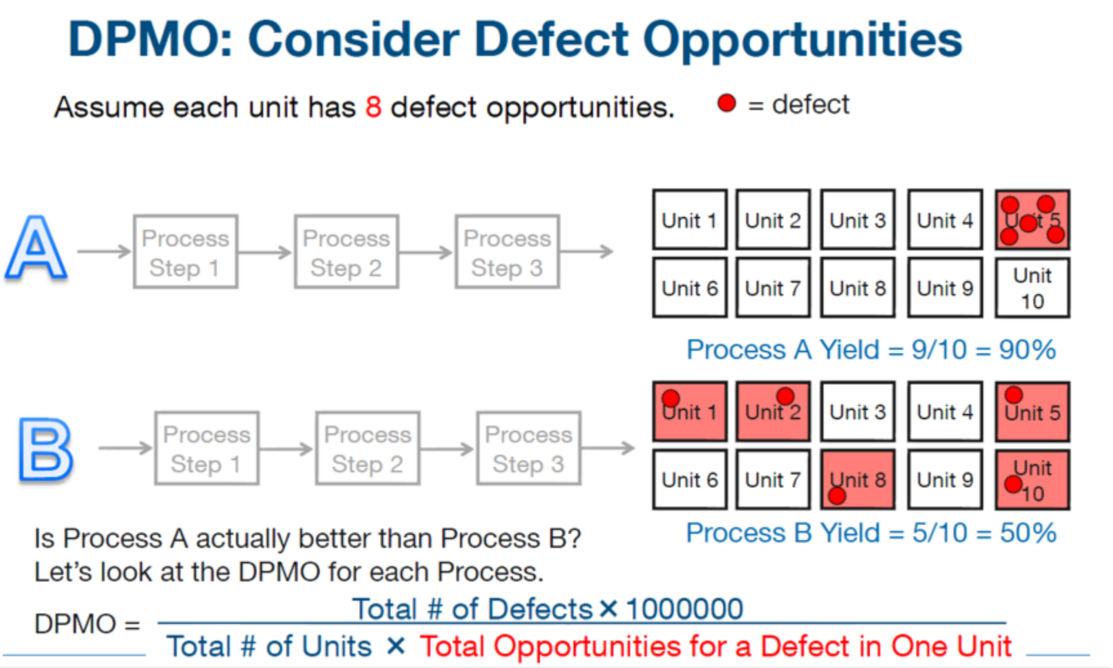
Examples:

You are influencing here the numbers, so here we have two processes; process A and process B, and we're going to process ten units through each. So here, we see process A with three steps, and ah! unit 5 comes out bad, so we have a process yield of 9 over 10 or 90%. For process B, hmmm 10 units and unit 1, unit 2, unit 8 unit 5, unit 8 and unit 10 are bad, so we have only 5 out of 10, so process yield for process B is only 50%.



So based on the process yield, you can see process A is better than process B, maybe they had a different machine, maybe these are slightly different operators and you're not sure what the processes should be the same.

Let's look now though, at the DPMO for each of these processes, and now we have to introduce actual defects; so we have each unit has eight defect opportunities, and we indicate a defect by this little red dot here.



Here, we see for process A, that we have to remember for process A that unit 5 was defective and all of our defects have occurred on unit 5 and it's officially defective.

For process B however, we see that the defects are actually on each of the defective units, each of these defects caused a defective unit but, they they all occurred on different units instead of all in the same one.

So, if you look at the DPMO for this, don't forget DPMO is the total number of defects times a million, divided by the total number of units, times the total opportunities for defect in one unit.

Both processes are generating five defects, here are five defects, and here are 1, 2, 3, 4, 5. So, for process A, DPMO total number of defects is five times a million, divided by the total number of units, divided by the total number of opportunities for defect in unit, and we said that was eight.

$$\text{DPMO} = \frac{\text{Total \# of Defects} \times 1000000}{\text{Total \# of Units} \times \text{Total Opportunities for a Defect in One Unit}}$$

- Process A: DPMO = (5)(1000000)/(10 × 8) = 62,500

Process B: DPMO = (5)(1000000)/(10 × 8) = 62,500 → **Same as Process A**

So, we end up getting five total number of defects, times a million divided by the ten units times eight, we get sixty two thousand five hundred as our DPMO, defects per million opportunities. And for process B, lo and behold, we get exactly the same thing, because we still have five defects for process B, so we see with DPMO, that the processes are equal both generate the same number of defects, even though the number of defective units that came out of the entire process is clearly not the same for A and B.

So, let's just make a couple more notes here, what is the difference to ppm? Here, we're talking about defects, we're not talking about defectives. In ppm, we say well in DPMO we're saying the parts of our process can have more than one defect opportunity, more defects can occur and create one defective, parts per million which is the number of defective units per million units.

So, you're looking at the defective units that are coming out of the process. Now, these are often used interchangeably in industry and we're going to look at this again, in the context of Six Sigma.

Yield, ppm and DPMU

p = # of defective units / total number of produced units ("*fraction defective*")

Yield = # good units produced at a process step / # total units going into the process step = ***1- p***

ppm = # defective units / million units = $\boldsymbol{p \times 1}$ **million**

$$\textbf{DPMO} = \frac{\text{Total \# of Defects} \times 1000000}{\text{Total \# of Units} \times \text{Total Opportunities for a Defect in One Unit}}$$

Now, if there is only 1 defect possible per unit, then the #defects will be equivalent to the # of defective units (every defect will produce a defective unit)

$$\textbf{DPMO} = \frac{\text{Total \# of Defectives} \times 1000000}{\text{Total \# of Units} \times (1)} = \textbf{ppm}$$

ppm and DPMO are often used interchangeably in industry and we will look at this again in the context of Six Sigma.

So, just to recap if 'p' is the fraction defective, the number of defective units over the number produced units, we have yield is then going to equal to 1 minus 'p', is the number of good units produced at process step versus the total units going in. If you have more than one process step, could write this down here, with the process yield equal to one minus 'p' to the power of n, for the same yield loss at each step. ppm is 'p' times 1 million and DPMO. We saw this is DPU times 1 million, divided by the total opportunities for a defect in one unit.

Now, if there's only one defect possible per unit, and that creates a defective, then you'll end up with DPMO equaling to ppm. You will then say that, the number of defects is going to be equal to the number of defective, there's only one opportunity and it causes a defective then you get DPO equal to DPM.

Measuring the defect rate

Let's look at measuring the defect rate, so why don't we just measure the defect rate directly? well first of all, the defect rate is hard to measure when defects are rare, and what we're going to be trying to do is to identify a key variable, we call this the critical to quality variable for the product. We want to measure this variable, to help us monitor our defect rate. If this variable moves out of specification, then we expect a defective.

We're going to call this then, the critical to quality or **CTQ** variable. The distribution of this key variable and its relation to the specification limits, our expected outcomes, will offer us insights into the how the defect rate the fraction defective can be reduced.

For examples, we'll see later targeting the mean and reducing the variation or both.

We're also going to see that measuring the distribution of this key variable, can be very straightforward when you're using for example, the control charts that we see later in Six Sigma.

And that will then also bring us to our next section in this course on process capability. And what can we do about defects? why don't we just measure them? well as we just said, it's hard to measure them when they're rare, there're also kind of many many different causes, so one thing to do, is to try to detect them early.

Early detection is better than late section inspection, why? well we talked about that with our crayon factory.

- First of all, we're losing our cost of our materials, for any defective that's produced and we're going to be then using even more capacity and manpower, if that defect continues to the process.
- And if it's defective detected early, then the idea is that we can quickly look into it, reduce the number of defects, we can then get rid of those defective parts and the capacity can be increased.
- And we'll introduce all this internal failure costs that we talked about. Um, so we just said the cause hopefully can be identified, we don't have to look through the entire line, we've detected early, so we can find the root cause and we said before,
- we then have this culture change, the idea that workers are involved to detect problems early, identifying problems, bringing attention to them and being rewarded for that, rather than having them having them, considered like that there's their problem. And you know, you can design your process so that you have built-in tests monitoring, that can signal these problems quickly and automatically and and very importantly, immediately.
- And finally, preventing defects; there's a lot of costs going into preventing but, you've got to make sure that you have the right type of, so we were just saying automatic checks, you've got to put the time in and if you just have an inspection at the end of the process, you've got these non-value-added costs and capital, just for the inspection. And of course, you'll still end up with scrap or rework cost, rather than having prevented the defects all the way at the beginning and inspection is never perfect, as we were talking about the external failure cost, you can end up some of those defects may slip through, and that can be then lead to very large problems, and if when the defects get out into the field.
- Additionally, again with the idea of culture, inspecting at the end removes responsibility and again, not that we want to finger point, but as soon as you find where the defect occurs, you can look at it and attack it right away, rather than waiting until the end. And you can end up, quite off of fighting that you have a bottleneck in your process just at the end, at the inspection point. So, prevention typically cost less, than the combination of all the inspection, internal and external failure costs. And how do you do this? You want to develop capable business processes, through standardization and continuous improvement, for which is our goal of Six Sigma.

Chapter 5: Defining Quality

What you will learn in this chapter:

In this chapter, you will learn:

- Define quality as relative to a set of requirements and in terms of customer expectations.
- Compare the concept of quality management today to the past.
- List major milestones in the development of Quality Management.
- Describe the quality losses associated with not producing producing quality products and the economic gains arising from producing quality products through the use of quality methods.
- Describe today's view of quality management.

Define Quality

But first, how can we define quality?

One of the most famous definitions is by Dr. Joseph M. Juran, one of the fathers of modern day Quality Management, and as we'll see here later also, he's known for incorporating the human aspect of quality management. Dr. Juran stated that, quality means "**fitness for use**", however a more precise definition, we could say is "**fitness for use and meeting or exceeding customer expectations"**.

However, another definition of quality which is worth quoting is from Dr. A Blanton Godfrey, a modern day quality guru, and in a 2002 article he says the most fundamental truth is that, "**quality is relative; the customer focus is simply on value, seeing it as a ratio of quality over price and only when we offer more value than our competitor, do we really succeed"**. And this definition, goes beyond the idea that quality is simply being fit for customers' use, it includes:

- customer satisfaction,
- it includes efficiency in production and
- Price competitiveness.

It conveys the idea that, not only is it enough for customers to make the products with the right characteristics but, the business needs to make a profit. It needs to be successful as an enterprise, in order to truly have quality.

Quality Dimensions:

Now, of course as we all know there's very many different dimensions of quality. This, of course reinforces the idea that to define quality is very difficult, so cannot do this in just one simple sentence.

Quality may have different meanings for different products, or even for the same product, has different meanings for different users, for different markets.

For example, you may be interested in the performance, how fast something goes, how smooth something sounds, how sharp something is, how wide something. You may be interested in the reliability; how long does something last. You may be interested in the durability of a product, or how easy it is to service.

Today, people are also looking at a new dimension; Sustainability. How much does our own product impact the environment? How much wastes does it generate?

The quality must be defined for each product, based on the particular customer needs, what they want in the product and this has to be, this is part of our course, this has to be done through measurable characteristics, and their limits of variability.

So for complete definition of product quality, we need to stress the importance of identifying the needs and expectations of a customer. The product designer will take these needs and expectations, select features of the product and create a design. Then, the targets and the limits of these variations, for these features will be selected so that, the product can be produced at a reasonable cost, while meeting the customer needs.

These products' features which must be measurable, we call **critical to quality** characteristics.

And as we said, though quality is going to be relative to the set of requirements, so we have functional requirements. For example, if it doesn't meet those limits, there will be a breakdown, there'll be a loss of function and then, we have subjective requirements, aesthetic, optical requirements, that aren't essential to the function of the product but, could have very important quality aspects.

None Quality

And as we said, quality must meet needs or exceed customer expectations but, what does Non-Quality mean? What do we mean by Non-Quality? And here, we have a quote from Warren Buffett "**it takes 20 years to build a reputation and five minutes to ruin it"**. If you think about that, you'll do things differently. And we look at this, in terms of costs; quality costs a little bit later.

Past view of Quality Management

Let's go back though, what was the past view? Quality Management meant simply, the product would come out of the line, would be inspected, and then either scrapped, or possibly reworked.

Preconception was that, **quality means to test**, it means additional resources used for testing, time used for testing. This is very costly, this reduces your throughput, cost manpower and it's very reactive. Something has happened and therefore, we either have to scrap or we can maybe rework.

But things have changed since then, and we're going to go through now, the major milestones that have happened in the quality management movement since the 1900s.

Early 1900s:

Let's start in the early 1900s, when "**Henry Ford"** began the mass production of automobiles, the Ford Model T. Ford was inspired, by the slaughterhouses in Chicago, where he observed the processing of the cow carcasses, and he decided to use this assembly line production, for his automobiles, with workers doing specialized tasks, using specialized tools and interchangeable parts.

This allowed for the first time, well almost the first time, fast and cheap production of automobiles, propelling the before craft production of cars, to a huge industry.

1920s:

Now, this is going on but, we had important contributions to the quality movement from first, in the 1920s, we can mention Bell Laboratories. They've been working to improve the reliability of their transmission systems, and **"Dr. Shewhart"** developed at the time, the methods used today for **statistical control charts**.

He applied these then at **Western Electric**, emphasizing the importance of reducing variation, in manufacturing processes.

Now, in England in the 1920s, Sir **Ronald Fisher** was working on improving agricultural yields, using designed experiments. And later we had **Dr. Taguchi**, also working on the development of designed experiments for product and process engineering.

1940s:

In 1940s in World War II, we saw the use of statistical methods by the **military in the U.S**. , for the production of goods and ammunition.

1950s:

And after the war, in the 1950s, there was a development of the science of reliability, which is why our products today last so long. But it really wasn't until after World War II, that the more exciting quality concepts and movements appeared and moved towards consumer applications.

For example, in 1950s, **Edward Deming**, he was a colleague of **Dr. Shewhart** and he went to Japan as part of their post-war rebuilding efforts, and he brought Dr. shewhart ideas of process control to the Japanese industry, in particular to the automobile industry.

1951:

We also had the publication of **Dr. Joseph Durham's**, last quality control handbook in 1951, he was in charge of applying and just disseminating the Bell Labs' statistical quality control innovations, in **Western Electric** in the in the 1920s and he, as we said before, was one of the people credited or the person credited, with **bringing the human element of quality** into the quality movement.

But then, of course we come to the famous **Toyota Production system**, which plays of course a huge role in quality management, and there's many interesting books dedicated to this, mentioning for example, the original Toyota loom works, founded by **Sakichi Toyoda**, and how these automatic looms would halt, as soon as a thread broke, so defects would stop the line immediately, stopping all further production. The firm was then led later by his son, **Kiichiro Toyoda** and he decided to move the production to automobiles after the war, and the firm struggling, needed to work differently than their American counterparts.

They realized they needed to reduce waste and be much more efficient, and have much higher quality. This developed the basis for what we call today, **lean manufacturing** and here yes, **Edward Deming** played an important role in this development, and we need to mention of course ,the engineer **Taiichi Ohno**, he's considered to be the father of the Toyota Production system, developing ideas such as the **seven forms of waste**, and **just-in-time** production.

We also have the **Ishikawa diagrams**, by Professor Ishikawa at the University of Tokyo, looking at causes and effect analysis and while all these things are going on, the Japanese automobile industry surged, to become a huge competitor to the big US automakers.

1980s:

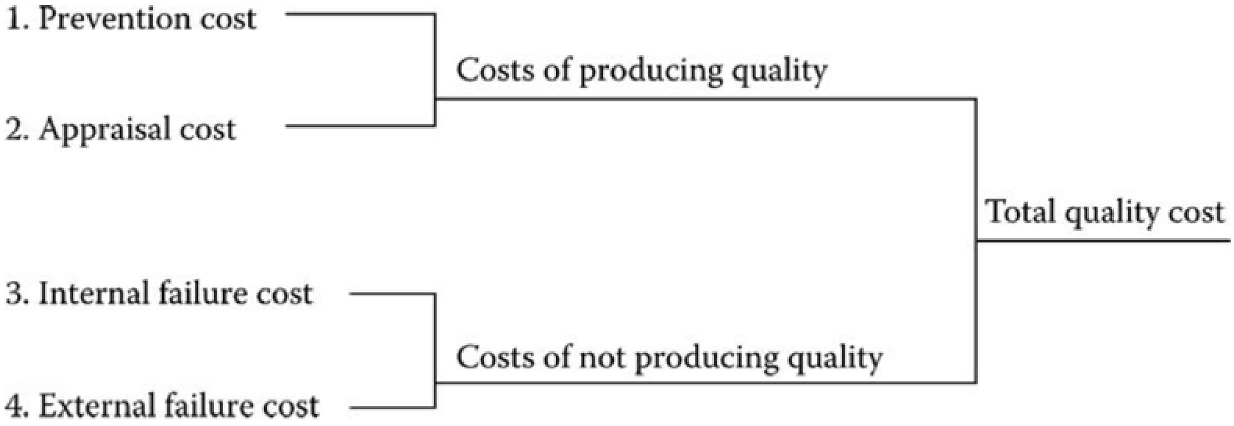
Now, what was actually happening in the U.S. that's another interesting story. In the 1901, though it was not following these amazing changes that was happening in Japan, but in 1980 **Motorola** made a huge step. **Bill Smith** engineer, introduced the Six Sigma methodology, a data-driven, systematic problem solving approach, for process improvement, following the DMAIC cycle.

In 1987, there was the creation of standards for Quality Assurance, by the International Organization for Standardization (ISO), that was then at the time called ISO 9000 and today, we see the acceptance of quality, as a critical, strategic parameter, in business planning.

And we, as consumers we have a huge awareness of quality, we're interested in as we said different aspects of quality, we're interested in the reliability, we're interested in the performance and today, more and more also interested, in how our products affect the environment. We're interested in sustainability.

Quality Cost:

We want to look very briefly now at quality costs, so a quality cost study summarizes **any economic losses that occur in an organization because of not producing quality products** and such a study would also then highlight the potential for gains, which would arise from producing quality products, through the use of quality methods. And in such a study, you would need to collect data on different types of costs, in order to generate a measure called, **the total quality cost or TQC**.



This is a summary measure, that reflects in economic terms, how well an organization performs, in delivering products that satisfy customers, but in terms of the expenses; the sum of the expenses required in producing quality process and, the losses arising from producing defective products.

And here, we don't have an exhaustive list but, the four categories of quality costs and possible sources of these costs here are listed. And again, we should maybe note that these quality cost categories only include operating costs and don't call any and conclude any capital expenditure, so any type of expenditure on equipment that would have a lifespan of more than a year, so these quality costs we call **operating quality costs**.

And for example, we have the **prevention cost, planning cost**, do we have a **quality information system**? Do we have enough **training** for our employees? Do we have **process control** implemented? What kind of improvement projects do we have available? and you know the cost of having quality system development.

We've also then the **appraisal cost**, what is the **quality of our incoming materials**? how do we **check** this? Are we able to **inspect** and **test** our product at the end of the line? Or even as it moves through the line? And what about the **integrity** of our equipment? What cost is that intern incur?

Then we have **internal failure** costs, and what this means is, once you have a failure where it is in line, you know we have **scrap**; a cost associated with the scrap, we have **rework** costs, we have **failure analysis** cost, we have the fact that, it might have some **production downtime** or not, we've **lost the capacity** we've used to make those products and, we've also maybe lost capacity because we've got to do some repairs and then, just from having bad quality products as we saw earlier, we have the **yield loss** the cost of the **yield loss.**

And then finally, **external failure** cost and this is where we go back to **Warren Buffett's** quote. What can this mean? This can be this is often underestimated, this could be a huge cost. We have the cost of **returns**, we have the **recursive recalls**, we have the cost of **warranties**, **replacements**. We have the cost of **Loss** and beyond that, of **loss of customer confidence**, **loss of market** and then, that could even mean a **price reduction** for our product; so a loss a direct of **profit** gross margin on our bottom line and in the end, maybe a **loss of reputation**.

So, all these costs at a quality cost study, need to be considered in order to decide what we need in order to make a quality product.

Statistics in Quality –Six Sigma

Now, our course does focus on Six Sigma, as a way to reduce variation, to avoid defects and we know that for example, with our example here with a little automobile.

Example: Assume a car consists of **10000** parts and production processes.

6210 ppm → 0.0062 fraction defective at each process step or part

→ **Process Yield = $(0.99379)^{10000}$ = 8.84×10^{-28} = all vehicles faulty**

If we assume we have ten thousand parts or processes, if we have six thousand, two hundred and ten parts per million defective or process is defective, then we would get no cars out of our assembly line, that would be would be able to be put to drive.

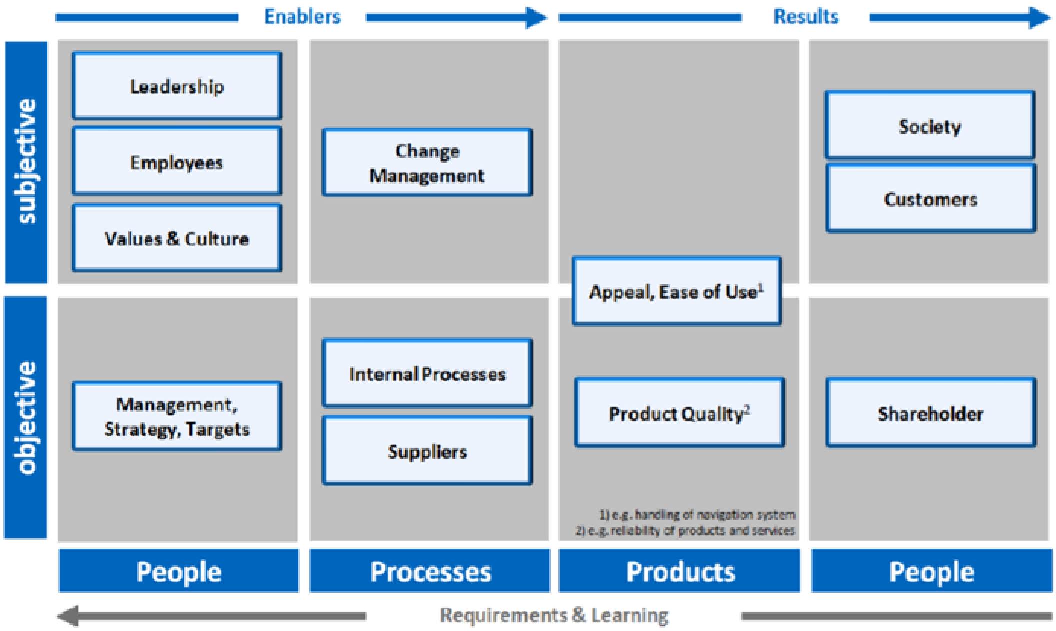
3.4 ppm → 0.0000034 fraction defective at each step process step or part

→ **Process Yield = $(0.9999966)^{10000}$ = 0.97 = 97% !**

If however, we have just 3.4 parts per million, then ninety seven percent of our cars would come off that assembly line in good quality.

Today’s View of Quality

So we're going to be focusing on this, but we should be aware of the total quality cost and of today's view of quality management. So, here we have an excerpt from a presentation, given by **Dr. Manfred Seika** who's living in Munich, and he sometimes gives it to the TUM students he's worked many years in quality management, in the automobile industry and he shows quality management as a set of enablers and results.



Now, what these what these involve are **people, processes, products** and then back to **people** again. And he divides this into two sides, you have the **subjective** side of quality management and the **objective** side of quality management and so if you if you look here, in this upper or corner you start with.

In order to have quality management you need **leadership**, you need **employees** and a **culture** in the company and **values** on the company that are dedicated to quality. These are subjective ideas, that support the objective of producing quality products, through quality processes and these then are translated into the objective targets, which become **management target strategy targets**, for example. Now, to do this then, you need to manage change, you will, you need to accept and drive change towards a quality company. And these require then, that you work with your internal and external processes, processes with the suppliers, and these become then all together, enablers of a quality organization.

Now, we then move to the **results**, here we have once we have quality processes and a quality mindset, we can get **quality products**, so you know what the customer wants in the products, this depends on the customer expectations and you need to exceed those and then, this then translate as results of people that are interested.

Who are interested? Well, customers are interested. We may have stakeholders around us that are interested and of course, the shareholders in the company that are interested. And how the company is performing. Now, what does it take to realize all these different things? Well, you know we're going to look at the statistics, and we're going to look at processes, products, critical to quality parameters, performance but it takes a lot more.

And here, we see on this slide that **Dr. Seika** has added all the different people or departments involved, in a quality organization. For example, **finance** is very involved right? You have people doing **statistics engineering**, you have the **design**, the **marketing**, **communication**, **corporate social responsibility**, **communication**, **ethics supply chain production**, the entire business strategy, and then what you see here is that everybody in the company has a stake in quality. Quality is no longer just the inspection team at the end of the line that costs resources and time, quality is a mindset and a culture, and it drives the company, towards the goal of total quality management.

Chapter 6: Kano Model Theory

What you will learn in this chapter:

In this chapter, you will learn:

- Understand the difference between Design Quality and Conformance Quality.
- Explain the Kano Model and how it is useful for categorizing and prioritizing customer wants and needs.

Define of Quality:

As we discussed in the earlier lecture, when we consider quality, we think of two aspects:

- The first is **a quality of design**; this is embedded in the design specifications of the product or service. Does the design satisfy the customer needs? And how does the design compare with competition.
- The second is **conformance quality**; and this depends on the production and delivery processes or the operations. Does the process output match the design specifications? And, do we have generation of defects and discrepancies?

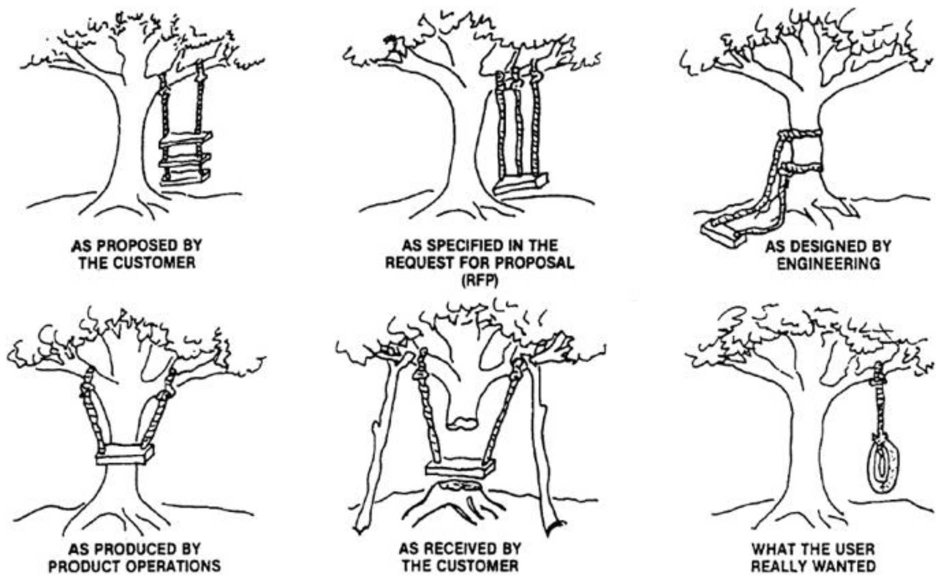
So, to achieve quality of design, we need to identify the customers' wants and needs; the **voice-of-the-customer** or **VOC** and sometimes, you also hear voice**-of-business** or **VOB**. These are what the customer is expecting from our product and services, the features that the customer wants.

These become then, our product design specifications, and we try to make these robust against changes. These now need to be translated, these wants and needs translated into the so called, **critical-to-quality** characteristics or **CTQ's**, and these should be **measurable**. And these allow us to evaluate, whether or not our product or service is meeting the **voice-of-the-customer**.

Now, in order to assure a **conformance quality**, we need to ensure that the outcome, or the performance is what is specified by the design specifications, for these CTQ parameters. So here, we will use statistical techniques, to control and to optimize our CTQ parameters.

In this section, we're going to focus on the quality of design and the voice of the customer. We need to capture what is the essential customer expectations, for a specific type of product or service. And as we'll see, one challenge is that every need of the customer is not equally weighted by the customer.

Here, we have a little well-known cartoon from, www.projectcartoon.com :



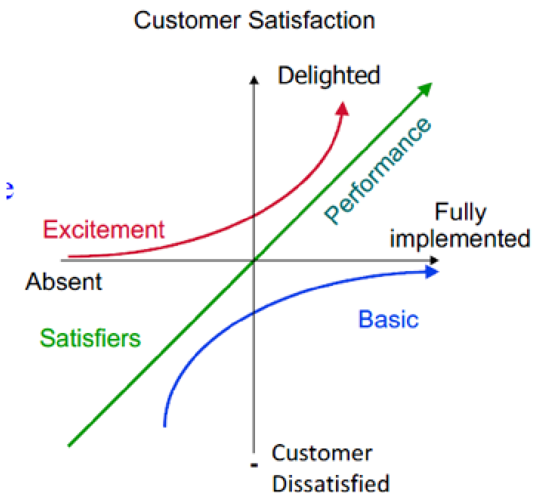
You can also use this as a source and create your own. Here, we have a swing as our product as proposed by the customer, as specified in the request for proposal, as designed by the engineering, as produced by product operations and then, as received by the customer. And finally, what did the customer really want?

And so this is a joke you're supposed to find this an exaggerated example but, finding out what the customer really wants, finding out in the context of projects, what the problem really is can be very difficult. And it's critically important because, if you do not identify the actual customer wants and needs, you go in the wrong direction, and you can move very quickly in the wrong direction, but it's still the wrong direction.

So, we need to identify first, the voice-of-the-customer and then, categorize and prioritize these needs, and this must occur for every Improvement Project. So the critical to quality parameters reflect the important quality characteristics from the customer.

Kano Diagram

One well-known method, of categorizing and prioritizing, the different customer requirements was proposed by Professor **Noriaki Kano**, a professor at Tokyo Rika University. The Kano model is a theory of product development and customer satisfaction, developed in the 1980s and this classifies customer preferences into different categories. The concept was first published, in an article by Kano and his colleagues in 1984, in the Journal of Japanese society for quality control. Professor Kano received the prestigious Deming prize for individuals in 1997, to recognize his contribution to the field of total quality management.



Let me sketch the basic idea of the Kano model. So we have two axes:

- We have an x-axis and a y-axis in the model, and the x-axis stands for the implementation level of a customer characteristic. So here, on the right, we have a customer characteristics, a characteristic of your product or service is fully implemented. And here, on the left side, you have that that characteristic is absent.
- Now, the y-axis indicates the customer satisfaction, so here you have satisfied customer, and here you have a very unhappy customer.

Next, Kano proposed five different categories of customer wants and needs, and we'll look at three of them here. And just be aware that people use different terminology, I tried to put as much as I could together, but these are the three main attributes that Kano was emphasizing:

1. The first is **the basic or expected quality**, and it looks like this. These requirements are not usually mentioned by customers, these are mentioned only when they're absent from the product. So you see, if you're in the absent area, you have a very unhappy customer, but even if they're fully 100% implemented, the customer is still not happy. These are things that are expected from the product.

2. Next, we have green line here characteristics **that meet performance quality**, or one-dimensional. And what this means, that whenever you have an increase in performance, as your performance improves you have an increase in satisfaction. There's a linear relationship between the customer satisfactions with the increase in the performance, the more the better.

3. Then finally, we have a characteristic category called the **delighters** or the **excitement** or **attractive quality**. And these look like this, they don't even have to be fully implemented, your customers are happy. These are excitement or attractive quality. The delighters or the Wow characteristics. These are often also not discussed, you don't you're not often asked to express what you dream about, creation of some excitement features in a design differentiates the product from expectations. These delighters or these excitement and attractive quality characteristics are unexpected.

Now, here you see the three basic characteristics listed here. Again, basic quality characteristics are required for entering a market, here you need certain features of your product or service which are common and offered by the competition as well. They may be not specifically identified, but the customer will be dissatisfied, if these features are not present. And these basic things, do not improve the customer satisfaction anyway.

For example, on a bicycle what do you expect? Expect some wheels, the frame, breaks for example? And here, the blue line indicates, that there’s no increase in satisfaction as these basic features are implemented. But if again, if they're absent, no wheels, you’re not going to be happy with your bike.

The performance or one-dimensional quality and green, these provide an increase in satisfaction as their performance increases. For bicycle, this could be the weight of the bike, the lighter the bike the happier you are. It could be the number of gears or maybe additional components, you have a light you know you have a bike with lights you’ll be happier than one without.

And, the last one is the red one; the excitement or attractive quality features. These are unexpected and they delight the customers. Now, what could this be for your bike, depends on what kind of bike rider you are. For me, you’d be nice to have an electric motor on the bike, or maybe you'd have a built in bike lock. . Delighters though, they will differentiate your product from the competition. They'll create customer loyalty and they'll build an additional brand equity, people will come back for more of your products.

Now, the Kano model allows us to categorize these different ones and needs of the customers, into these different categories. We also have three different two more categories that are not emphasized here; **Indifferent quality** and **reverse quality**.

1. So, **indifferent quality** features are those to which the customer attach is no important, and that could be for example, the rain, the rain hood. These features, if you have parameters that your customer is simply not interested in, they don't create any satisfaction but nor do they create dissatisfaction.

2. **Reverse quality features**, are those which result in **dissatisfaction**, often due to the fact that not all customers are alike. A good example is if you have great features, but it makes the product too complex, then the customer can't handle it and they become dissatisfied. And again, we’re

focusing on the three, basic quality, performance quality and excitement quality.

Now, even with my bike example, obviously different customer groups have different ideas of what quality features should be and additionally, **an attribute will drift over time from excitements to performance, and then finally to basic**. This drift is driven by customer expectations, and by the level of performance from competing products.

And an example, that **Professor Indrajit** gave us, was that **mobile phone batteries**; they were originally very large bulky with only a few hours of charge, but now we expect 12 hours of battery life, very slim lightweight phones. The battery attributes have had to change, to keep up with our customer expectations.

Here is another example from **Professor Mukherjee**, for a Kano diagram for a hotel room, and it depends on the customer group. But for a simple holiday, maybe for the basic quality you would expect a clean bathroom? If you've a backpack you maybe just share a bathroom, but you expect it to be clean, you expect to have a choice between a non-smoking and a smoking room.

Those are basic attributes that, you don't look for a hotel based on those, those are ones you expect. Performance quality and this you see this in the hotel industry, how can they lure their customers? How could they create something that will cause the customer satisfaction to increase? Free breakfast, lower room price, convenient location, maybe checkout flexi time, all things that are not unique will not delight, but if you get a free breakfast, you're more likely to choose one hotel than another.

Excitement quality? It depends on who you are, I prefer that they don't welcome you by but, maybe you're attached a lot of importance to this personal service, maybe you want to have a choice of pillows, maybe they give you a bottle of wine on your bed, whatever makes you happy. Those are the things that differentiate then your choice, from the competition and make you think ooh I'll come back there again.

These are the basics of the Kano model and now, we just want to show you how we can use this information.

- The first here is the Kano questionnaire, we need to discover what does a customer want, and how does a customer view this. How does a customer prioritize this, so we create then a questionnaire, where different attributes, different characteristics are identified. And the customer can then express, how they feel about these different attributes or characteristics. The questionnaire consists of a pair of questions, a functional form of the question, where's my pen, a functional form of the question and a dysfunctional form of the question. This is very important, the function ask our customer how they feel, if they have a feature. Well, the other question, the dysfunctional form asks how they feel if they do not have the feature.

And with these responses, so you have; I like, I expect, I do not care, I can live with it and I dislike it.
So for example, if the room has a smoking preference, how do you feel? Well, as a customer, I say I expect that I expect my room to say whether it's smoking or not. So, I expect to have that choice. If the room does not have a smoking preference, I would say I dislike that, I am NOT happy. Correct the English here, has this one. So, two different responses; one functional, it has something I expect, one dysfunctional, it doesn't have something and I actually dislike it.

- Now, what we want to do, is to graph these in an evaluation table. It looks like this.

Customer Requirements		Dysfunctional				
		1. Like	2. Expect (Must)	3. Do not care	4. Can live with it	5. Dislike
Functional	1. Like	Q	A	A	A	O
	2. Expect (Must)	R	I	I	I	E
	3. Do not care	R	I	I	I	E
	4. Can live with it	R	I	I	I	E
	5. Dislike	R	R	R	I	Q

Customer Attribute is:
A: Attractive/Excitement
E: Expected/Basic
O: One-Dimensional/Performance
I: Indifferent
R: Reverse
Q: Questionable Response

So you have on this side here, the functional question response, on this side the dysfunctional response. So, I said for the functional question, does my room have a smoking preference? I expect that, it must be there but, if it doesn't then I dislike it. And so in this table, we see the different attributes we see the zero, indicating the performance, the one dimensional quality; this is the linear increase we talked about. We see the expected quality, here it should be in blue, expected quality; things that we expect, basic quality to have. And we see here, this excitement, attractive quality.

Um could write this in blue, your basic quality here and in green, we have our one-dimensional, performance of quality. And everything else, everything else in this table, either we have reverse quality or indifferent quality or we have a questionable response, so if our if our responses lie outside of these upper and right edges, then clearly there's something that easy that it doesn't matter to the customer or the response is questionable or it's a reverse quality, where too much is not acceptable. So, we take that data and for example we say, I have a total of, change my color again here I have a total of 23 respondents and I have five different attributes that I'm looking at, for example smoking, non-smoking, clean bathroom, non-clean bathroom, bottle of wine, no bottle of wine.

So, of those five attributes we go ahead and ask them the functional and dysfunctional questions in the Kano questionnaire, and for the first attribute three people, when we put them in the table, they came out that they had that attribute was exciting, it was an attractive quality, a Wow, a delighter. Six of the respondents said nope, that's just what they expect, if that's not there, they're not happy. Whereas 14 of my 23 respondents said yeah, if it's there good, I'm happier and I will the more the more the better; linear performance. And since this is the largest response box, we categorize that with an O and you go through the rest of them in this case number two is also most respondents said it was a one-dimensional performance quality.

Here, we have for attribute number three, people were indifferent, maybe that was the wine, people were indifferent for the expected quality number four, people were looking at that as expected quality, and for number five they found that exciting, they found that attractive.

And so when you're designing your product, you would use these five different attributes and would say how should we prioritize these? Clearly, attribute three is not important and attribute four, we need to have that, it's expected. Attribute one and two, we can improve those make them make them better, make it more and we would likely see an increase in customer satisfaction. And if we can include number five, as our wow, as our delighter, we would then increase our brand image, we would increase customer loyalty, it will make our customers delighted. So, that's the basic idea of the Kano model

Applied Question:

A popular Airline in your city is having problem meeting the sales target on their First-class flights from and to some destinations that they believe is critical to meeting their overall profit target for the year.

Several of their clients have complained about the quality of services they get on these routes on the business and first class categories of this airline and are ready to switch to another competitor that in their view offers better service quality.

Your company have just been contracted to come up with a solution on how they could improve the quality of service on this route.

During one of your brainstorming sessions in your company, your group have come up with a list of all possible features on how to improve the quality of services on this route but doesn't know which of these ideas to prioritize.

We did two questions for each category... For example:

Function Question: If the suites have an On-board shower spa
Dysfunctional question: If the suites does not have an On-board shower spa

Possible Feature	Functional question	Dysfunctional question	Category
Complimentary Chauffeur-drive service.	*Like*	*Dislike*	
Additional legroom. Response	*Expect/Must,*	*Do not care*	
Expedited baggage service.	*Like,*	*Can live with it*	

LED mood lighting.	*Do not care,*	*Dislike*	
Social seating arrangement.	*Can live with it,*	*Dislike*	
New selection of wine, beer, spirit and cocktail.	*Like,*	*Do not care*	
Live events with fellow travelers on the 55-inch LCD TV screen.	*Do not care,*	*Can live with it*	
Complimentary gift package on board.	*Like,*	*Do not care*	
Privacy suite doors.	*Can live with it,*	*Dislike*	
Private cinema.	*Like,*	*Can live with it*	
Personal dining service.	*Like,*	*Dislike*	

Now: Categorize them by using the Kano Evaluation Table

Make Recommendation

Answer:

Possible Feature	Functional question	Dysfunctional question	Category
Complimentary Chauffeur-drive service.	Like	Dislike	O
Additional legroom. Response	Expect/Must,	Do not care	I
Expedited baggage service.	Like,	Can live with it	A
LED mood lighting.	Do not care,	Dislike	E
Social seating arrangement.	Can live with it,	Dislike	E

Possible Feature	Functional question	Dysfunctional question	Category
New selection of wine, beer, spirit and cocktail.	Like,	Do not care	A
Live events with fellow travelers on the 55-inch LCD TV screen.	Do not care,	Can live with it	I
Complimentary gift package on board.	Like,	Do not care	A
Privacy suite doors.	Can live with it,	Dislike	E
Private cinema.	Like,	Can live with it	A
Personal dining service.	Like,	Dislike	O

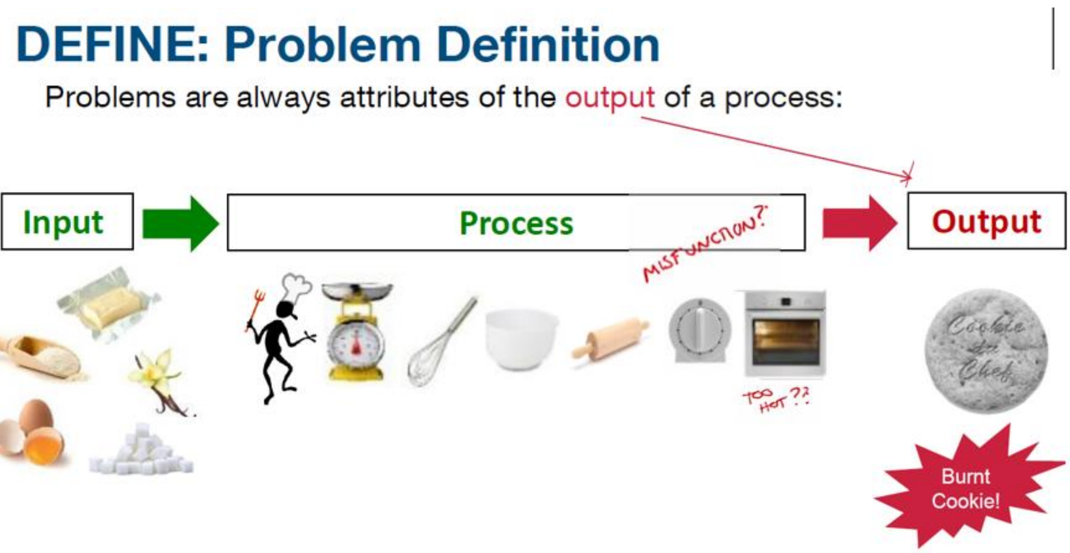
Chapter 7: Problem Definition

What you will learn in this chapter:

In this chapter, you will learn:

- Discuss the difference between a problem (in the process output) and causes of the problem (in the process or the inputs).
- Understand that a problem is the deviation of a required attribute in the product (output of process).

For this session, we want to be able to discuss the difference between a problem in the process output, and causes of the problem, which are in the process or in the inputs to the process. And, we want to understand that, a problem means a deviation of a required attribute in the product, a problem is in the output of a process.



This is his cookie scenario and what we can see that in a process, we have

- Various inputs, like for our cookies, we have we see her eggs, sugar, flour, salt, butter.
- And, we have various resources that go into a defined sequence of steps. So, we have the ingredients going to particular machines, we have to weigh things, we have to mix things, we have to maybe form things, we have to bake things and we have generally operators, that are taking care of these different steps.

Now, at the end of our process we have a **burnt cookie**, how do you know, that this is not meeting your customer expectations? Well, if you're thinking about cookies probably you want your cookies to be the right color, you don't want them to be green or yellow, and you want them brown or maybe chocolatey dark brown. You want them to be not burned, you want them to be sweet, have a good taste. So different characteristics that you've worked with your Kano model for example, and you found out what is a priority for customers.

And if you're producing mass-produced cookies then probably, you're very interested that all your cookies look **exactly the same**. They have exactly the same feel to them, the same taste to them and qualities to them. So, you have your customer expectations for your process.

Now, how do we define a problem? There's a lot of this in literature, discussed extensively over the years and people aren't looking at what is a problem. And so, the debate kind of moves towards it's an undesirable situation.

Problem definition

It's a gap between a current state and a desirable desired state. We, in our Six Sigma are coming in the define stage to looking at a problem definition, so if a problem is an undesirable state, we're not meeting the customer expectations, it could be improved in order to exceed the customer expectations. As part of define, we need to define the problem and here, we see again there's a lot of debate among the scholars.

How can you verbally state the problem, how can you write down clearly in your contract, what is the problem or the improvement that we want to achieve. And the conclusion is, it depends.

The conclusion is that, problem definitions can be defined in many different ways, depending on the perspective of the people. So, what do you need to take away from here? **Problem definition is not trivial**, and this is where the Six Sigma framework supports us.

For the define part of the project, we need to understand, what the customer expectations are, to understand what the problem is, so that we can follow our flow in order to affect a process improvement.

Just to show you, here we have our cookie baking process. Now, we have all the different inputs to the process, we have the process itself, with the resource that are used, and we have our burnt cookie. So here, what's the problem?

Could it be that the oven was too hot? Could it be that our timer miss-functioned, and we left our cookies in too long? What could be our problem? Now, you guys I hope you're all shaking your heads and saying, hmmm, he doesn't get it. Where's the problem?

The problem is in the output of the process, the problem is that the **cookie is burnt**.

These are possible causes of the problem. The causes of the problem are in the process or in the inputs. The problem that we have, when we're going into our define page, is in the output; cookies burnt.

So, **a problems are always attributes of the output of a process**, and these can be assigned to different categories; quality, available, meaning the quantity available, or when it's available and the consumption of resources.

So, you have a **target**, your **maximum** and a **minimum** and you see if your output is meeting those targets. Is it meeting the characteristics that our customers require? In terms of quality? Is it available, in the right quantity in the right time? And does it consume the resources in such a way, so that our product and service can be created, produced in a competitive manner and not consumed too much.

So, to restate this again, this is from Dr. Hutwelker, a problem is in the deviation of required tribute in the product, an output of resources, can be assigned to three different categories and when you look at the output you can see if these categories are achieved or not.

Chapter 8: SIPOC Diagram

What you will learn in this chapter:

In this chapter, you will learn:

- Understand what a business process is and explain the benefits of a process view of an organization.
- Understand the relevance and importance of a SIPOC diagram in a process improvement project.
- Create an overview of all the relevant elements in a process improvement project using the SIPOC diagram.

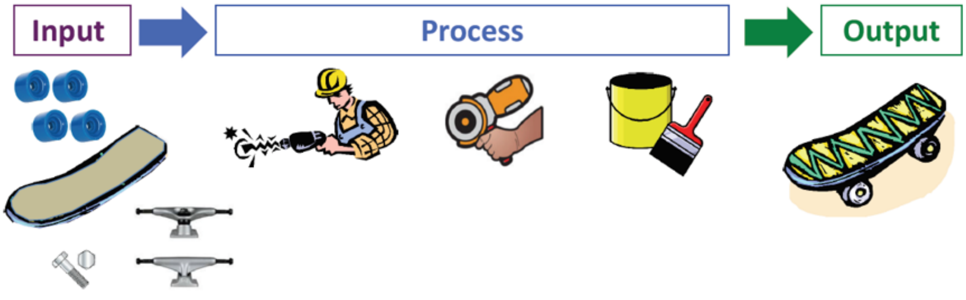
What is a business process?

A business process is a repeatable, coherent, sequence of activities, with a clearly defined input, with a certain material or non-material achievement; the output or internal or external customers.

The flow of a process consumes time and resources, and is often associated with repetitive tasks.

When we refer to business processes in operations, we're often referring to the volume production of goods or services, in a sequence of activities performed, by a set of specialized resources.

For example, for a skateboard producer, you need to have the inputs of wheels, and the board and these supports are called trucks. Then, you need to perform process steps, you need to assemble the trucks and the wheels to the board, you need to sand the board, you need to paint the board.



You're transforming the inputs into the outputs, which of course here, is a skateboard.

And, this business processes, process flow, is of course not just applicable to manufacturing, but also to services.

Advantages of Process View

And there's many advantages to looking at your organization, in terms of processes:

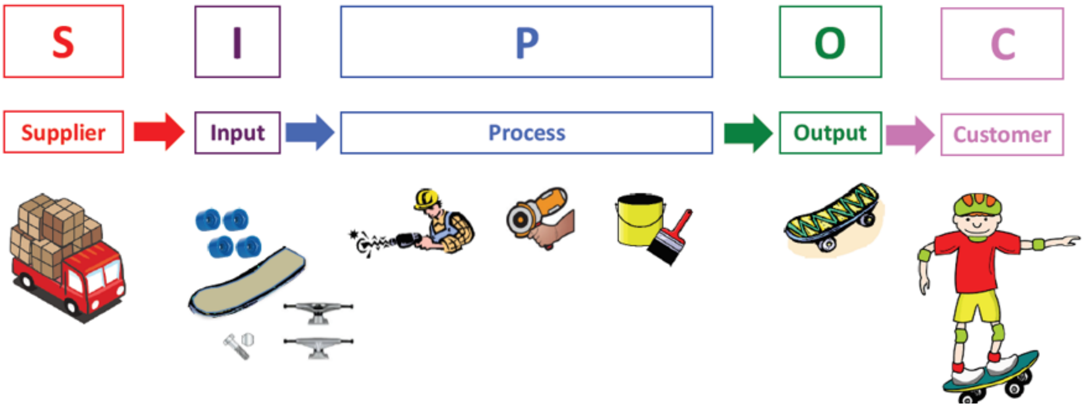
- It allows you to have a view of the activities as cross-functional flows, instead of individual activities, done in isolated silo functions. The process flows, map the activities needed to complete a value-added step, to generate a product or service. And here, the focus is on the **customer**; the **value-added activities**, that create the product or the service, to meet the customer expectations.

- Process views are also applicable to any type of organization, in production we can think of producing for example, our skateboard using a simple production flow. If we're in a bank and processing a loan application, there would be an approval process flow that needs to be followed. For purchasing raw materials, for example you need to first identify your suppliers, receive different quotes, and develop a contract with the supplier. There's a certain process flow, that you have to follow.

- Flows can also be applied at any and all levels of an organization. For example, our skateboard we were looking at the individual activities, used in making the skateboard, you could though, consider the skateboard factory and look at the entire production processes, as a flow in the factory. We can also look at that factory, as part of the flow, for a sports' producers, sports equipment producer.

- And also, managing the processes, rather than the individual activities, allows the definition of clear performance metrics that reflect the value to the customers, and allow an end-to-end process improvement.

Here, we show our skateboard flow, but this time we're including also the supplier of the individual components and we're considering, we're showing the customer, here writing is it her skateboard.



And here, we can see we have then, all the entire end-to-end stages, for our process flow. Supplier, input, process, output and customers.

SIPOC Diagram:

And this is abbreviated as **SIPOC**. This is the basis then, for creating the so called SIPOC diagram; a tool that lists the components and/or the activities that can occur in a process.

And why is this useful? We're starting to trace the activities, not just to produce a product or services, but from the supplier of the inputs, through the entire process, to the customer.

SIPOC diagram gives us a high-level picture of the value-added steps in the process, and it's often used in any type of business process management, and it is a common tool in Six Sigma projects.

Why use SIPOC?

As we just said, it allows us to trace the activities from the supplier all the way through the customer:

- It gives us a high-level picture, and shows us the value-added steps in the process. Importantly though, it sets down the process in black and white, for common understanding by the team, and can be used as a first step for thinking about the process, and of course the scope of the project. The customer expectations, the materials, inputs, and different entities and resources involved.

- It also can provide the basis for the first discussion, of what could be influencing the **critical of quality parameters**.

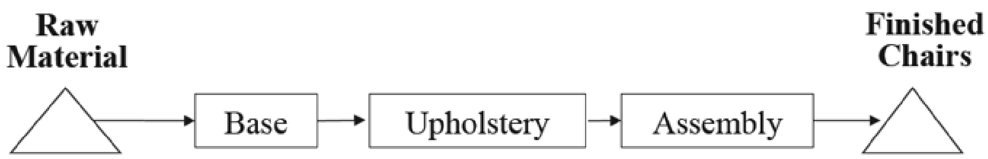
Disadvantage of SIPOC:

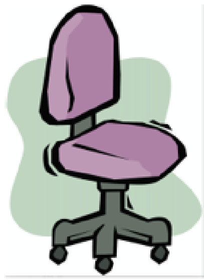
Disadvantage is that:

- The SIPOC is very top level; it doesn't show any time ordering or process structure dependencies, and
- The process details can be indeed very sparse.

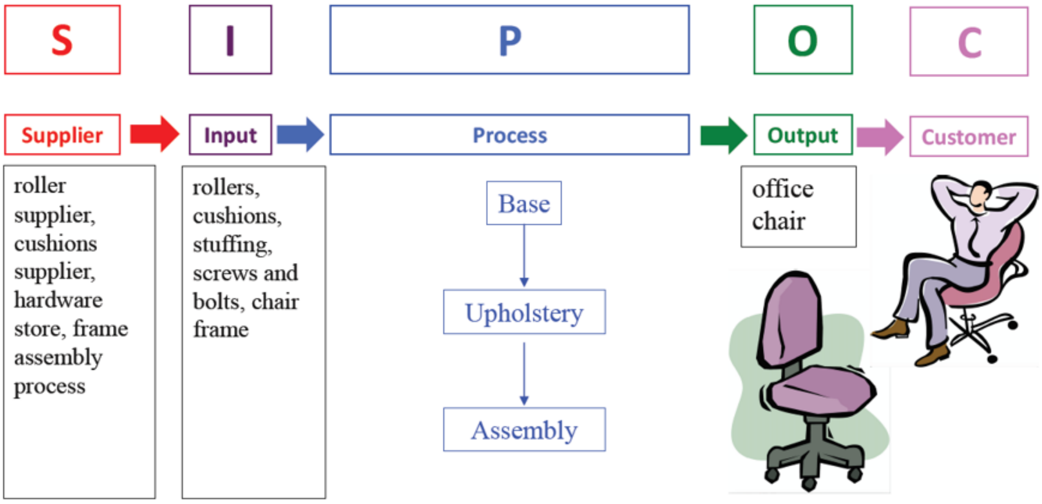
SIPOC Example: Office Chair:

Now, let's look at an example, here, we have a SIPOC for an office chair, we have this assembled from different components, in a very simple process, raw materials unto the process.





We have the base of the chair is then connected to the frame, and then the upholstery, the cushions are attached to the base, and then we have a final assembly, where the wheels and arms are attached, and then you have your complete chair.



Suppliers:

First of all, let's look at the suppliers; so in this process, the suppliers are going to be any entity that brings the required inputs for the process, to the start of a process. Here, we have:

- Suppliers of different types of raw material, if you have a service, then the suppliers are the people which will perform the service. In this example, the suppliers for the office chair assembly process, are those who supply the components; such as the wheels, and the cushions, and the nuts, and the bolts.
- But also, you have the chair frame, a partially assembled part of the chair, and that might actually come from a different part of the factory, as the output of another process.

Input:

Now, let's look at the inputs; inputs are then the raw materials, the actual things that are supplied and here, for our chair we've got **rollers**, **cushions**, **stuffing**, **screws** and **bolts**, and the **cushions**, and everything that would go in to making our chair.

And again, we're looking these inputs are going to be transformed, into something that has added value for the customer.

Process:

Next, we look at the process and here, we have the transformation of the inputs, using a sequence of steps to the output. And here, we're going to assemble our chair with three different process steps that we mentioned before:

- First, we attach the base of the frame,
- we add the cushions in the upholstery and then,
- We finally assemble all the components.

But of course, the process can be the steps in completing a service; wash hair, apply conditioner, rinse dry and style, apply hair spray.

And as we mentioned before, the business process is often **repetitive tasks**; these tasks then are performed as a sequence with specialized resources.

Output:

Now, we go to the outputs, here of course, what we have is our office chair. We've assembled our chair, this is then the physical or non-physical achievement or results of the process.

Customer:

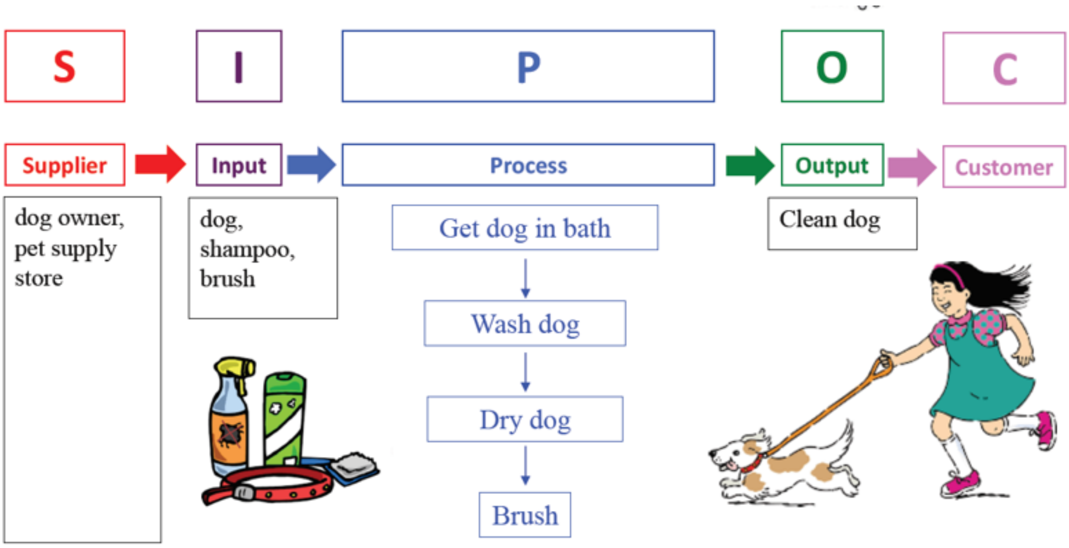
The last stage is then, for the SIPOC diagram; the customer. And it is really, the most important because it's the customer who decides that we're making this chair in the first place.

This is the person who is valuing our output and so for example, a businessman, business person sitting in his office chair. And this customer is willing to pay more than the raw materials and the process costs, so when we think of the customer, we normally think of the end customer.

Here, we have our office worker but of course, the customer is any entity that receives the goods. For example, this could be the retail store that sells the office furniture to then the end customer, or it could be of a production process, that will take as its input, the output of your current process.

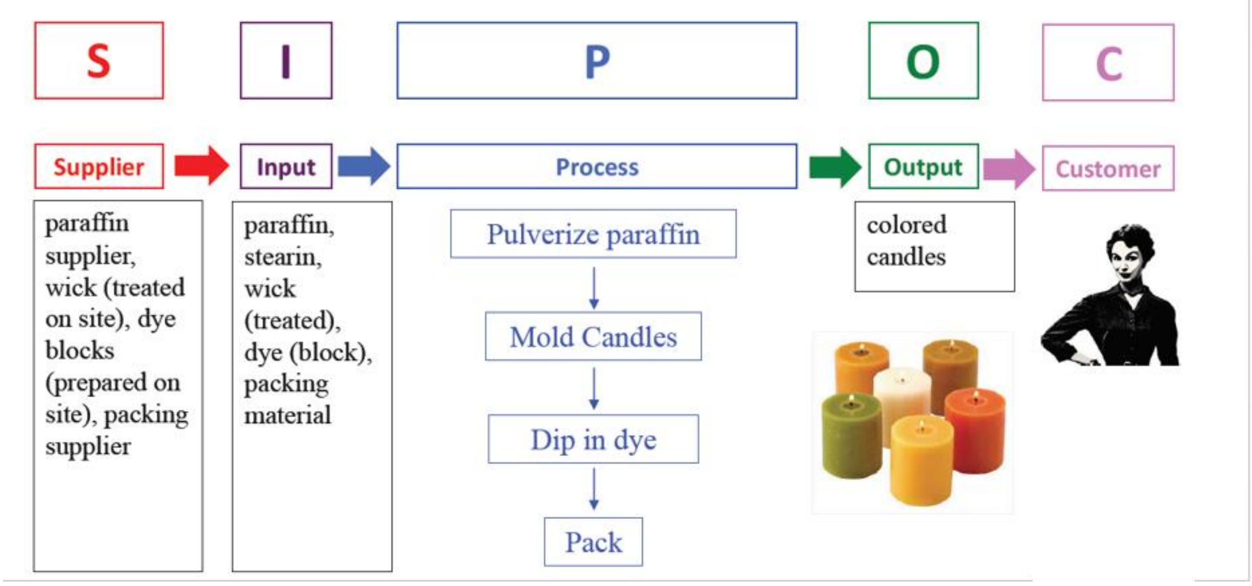
More Examples

Now, we have two more small examples in this lecture, here we have the SIPOC for Washington dog:



- **Inputs** you have your dog and your shampoo, and your materials and the
- **Suppliers** then, would be of course the dog owner and then maybe a pet supply store, for the special shampoo, special brush.
- In the **process**, you're going to put the dog into the bath, you're going to wash the dog, you're going to dry the dog, and brush them off.
- The **output** will be here, then your clean dog
- And your **customer** will be the dog owner, really simple process.

If we look at candle production, slightly may be less familiar process for most of us.



- We have as an **input**, inputs things like raw paraffin, we have and we have to clarify as to where this come from but put the inputs on there. We have the wick that comes in, we have different types of dye to dye, our candles into different colors and we'll have our packing material. So we need to have that coming from suppliers, the commodities, the paraffin, we need to have maybe, a process that treats the dye and that treats the wick, and then that will be input into our candle production.
- We need to have the dye blocks that could be also prepared in a different part of the process, so that we can then use those to dye our candles. And of course, we need some kind of **supplier** of the packing material.
- These then go through a more complex **process**, here is very simply written, we're going to have to pulverize the paraffin so that we can use that to mold the candles, those will get then dipped in the dye and the wicks will be inserted, I haven't put that in there And then, we'll pack up the candles. So the output would be, then our colored candles and
- the **customer** would be maybe a housewife, the picture there; traditional old film housewife,

But there's one other thing I want to point out here, there are different entities that can govern the quality, so not only do you have the customer who would like to have a yellow candle for her table, but you have **restrictions** and **specifications**, that are required by different entities; this is here, the European Candle Association. They specify for example, how much soot your candle can generate, and so your customer could also be then, these specifications so that then, you can put a particular label on your candle and show that you meet these quality specifications.

Process Mapping

We would like to explain what process mapping is, and its importance in a process improvement project. And we want to be able to create a process map, using conventional symbols.

Learning Objectives

- Explain what process mapping is and its importance in a process improvement project.
- Create a process map using conventional symbols.

Now, we've discussed SIPOC; **supplier**, **input**, **process**, **output** and **customer**. We've discussed that, this is a high-level schematic of the overall process, from the suppliers and of the inputs to the process, to the customers of the output. It allows discussion, it allows consensus and is a starting point for mapping out the scope of many process improvement projects.

But now, we are going to focus on the "**P**" in the SIPOC. The process, and we're going to learn about, how we can map our process.

What is process mapping?

Every product or service is created or produced by a process, whether it is making a cup of tea, designing a product, preparing an invoice, approving a loan, answering a customer complaint.

These activities, can be mapped as a process involving a sequence of steps and a sequence of resources. Process mapping then, can be defined as "**identifying all the steps in a process, the inputs and outputs, the controls in each step, the resources used in each step, the responsibilities for each step and then mapping these steps as they occur**".

And why do we use process mapping?

Well first of all, because:

- **Problems are always the result of a process**, so we need to understand the process.
- And also, when processes are mapped using charts on paper, they can be better understood, better analyzed, improved and managed. Understand the process fully, in order to be able to control and improve it, is the key precept leading to the success of quality improvement program and for the Six Sigma methodology.
- And also, is a team visual tool, the process map can help share knowledge and build consensus among the team members.

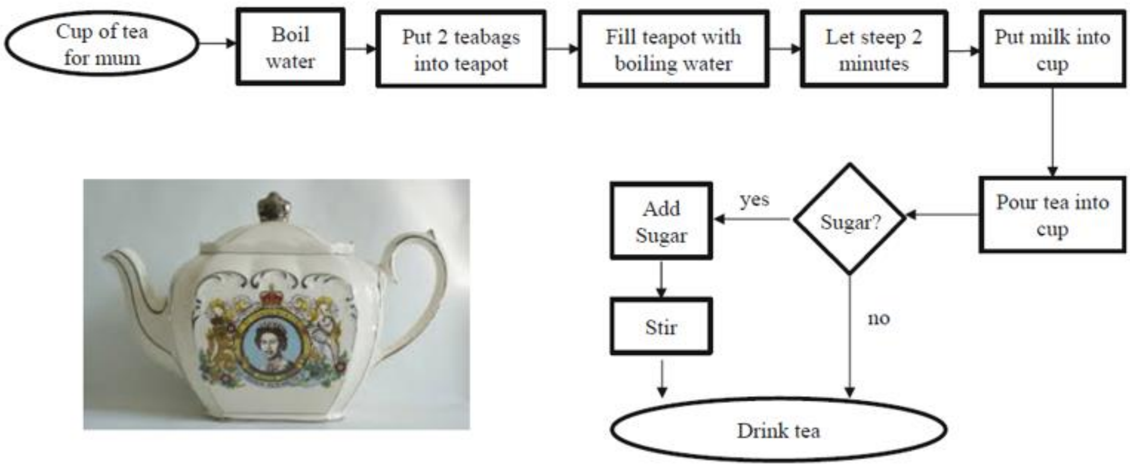
Process Flow Chart:

- A process flowchart is a schematic representation of the operations or activities, starting from raw material and leading to the production of the final product.
- The process flowchart is an important planning document, used by for example, manufacturing engineers, when they're selecting appropriate machinery, appropriate methods and appropriate measurement tools.
- It provides a perspective on the flow of activities, in a production process and thus facilitates also planning for quality related activities at appropriate junctures in the course of production.
- And of course, it is the basis for starting discussions in the Six Sigma methodology, for investigating the influencing factors, for the critical to quality characteristics.

And here, we just have in the rest of the section a few examples.

Example: Making a cup of tea for mum:

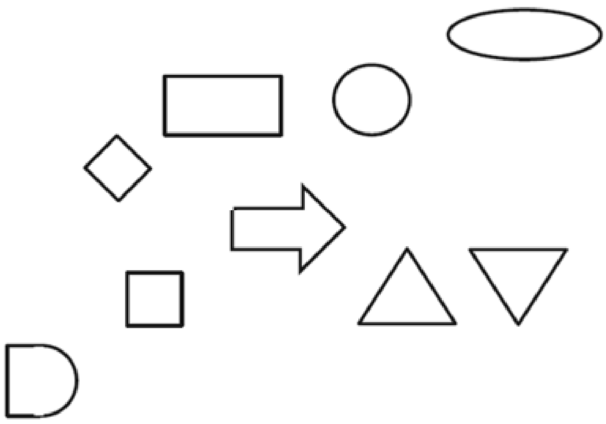
So, in making a cup of tea for mom who is English,



You first of all need to boil the water, you need to put two tea bags into the tea pot, she like strong tea, fill the teapot with the boiling water and let steep for a few minutes. Then, importantly you need to pour the milk into the cup, and this is because you don't want the milk to scald, when you put it into the tea water. You put the milk in first, then you put the tea into the cup and then, you decide if you want some sugar. If you do, then you follow your low chart over here, and you say yes, you add some sugar, you stir and drink your tea. If not, you can go ahead and drink your tea.

Conventional symbols:

A pretty easy flow chart and, what we're using there are some conventional symbols.



So you may see this differently but typically, you see:

- An **ellipse** for the start and the end of the process.
- Then you use either **rectangles** or **circles**, for different process steps

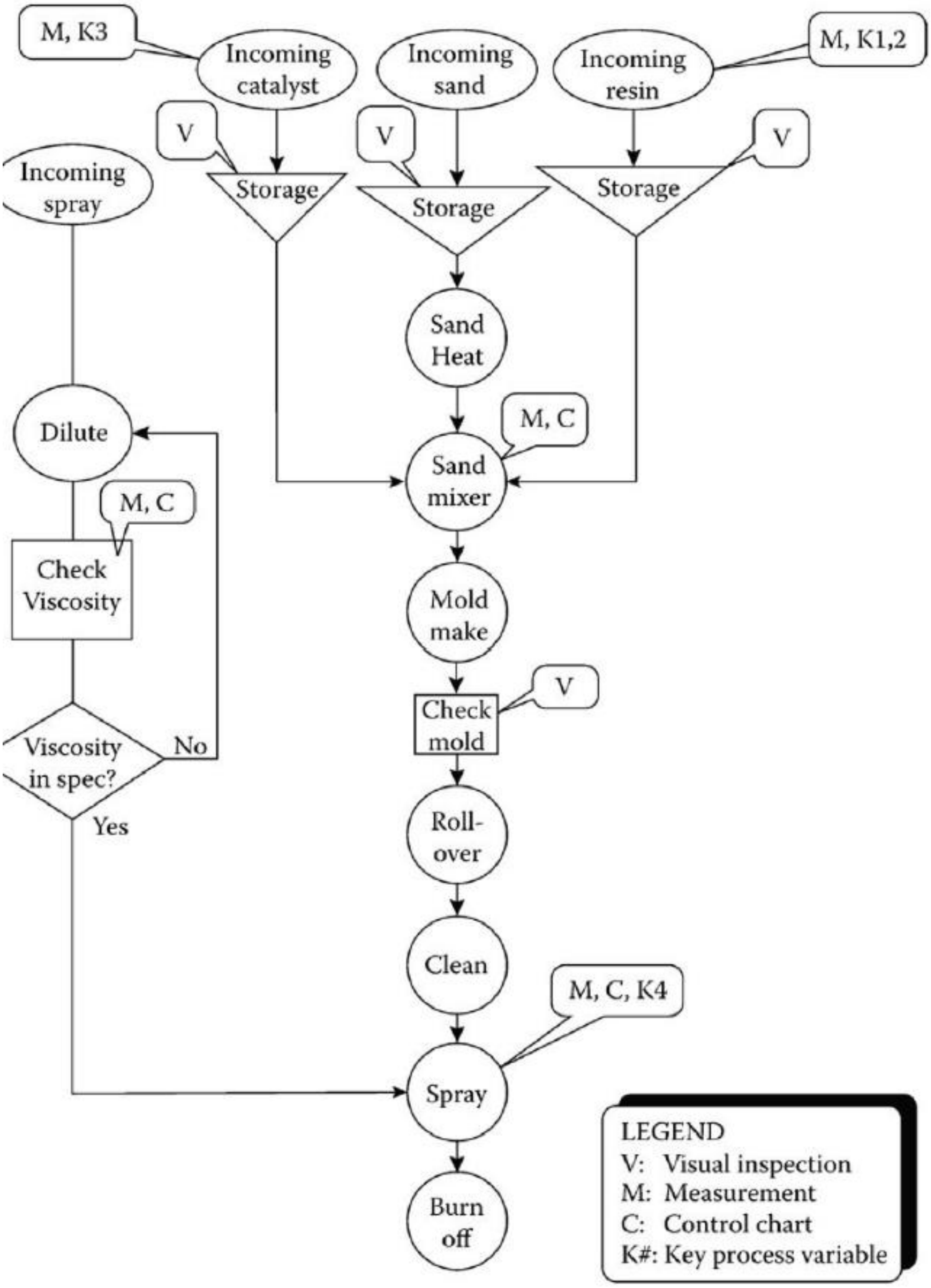
- And a **diamond** will indicate a decision point. So sugar or no sugar?
- If there's transportation that is often represented by a **big arrow**
- And a **triangle** or sometimes an **inverted triangle** is used to indicate **storage**.
- A **square**, can be used and also for **inspection step**
- And a large **D**, is often used for a **delay**.

There's also many software packages you can find online, one that I like is the **www.gliffy.com** So you can find different resources, to help you draw your process chart, but the best way to do it for a project of course, is just to start on paper, and start writing down the process as you go.

Example: Making a mold in Foundry

Here, we have an example from our textbook, of making a mold and a foundry. So you can look at this and a little more carefully, but if we go through this one by one, you have here, so the legend says here, V is visual inspection, M is measurement, C is control chart and K is a key process variable.

So what we have in is the incoming ingredients; a catalysts, sand and resin, making this foundry mold.

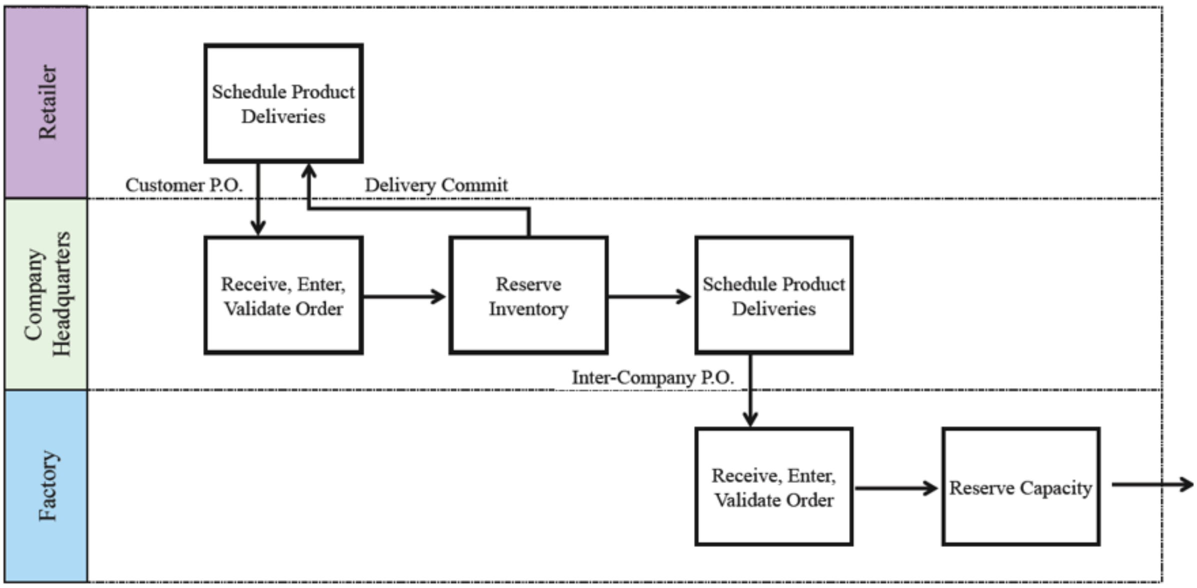


And then each of these are held in storage, you see that with the upside down arrow and then in this chart, you have circles to represent the different steps. And you can see that first, the sand is heated and then, the sand, the catalyst and the resin, are all then mixed together.

Then, the mold is made and you have a checkpoint here, this little square; where you're checking the mold, then you have a step rollover, clean spray and in parallel, you have another process with the incoming spray, those get combined and spray, and the final is burn off, for that last step.

Example: swim lane

Here, we have an example of a swim lane flow chart, and this is one way of doing a flow chart, where you can see the different responsible parties, and what you're doing with this type of flow chart is reflecting the organizational boundaries.



So in each lane, the processes which have responsibility for that part of the organization are identified, and the description to these work flows, to reflect inputs and outputs can also be added.

So here, we have a simple one about how the retailer orders are received at the company headquarters, and the information is then transferred to the factories for capacity reservation. So at the retailer, on the top of swim lane you send a customer P.O, a purchase order, over to the company headquarters.

The company headquarters, that is responsible for receiving that order, they have to enter it into their systems, maybe somebody will type it in, maybe it comes electronically, they then reserve inventory and commit the delivery back to the retailer.

They then schedule the project deliveries, and this generates then a company purchase order, within the company to the factory, and here again the factory then has to receive the order from the headquarters, reserve capacity and on with the flow, produce the parts, and make sure they get shipped out.

So for example, you can use a slightly different type of flow chart, this one line flow chart.

Who should be involved in process mapping?

Who should be involved then in your process mapping exercise, as part of your project? Process mapping should involve all the stakeholders in the process.

Now, what is very important; who are all the stakeholders in a process? These will be the people involved, in the daily process execution. These people are critical to the process mapping.

And what is the goal of the process?

It's to develop a common, holistic understanding of the process, the process steps and how they work; creating a tool for quality improvement.

Once the process is mapped, it can be better understood, analyzed improved and managed. And here, we have to remember our discussion in the first session, what is quality? What does the customer expect, and what customer needs, have we decided to fulfill with our product, given our target market and costs.

The process map, then provides a clear starting point to start discussion, to identify where and how the process then can be improved, to meet those expectations.

Process mapping in practice:

If we look at process mapping in practice, we would suggest that:

- It’s initially done on paper, on flip charts or whiteboards.
- Process mapping involves choice, choosing the scope of the project, defining process boundaries and the level of detail, and even the level of formality of the process map. And one way of doing it, is to start with the boundaries and then build inwards.
- And another practical point is to just get started, don't wait for perfect accuracy from the beginning, and leave extra space in your diagram, for additions, revisions and more detail. The process needs to be worked and inputs from the process owners, and those using the process need to be considered and of course, when it's on paper, you can then change it, you can then make changes before it actually gets saved electronically.
- And watch out for what's known, as **the hidden factory inspection points**, **measurement points rework loops**, **scrapping procedures**; these are all things that are normally not considered, when you're thinking about the process of making a product or a service. These are parts of the process that are often hidden and take additional time and additional resources, and these should be included.

- And you also want to map the **information flow**, as well as the material flow. And in many cases, it's even recommended to map the **financial flow**, so that when you complete your process map, you have a clear mapping of all the critical steps, the hidden steps and all the different flows, in order to create your product or service