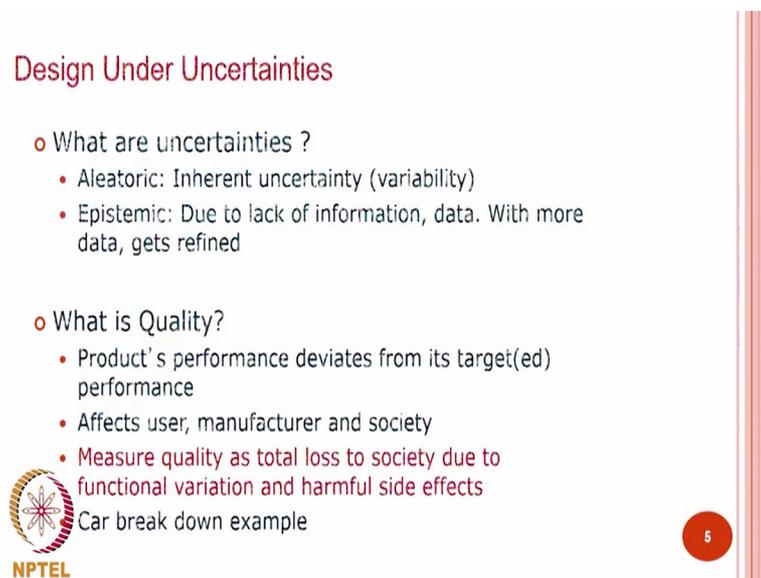


**Design For Quality, Manufacturing And Assembly**  
**Prof. Palaniappan Ramu**  
**Department of Engineering Design**  
**Indian Institute of Technology, Madras**

**Lecture – 02**  
**Introduction To Quality**

So, we will first start with some questions on quality, what is your understanding on quality, and from there we will drive how that is slightly is likely to be different from the actual definition of quality.

(Refer Slide Time: 00:21)



**Design Under Uncertainties**

- What are uncertainties ?
  - Aleatoric: Inherent uncertainty (variability)
  - Epistemic: Due to lack of information, data. With more data, gets refined
  
- What is Quality?
  - Product's performance deviates from its target(ed) performance
  - Affects user, manufacturer and society
  - Measure quality as total loss to society due to functional variation and harmful side effects

Car break down example

 NPTEL

5

But before that we also will explain, this is just to give you what you call like an birds eye perspective. So, all these come under a big umbrella, all these type of studies come under a big umbrella called design under uncertainties or a decision under uncertainties.

You can take any example, you can take a doctor for instance a surgeon. So, we work with a spine surgeon, we work with a gastroenterologist, the success of such surgeons if you look at it is how quickly they can make decisions in the face of uncertainties this is all it is. So, this holds good for anything you take a cricket player for instance. If everything is nice, what is the big deal in plane? Why was Dhoni celebrated that much because he was a match winner. When everything is going down he is a single person who will stand there and play the game and win the game for the country.

So, that is called uncertainty if everything was given to you very nice pitch, a bowler who will bowl to your bat, there is no big deal. You will play against a tough team, who will bowl at a very high speed, they can you know spin the ball, and there will be due that will be set on your thing, and you know the crowd might be against you. Under all those conditions how do you play against all those conditions and still win the game? So, that is what these are all the uncertainties that I am talking about. So, in a similar fashion for a car you cannot design a car the you will say like, this car was design for Chennai.

So, it will only work under like a heavy sunny conditions. You cannot drive it in snowy weather. You can always say there is a car that is a 4-wheel drive it is better suited for snowy conditions. But you cannot say that this car will not perform under snowy condition. So, a car has to perform under uncertain conditions as well. So, all these things come under the big umbrella called design under uncertainty. So, the uncertainties happens in multiple stuff for instance classically, where does uncertainties happen in a manufacturing senses in the material property.

For instance, in the strength of materials one of the important property, material property that you discuss is the young's modulus. The young's modulus is usually given by a single word. So, basically if you take the young's modulus for instance, predominantly we have used it in a deterministic sense. So, there will be a single value that is given. But if you realistically if you look at it, if you take a particular specimen of that particular material, and run a stress strain curve to identify the young's modulus. Between 2 different specimens the values are likely to vary. So, there is an uncertainty in that.

Where does this uncertainty come from? It might come from the material itself the way in which the material was made. It could come from the way in which the technician actually tightened that particular or fasten that particular specimen. The way in which the specimen was machined, there are several things, the at what point in day was this specimen tested and this specimen was tested that could also have an influence. So, basically there is variability in the material property. Then there can be variability in loads then there can be variability in geometry which comes from the manufacturing aspect of it.

So, all these things will influence the performance. So, it is very important to consider design under randomness you cannot say that the design is deterministic. You cannot say

the load is this much and it will work. No not necessarily, the load can be larger than this. In classical design how do you think we account for this randomness? Because we have built airplanes and you know ships and cars and bridges; all knowing that there will be uncertainties in the in the loads, uncertainties in the material properties. It is just that with technology we might have been able to control these uncertainties a little better, but that is that is still uncertainties have existed forever.

How do you think in classical design we treated these randomness or uncertainties? You have used factor of safety. When you do design finally, you use something called a factor of safety. Usually what you do with the factor of safety is you either use a load factor of safety, or you use a material load factor of safety, right. The load factor of safety says if you are going to apply 1 unit you put a 20 percent on it, 20 percent factor of safety. So, you say instead of 1 unit I am going to apply 1.2 units. So, in reality you will be only applying 1 unit, but you are over designing here by saying that I am going to apply 1.2 units.

Similarly, if you are going to account the factor of safety in your material property, what do you will do is you will make the material property weaker. If it is 1 unit is what the material property is you will make it 0.8. So, you will design it for a weaker material so that it can the actual design is stronger. So, this is how we have done, but these techniques let you and take care of those uncertainties in a slightly better way. So, that you do not have to over design. So, that is and it gives you more insight into the failure mechanism that is the idea of this whole thing.

So, there are different ways in which people look at uncertainty. And that itself is a research area. Because when you say uncertainties this is not only in structural design or mechanical design or engineering design in general. Uncertainties exist in everything in that as I told you like for instance in finance, finance engineering or any kind of an investment banking systems and all that, uncertainties is the most important stuff. Weather prediction, stock markets, all these are heavily influenced by the uncertainties. Today one of the major things in the climate change stuff is predictions, why it is very difficult for us to predict whether there is going to be rain this year or not. You can always predict whether there is rain tomorrow or not, there with much larger confidence compared to 8 months before. So, the problem is you need to understand the physics behind that.

So, that you can will you be able to forecast. So, similarly if you want to invest you have some money and then you want to invest in shares, the question that you have is what is the probability that this particular share is going to be greater than that value. If you know that a priori you can happily invest, but if you know that that particular share is going to go down 8 months from now, that you will not know. But let us say that you have the ability to predict that, then you will not invest in that. So now, there are mathematical models, statistical models that kind of let you not always, see that that is a strength of probability, right it is only a probability that this is going to happen.

In a statistical sense it is going to happen. It is not a guarantee that it will happen. So, the forecasting models and prediction models, this is what they do, and this is what this majority of the aa is a all about. With all this data that you have can you predict can you forecast. So, that is what they call it as prescriptive, predictive analytics. And then the moment you predict can you prescribe something to that. If there is a problem what does a doctor? The doctor prescribes medicines to you. So, if you can predict using analytics can you also prescribe the solution using analytics. So, that is what that is coming, right.

So, there are different ways of looking at it. But one widely accepted way of looking at uncertainty, there are 2 types of uncertainties. One is the aleatoric uncertainty and the other one is the epistemic uncertainty. Do not worry too much about the words we look at the concepts as such. The aleatoric uncertainly means it is the inherent uncertainty. The uncertainty that we spoke about, not all of you are of the same height in this classroom. Not all of you weigh the same in this classroom. Not all of you are going to perform the same in this classroom. Are the instructor different for each one of you? The instructor is the same, I am the instructor, I am sitting here, I am being video graphed, everything is the same.

The environmental conditions is the same, but you think that all of you are going to get an A grade. Even if all of you get an A grade, let us say, not all of you are going to get 80. Someone might get 82, someone might have got 78, still all might fall into an a grade, but points wise you might be different. So, there is an inherent variability, I might try to minimize that variability you might try to maximize that variability, that is a different stuff. But there is an inherent variability. The wind speeds there is an inherent variability. Performance of car engine inherent variability is there. Whereas, the epistemic uncertainty comes from the lack of information or data, when I said a digital twin, what I

said is there is a physical car and you have a car on the computer. The computer the car on the computer is a numerical representation, you can visually see a car, but when you crash what happens is it is going to solve partial differential equations at the back. A finite element analysis is what? Visually you can see stresses and forces and all that. That is only for us, for our naked eyes to appreciate that. But at the back end what the computer does is it is actually solving partial differential equations, right?

So, this curve that you see on the computer is only an approximation. It is only as good as your mathematical representation, is only as good as your numerical representation. So, that again comes from my limitations on how much I understand the curves mechanism. It is only a approximation; for instance, today people are trying to model blood, they are trying to model skin both from a decision perspective and both from a product perspective. People are trying to come up with materials that are equivalent to skin, they are trying to do that. So, for instance if you were to do this kind of stuff if I have to develop a model of a skin, I need to understand the skin or the muscle mechanics.

Or the concepts of how these work or how these exist. So, I would start with a simple model, and then I will build up the complexity in the model, right. So, that is where it comes the due to due to lack of information, and it gets refine as and when I get a little bit of an understanding on the skin part, then I will try to bring the nonlinearities into it, and then the model gets refined. So, that is what is a epistemic uncertainty, what we will predominantly discuss in this course is the aleatoric uncertainty.

Why predominantly we will discuss only aleatoric uncertainty, we will not be talking about epistemic uncertainty, we will only talk about aleatoric uncertainty. And which is the randomness or variability, these are the words that are usually used, uncertainty is a fashionable term. So, for you the word that you might have already been used to is called the randomness or variability that is what we are going to look at. Now the next the first learning of this course could be this particular stuff, what is quality? This word is not new to you, we been using this word you know quite often we use the word quality.

We have now started using it for anything, you know, buying a pen, buying a cell phone, buying a jewelry, buying a computer, buying a bicycle, buying a car, anywhere and everywhere you can people use the word quality, right. So, what do you think quality is?

Yeah, I do not want a textbook definition where you say quality is a property by virtue of it, no I do not want that. What is your understanding of quality in your own words?

You need to interact, we are on the video, you need to interact, eventually I will tell the answer, but you need to interact, I cannot run the course for the video, yeah, there is no unique answer. So, you can answer.

Student: (Refer Time: 13:44) meet the desired specifications.

They are built to meet the desired specifications, good.

Student: (Refer Time: 13:50).

Sorry?

Student: durability, lifetime.

Durability lifetime, you are giving me hints to develop or what?

Student: (Refer Time: 13:56).

Can you frame sentences?

Student: (Refer Time: 13:59).

Imagine I teach course like this.

Student: It must deliver the (Refer Time: 14:05) same quality as like.

Oh

Student: (Refer Time: 14:08).

Now, you cannot use the word while you are defining the word. I am asking who is Kuldeep. So, you are saying Kuldeep is someone who looks like Kuldeep, you know. So, that is what you are telling. So, that is not allowed. We should tell me features of Kuldeep, then I will know who Kuldeep is. Like that what is quality? you cannot use the word quality in trying to define quality that is all it is, yeah.

Student: (Refer Time: 14:31).

So there are some benchmarks and metrics, and if your product meets that specifications then it is called a quality product, is that right? Anything else? So, whatever you guys told is right, but it covers only the partially, it covers only partially. The deal is majority of what you are talking about is until you go and buy. When I am buying it, you are asking, was it is meet the specifications? Yes, it did meet the specification. So, you see it is a quality product, but does it stop there. As a buyer, my experience starts there, it does not stop it starts there. How do I care until then whether it is quality or not. I am worried after I pay, this is important, right? If you give it to for free I do not care. It works it does not work, I do not have the right to complain, but the moment I pay, there is some expectations from my side.

The moment I spend some time teaching you there is an expectation from me. The moment I pay and then I get something, there is an expectation for me. But can I have a wild expectation, no the product comes with a specification and an expectation also. For instance, the x kilometer per liter is what the expectation is. The example that we gave x kilometer per liter is what your expectation that there is a higher priced car. The reason that it is higher priced there is a luxury, it is in the luxury segment. So, I should necessarily feel luxurious when I sit in that. I should necessarily feel comfortable when I sit in the other car that was more expensive than that, because that is what was promised to me. They said there was another car, which is even more expensive, the expensiveness comes because it is really safe, it had like some 6 airbags. It had other sensors and all that which will you know allow you 2 are which kinds of guides you out of a accident, before it happens.

And it has to do that. So, there is an expectation the moment I pay that higher price I expected to perform. So, the important part are not necessarily the important part, but one of the part that missed that was missed in your answers is, how it performed after I bought it, until then you are only talking about what is there on the showroom. The wire what I will be interested more is after I bought it, how is it going to perform to me. See I can always have a very high expectation, but that cannot be met. There is a I tell you, as a seller I tell you this is your product and this is what you can expect and this is what I promise. I say this is your product and this is what I promise. And you are paying and you are getting that.

Now, the question is how far did the product stay up to what I promised. How far did the product stay up to what you expected? Here the understanding is that your expectation and my promise were more or less the same. They can be different, they can be different for the purpose of selling I might make an over promise. For the purpose of buying it for the first time, your expectations could be more, there could have been a hype created because of the advertisement. So, your expectation is slightly more that is, there will be a slight difference. But end of the day the question is, how far the product live up to the manufacturers promise, or how far did it live up to your expectations.

So, that is one part of quality. So, to go with what Kuldeep was trying to say is, if you have a product. So, I have a pen, right. So, if I am going to talk about the quality of the pen. The first question is what is this pen suppose to do?

Student: (Refer Time: 18:52).

Simple, the pen is suppose to write. So, the point is when I open and write, this guy should write, today, tomorrow, next week, 10 days from now, one month from now. So, the deal is, this is the promise that the manufacturer gives me. You buy my pen it will write, that is the basic performance that is expected out of this pen. It will do this performance every time you try to do that. You cannot say, it will write for the first 2 times, the third time maybe, then I will not buy your pen. It should perform every time you would like to do to the extent. After 5 years will it write? Unlikely, will it write after 3 months? Maybe, but there is a limitation to it. They will say that it is going to work for these many days. It is going to work for these many hours. It will work for this much time that you are going to write how many pages you will write. Someone might write 10 pages; someone might write one page per day.

So, I cannot always give a time limit on it how many words are you know, how many usages for sure for those many usages it has to stay, it has to stay fit and it has to serve the purpose. So, the important part is performed every time you want to do that, governed by their time factor. So, how many our times I do it in that time limited time it should perform. So, that is what one way of looking at quality. But there was this one guy from Japan who actually took an entirely different perspective on quality. You know whom I am talking about? There is this guy who is actually an electrical engineer called Genichi Taguchi, Taguchi techniques orthogonal array and all that is very famous.

He is a Japanese electrical engineer who post world war II. Japan was under tremendous pressure to manufacture quality products. But then the material that they got was not really great. But in spite of that they wanted their products to be quality had to meet some quality. When I am mean quality, the quality was always meant how far or how much we were deviating from the promised. So, if you are saying it is x kilometers per liter how much are you deviating from that that is how the definition of qualities. So, he comes up Taguchi came up with this orthogonal array and sn ratio, he brought his learning from electrical engineering to manufacturing industry. He used concepts mathematical concepts from electrical engineering into manufacturing industry, and that was a phenomenal success. Even today, people are using what Taguchi did. So, it has been sigh of course, there are some limitations and all that, but there is no doubt that it was a runaway success in the manufacturing industry even today. That is where the 6 sigma and all those ideas emerge from.

So, the quality can usually be measured that is what everyone said right like all the 3 answers was on some specification. What is the specification the promise, the promise is what the specification will. But predominantly you told it on the disk on the showroom. But it can directly be applied to the performance also. When I say performance the simplest example that you can imagine about is your kilometers per liter that is my performance, right. Or if you are all you know like youngsters that you want to buy I do not know what you look at modern bikes these days like 0 to 100 kilometers I mean yeah speed in like 60 seconds. You know, that does it do that every time that you want to do it that is one thing.

So, the point is it is the products performance deviates from it is target or what I promise, how much does it deviate is another question. The interesting perspective that Taguchi brought in is, he says if the product does not live up to the buyers expectation, or it does not live up to the manufacturers promise who all gets affected? So, immediately there are 2 people who are involved in this transaction. One is the buyer, one is the seller, right so, these two people are affected, but that is all predominantly people have looked at, but he brought another one. He said the society is also at loss. There are different perspectives to this. So, we will take a simple example, and we will see a where the society comes into picture.

So, there is a take a car breakdown example. So, let us imagine I mean this is unlikely to happen. But let us say that I mean the breakdown is unlikely to happen. So, let us say that I bought a new car. Let us not worry about the brand, I bought a new car, and any new car is suppose to have a very nice engine at least in the initial months, right like after about 6 months which is still the engine is very young it is not expected to fail. And I am having classroom of 60 people waiting to attend my class. And I am driving from my home, and right around the junction outside the institute, you know if at all you are there in the morning let us say around 9 o clock 9:30 you know what the traffic is.

So, right just before I enter the flyover, ok, I have not enter the flyover, I am not gone on the left, I am right there my car breaks down. So, I am heavily disappointed, because I didn't expect this failure, it is only 6 months old. And the manufacturer is also not happy, because he did not expect the failure, they didn't expect the failure. And it does not end there, there is a problem for them, because it is cover under warranty. So, warranty means it is cost for them. They need to tow the car, they need to fix the part, they need to bring it, they need to give a replacement car to me, until this car comes into picture. So this is only the 2 people. But if my car gets stuck at 9:30 right in the middle of the road what happens?

Student: (Refer Time: 25:40).

So, do I know the guy who is behind me, who is 10 rows behind me, when I am in the car, I when, I am when my car has broke down they have nothing to do with me. So, that is what the society is. And there might be some important doctor who is park 10 cars behind me, who has an important surgery at 10:30 that morning. So, you are going to affect innumerable people, you cannot imagine to what extent the effect is. I might still end up clearing the car, and I am in the road in about 15 to and a minutes by getting out of the car and pushing it and all that. But even that 15 to 20 minutes there is going to be a lot of traffic jam. I do not know if you understand the traffic jam that I am talking about, 15 minutes is fair enough to delay people by about an hour easily, easily.

So, the point is what Taguchi says is there are 3 factors that play a role when you try to define quality. So, it is the user, it is the manufacturer and it is the society. Then he says it should be measured as a total loss to the society, this is an a very interesting perspective. Later we will talk about a loss function that Taguchi advocated to use to measure quality.

And the loss function talks about as the word defines it only talks about the loss. It only measures the disappointment of someone. It does not measure the how happy you are. You can be like threefold, fivefold, tenfold happy, but the last function does not capture that. It will only capture how unhappy you are, because that is what matters in terms of quality, not the positives.

So, what Taguchi says is, the quality needs to be measured as a total loss to the society due to the functional variation. See this is the important part. The variation end of the day, you can say it is from the material property, it is from the operational conditions, this that. End of the day what matters is, how well did that product function. It could be for any reason the breakdown could have been for anything. It could have been a purely genuine reason that does not matter. End of the day the engine did not perform it is performance. It did not live up to the performance that was promised to me. If the same breakdown happened after 3 years, I understand. I did not maintain the vehicle so it did not. But then there was a promise that was given by the dealer. That at least for 3 years your engine will be fine, but that was not the case here.

So, the loss to the society often it cannot be quantified. But there are ways and there are economic models they try to quantify this. And harmful side effects the one thing that we spoke about is not necessarily a harmful side effect. But a harmful side effect predominantly comes from a sustainability perspective, what do you do with their products that there that do not work fine. For instance, now people have started including in sustainability the tolerance and how well you manufacture to the specifications. Because if you manufacture washer. And let us say that I will take your washers only if it is greater than 4.8 mm or lesser than 5.2 mm.

You manufactured about 1000 washers that were not within this specification. What do you do with those washers? You will throw them there is an environmental impact of that. So now, that has to be taken into account. You cannot just say that I am a manufacturer. So, what it is a loss to me, no it is not just a loss to you. It is also an impact to the environment. So, you have to mend your design conditions or your manufacturing condition, such that you will not generate that waste. So now, sustainability is being brought into the design cycle just like how we spoke about quality being or robustness being brought into the design cycle sustainability is also being brought into the design cycle. So, this is one way of looking at quality, right.