**Six Sigma**
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**Module No. # 01**
**Lecture No. # 37**
**DFM and Reliability**

Good afternoon. We resume our lecture again today. This is continuing the lecture series on Six sigma. The topics for today are going to be design for manufacturing which is also called DFM and reliability. This would be the first half of this introduction to FMEA and the second half is going to be basically an explanation of FMEA process itself. That is what we will be doing.

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So, we start off with the title slide which is DFM and reliability that is what we will be doing today. Design for manufacturing: this a particular approach to design products so that they become easier to manufacture. In fact, the coverage would be starting out with what is DFM, why use DFM, why use this particular approach, what is the process like, how you approach it, what are the tools used in DFM and what are the methods that you utilize and then of course, I will provide you with an overview and I will give a comparison of DFM versus other method for doing approaching design which does not consider manufacturability as an example and of course, I will give you some references.

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So that, you will be able to go on and study more about DFM. What exactly is design for manufacturing? If you look at the product almost any product ultimately you got to remember this is got to be manufactured through some manufacturing systems.

If it designed in a way that is not conducive to easy manufacturing, the cost is going to be high, perhaps the quality will be affected, perhaps the handling would be affected and so on and so forth. So we got to make sure that the design itself keeps this mission in mind that, eventually I am going to product produce this product produce this product in a manufacturing output. This being the goal, certain special approaches have to be taken to make sure that you can manufacture product that you have designed. Why do you do DFM? Of course, couple of benefits are there right away you lower your cost, you shorten the development time, you come up with a faster time to reach that start of build which is like when you go into commercial production you will have lower assembly cost and lower testing cost also. And of course, you will end up with high quality; these are the advantages in approaching the task using the DFM approach. There are many tools many processes and so on and so forth.

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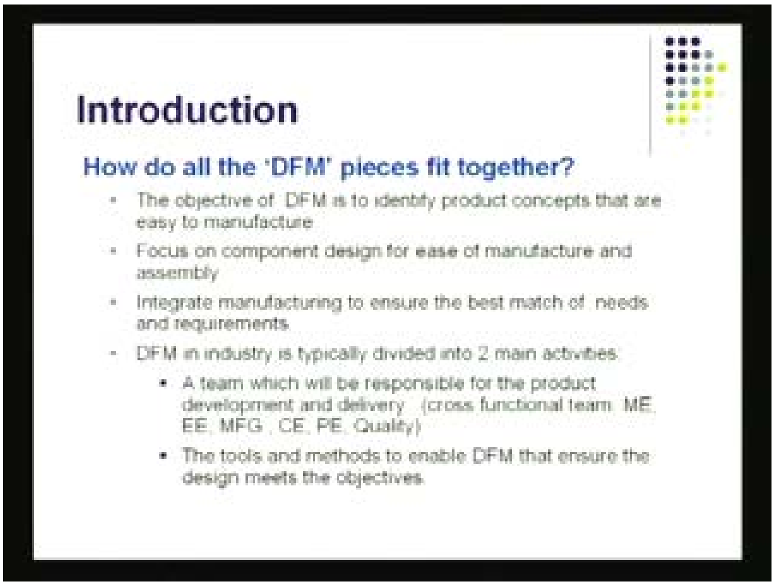


How do they all fit together? A couple of things you got to remember is, it is a fairly straight forward method in that it comes along with some guidelines. If you follow the guidelines you will be designing your components correctly, you will make sure that the assembly is right, you make sure that the assembly actually goes through some processing steps which are also easy to execute. These are some of the things that will be there to try to make sure what you produce can be done conveniently at a quick quick quick pace of time and of course, it would cost you less these are the goals of DFM.

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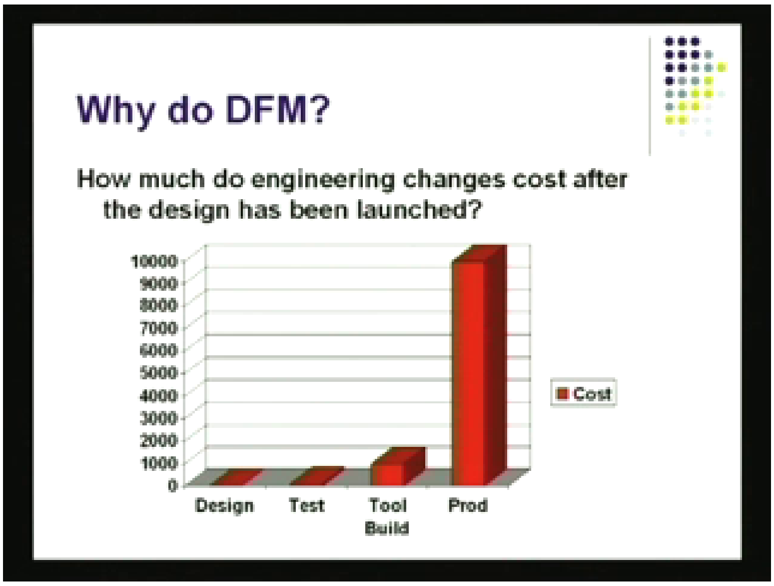


Why do DFM? In fact if you look at DFM and if you look at the engineering changes that are required many times after the design has been launched which means after it has been commercialized. If I would not kept in mind DFM, if I have not kept in mind this end step which is manufacturing in mind, if I have not done that and I if just do a design and I throw it over the wall and it lands up in the manufacturing shop there are going to be lot of problems. If you look at engineering changes many times a lot of things are discovered when you actually get into manufacturing. Lot of problems are discovered when you get into manufacturing. That is something you would like to avoid you would like to minimize.

I have got a i have got a little bar chart here. It actually shows the cost of a change when you do it at the design stage versus when you do it at the testing stage. The testing the prototype for example, or when you do some changes in the design, at the tool building stage or when production begins, you start doing some peddling with the design itself. That is going to be very expensive.

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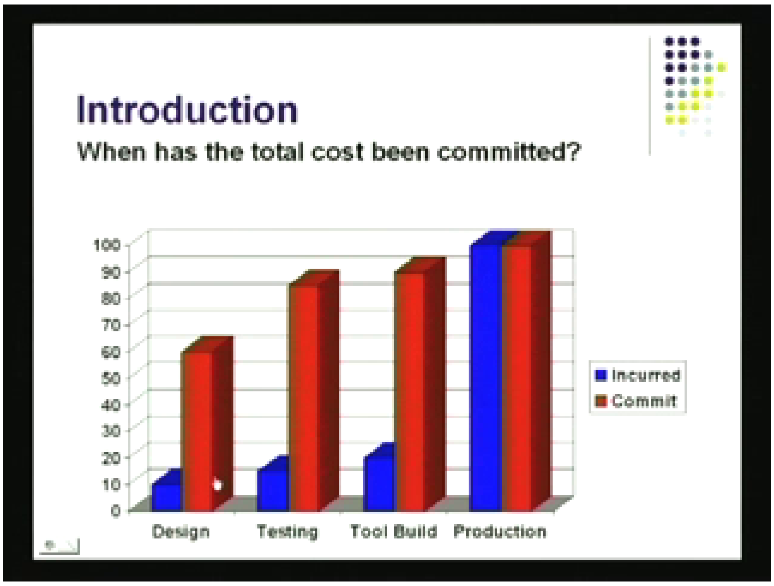


If you look at the impact if you look at the impact of DFM; DFM actually is is rather it is it is something that really saves your money right up front. There is a trace here of committed cost and the committed cost begins to rise as you go toward production. The committed cost that is the commitment made by the company to go ahead and produce something.

If you do it at the design stage the actual cost incurred is quite low then a testing again incurred the the the the cost incurred is quite low but, as you complete your tool building and you get into manufacturing most if a cost get's cost cost that actually incurred. If you could take care of this early on; in fact if you if you could reduce your commitment it turns out it is far better to approach.

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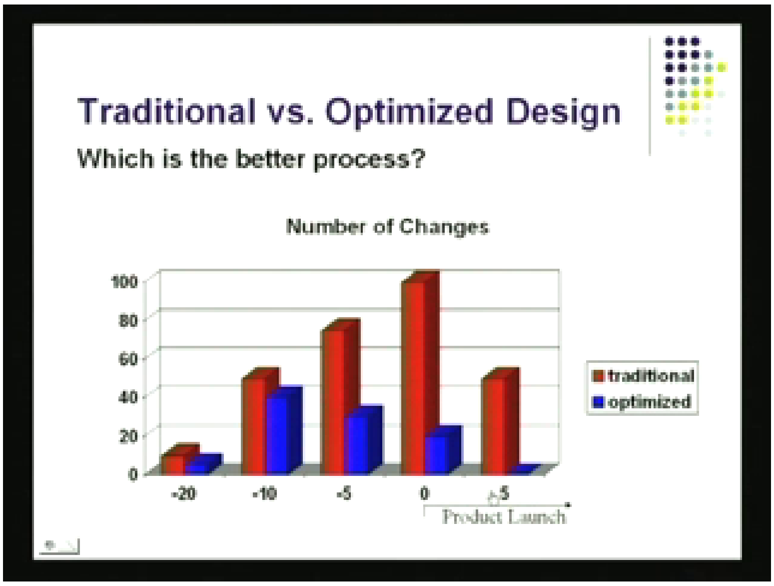


If you approach the total task in the DFM way than having to do it when for for example, when production begins. You look at two approaches to optimize a design one is of course, the traditional approach which means you let things go till they reach manufacturing and when the project is launched then you really try to optimize the design, optimize the parts, optimize materials, optimize manufacturing methods and so on so forth. That is going to be rather late. It is also going to cost you more. Instead if you start optimizing a little ahead of time which is like let us say, on some units of time twenty weeks ahead of time then may be ten weeks ahead of time.

If you put some commitments there the the cost that you'll be incurring; the extra that you will be incurring due to all these changes that have not been that are required now because these are these were not addressed when you are doing your real design. Those are going to be much less if you go go the optimized routers goes to, going going and doing it the conventional way. What is the manufacturing scenario today? I will i'll show a couple of examples. I will show one or two examples where you will see that manufacturing has become far more challenging, far more complex.

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It is very difficult to coordinate a lot of these things because our supplies have become global and there is global competition. We have to compete now with the best all over the world wherever they are from. They could be from Japan, Europe, India, Mexico, Malaysia anywhere. Manufacturing can be done anywhere, parts can be made anywhere and of course, they are all brought together in whoever is doing the final assembly. This is certainly true for cars it is also true for home appliances true for electronic parts and so on so forth. Even airplanes parts made are in different places and they are shifted over. Someone makes the engine, someone makes the elevator, someone makes diffuse box, someone makes wings and so on so forth. These all brought together in in one place and then the assembly is done finally. Quality requirement has also become global. ISO nine thousand of course, now, Six sigma, everyone is talking six sigma. The product cycles have become much shorter. That is where manufacturing is today. The rate of change is of course, also increasing. That is also there if you look at cost. Costs have been decreasing because of the learning effect and because of competition.

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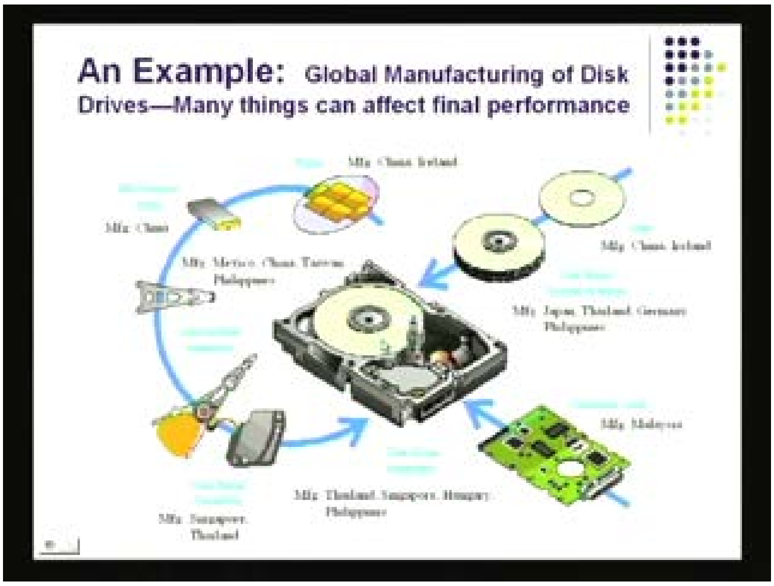


Take an example of a disk drive. Take a look at a disk drive which is just your just your standard DVD or ACD drives. There are components which are made in different places. For example, there are certain vapors required those are made in probably China or Ireland and some sliders are required to assemble this particular product and those might be made in China. Certain parts are made in Mexico, certain parts are made in Taiwan and Philippines and so on so forth and of course, Singapore also might be doing some manufacturing and so on so forth. Assembly might be done in a in a location that is quite different where parts were manufactured. The electronic cart may might might be being made in Malaysia and it is all brought together in a one place where the assembly is done which in some case could be Singapore or Hungary or Philippines or Thailand or somewhere there.

Now, there is lot of coordination to be done here. There is a lot of coordination that is the global picture today because you want to minimize the overall cost. This has a couple things for us to keep in mind. Once the supply chains have become long; you got to do quality assurance when you are when you when you got supply is coming from faraway places you got to take special approach to make sure your supplies are in place.

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The conventional approach to product design, how is it done? When we went through a development cycle, when we did a lot of changes and so on and so forth and there were nonstandard parts used in the conventional way and these usually had long lead times because they are not nonstandard parts they all had to be made each. Each of the kind quality also was something that I just mentioned to you it was the design was thrown over the wall and what was hope was that the manufacturer will catch it and you then go on with his detailing of the manufacturing process and so on so forth.

Now of course, things have changed. Manufactures are very closely involved with the designer and designers make a lot of tips to the manufacturing shop to try to understand what are the processes, what are the choice of materials, machining conditions, assembly conditions and so on so forth. All those things are brought into play when someone puts together a design today. That is like today's design.

If you look at cost because of unique designs as specialized parts; costs were higher traditionally and of course, equipment and tooling if these were not done right and they were generally not done right in the conventional product design approach, the whole product ended up costing a lot more.

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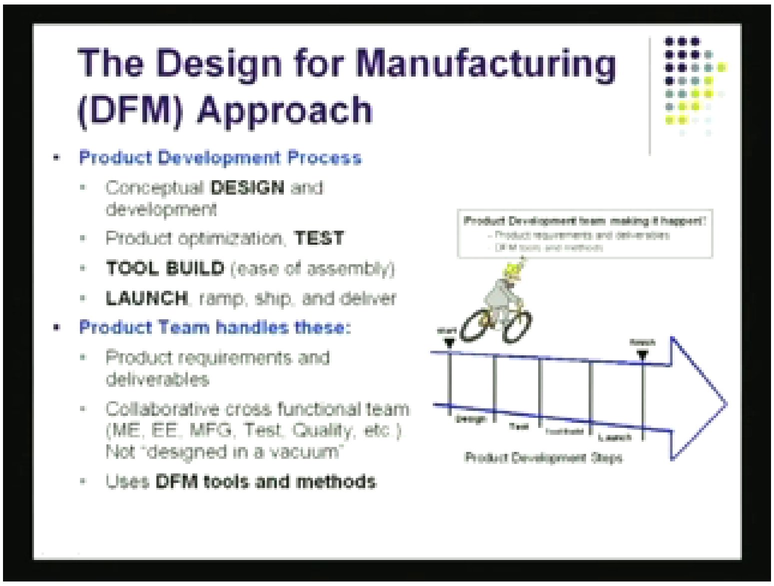


What is the new approach? Couple of things are changed one of course, the conceptual design is where you begin to design and then you would be doing some optimization you would be doing perhaps you might be doing experiments, perhaps you might be building prototypes, perhaps you might be doing Taguchi method and so on. You would be building the TU tools and these tools also have to built in such a way that, the assembly the final assembly is easier. Launch will be done by ramping and the shipping and delivering and so on so forth. This is the product launch. The product team; they are there these are the guys who are given the charge of bringing them bringing the product right out at the final gate.

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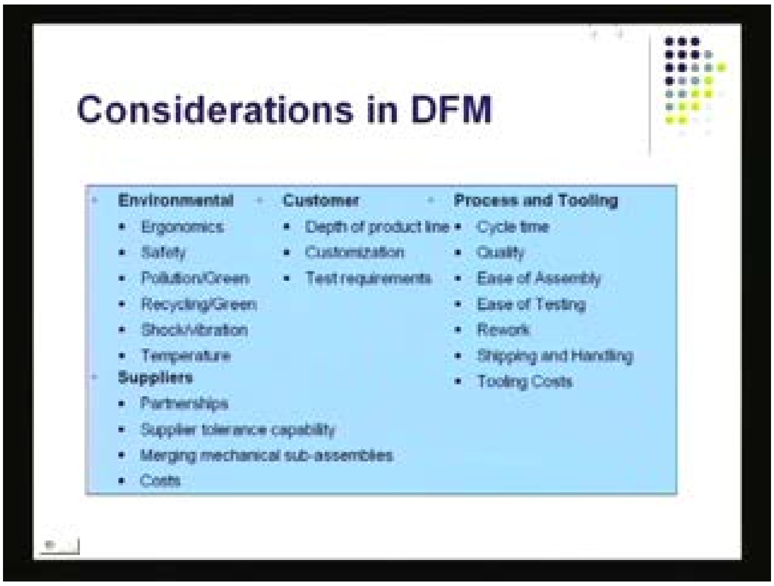


You know that their their charges start from design and take it all the way to the finish line. This is their job. Now you have product teams that take charge of this. That is like something that is also were DFM comes in, design for manufacturing. You going to make sure that you are designing something that can be manufactured manufactured easily. What are so the considerations in DFM? There are obviously the environmental considerations. That is definitely very much there. You got to worry about pollution, you got to worry about green manufacturing conditions, you got to make sure you do a certain amount recycling shock vibration, temperature these have to be looked at, there are their environmental factor there. You got to look at you got also look at suppliers and their capabilities and perhaps you will have some partnerships with your part suppliers and your measure assemblers. For example, those who produce the some assemblies. Then customers also play a major part here because you are got to make sure you understand their requirements.

And this is something that is you know, you get you get techniques like QFD, you get techniques like customization, you got techniques like the Cornell approach to categorized customer satisfaction, customer requirements and so on so forth. You got some special test requirements; these are sometimes required by certain customers these also have to kept in mind once you are going to design for manufacturing. And of course, processing and tooling, the processes they have to have their own you know, they have their constructs of cycle time and that has to be optimized again. Quality has to be looked after, ease of assembly, ease of testing, rework, shipping and handling. All these things and they have to be done right.

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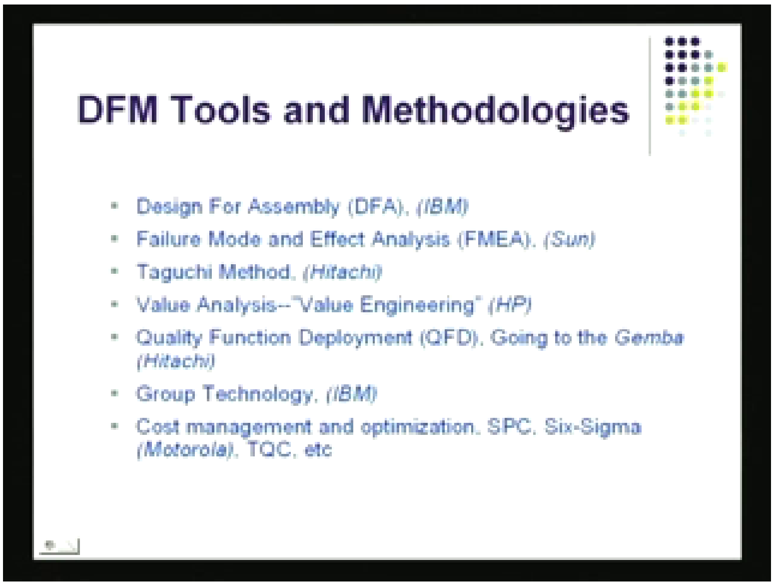


So today design for manufacturing would would require actually for you to go into all of these things. In none of these things can be left out and you hope to get a good design done. That is just not possible any more. What are some of the tools? Well, just to give you a few acronyms; Design for assembly: this is to make sure that the assembly can be done easily. it It does not become a strain after you got the parts made and the some assembly is made, the assembly itself does not become a bottleneck. FMEA: This is a technique that is utilized and I will be spending some more time. I will be spending a lot more time a little later to tell you about FMEA, this is failure mode and effective analysis. A design or a process or a product can fail many different ways and before you are go into commercial production or before you commission the final product; you got to make sure you've done FMEA. You try to predict in what different ways in what different modes can a product fail.

You also have to make sure when you are doing this you look at the effect and you look at the couple of things one; first thing you look at is, how would likely is it going to fail what is the likely hood of a particular mode of failure in, what different ways can it fail that is mode. Then you got the likely hood of failure, then you got to look at the impact. We look at the impact of that failure and then you got something called detect ability. All these things have to be there and this is what you got to do. If you got a for example, if you got, if you have designed a disk drive as an example, you have to predict through your analysis and this would be the FMEA analysis with that you will have to predict in what different ways can it stop functioning or give trouble to the user.

These have to be projected in terms of likelihood, their impact, their detectability and of course, later you will have some control actions or some rectification action which will make sure that the impact, eventual impact is low or probably the line turn is almost next to nil. You also have Taguchi method. That is also another design for manufacturing tools and we we discuss Taguchi methods early on in this course and that is like one method by which you can create robust design. Tour design should be such that the final performance is a is on target and it is not it is not affected too much by the environment. That is something that doctor Taguchi was to come up with. He was able to come up with this special method were you used experiments and we have seen many experiments in this lecture early on and they are special types of experiments which are multifactor experiments and these are called orthogonal array experiments. And these are the experiments that are utilized to try to make sure you find the optimum settings for the different design of parameters when you are trying to design something.

The same thing can be done for a process also and you can come up with a robust design from the process or a robust design for the for the product itself. That is something. Value engineering is also something that for example, I have listed the companies there value engineering is capitalized by Hewlett Packard as an example they are the one's who say whatever you put together it must give some value to the final user. It should not be there only as a bells and whistles. So, you got to make sure whatever you are adding if you have, if I have if i have put a strange clip on this, it must have some value. Otherwise I do not need it. If I have got something fancy inside this pen I have got to make sure it has added some value to it may be life of the ink or something it is got to do something useful. Otherwise just a waste and this is something that you would like to avoid and to be able to do that. What you do is once you got your basic design done, you try to do value engineering and with that you can reduce cost, you can it more reliable, you can make it more functional and so on so forth. And basically what you doing is whatever resource you are putting into the final product itself it is all going to add to value. Some value that should be of some some some some help or either its going reduce cost or its going to probably raise its value as far as the final user is concerned. That is something to be done.

QFD is also a tool quality function deployment, we have discussed this before. What it really does is, it looks at customer requirements before design specs are grown up. It looks at customer requirements as we discussed in trying to do our QFD exercises before. I think we we looked at this was a dry cleaning shop, what all features should be there in the service that they provide? And what should be their target values? what should be the target values of these different services that the the the this shop will provide this dry cleaning shop will provide? We of course, want to make sure we maximize customer satisfaction at same time we minimize cost these are some other things that we will have to do.

So whatever, the customer is looking for I have got to capture that by capturing the voice of the customer through this QFD process. Then of course, if there are several parts to be made I have got to take advantage of something called group technology. So, if there are lot of turning to done, of different dimensions. There are lot of turning to be done of different dimensions, what we will have to keep in mind is that these turnings are grouped together and they are at one workstation because otherwise what will happen you will have dissimilar processes all being thrown at the workstation and there'll lot of switchovers, lot of changes, lot of set up cost incurred. Additionally and this is something you would like to minimize and this is why you would like to go into something called group technology. IBM exploited this very, very well in doing their computer manufacturing. Then of course, you got this standard quality assurance methods and cost management methods. You have SPC and now of course, we have got Six sigma. In addition of course,, we got TQM and t TQC these also help out with DFM design for manufacturing when you are trying to do this.

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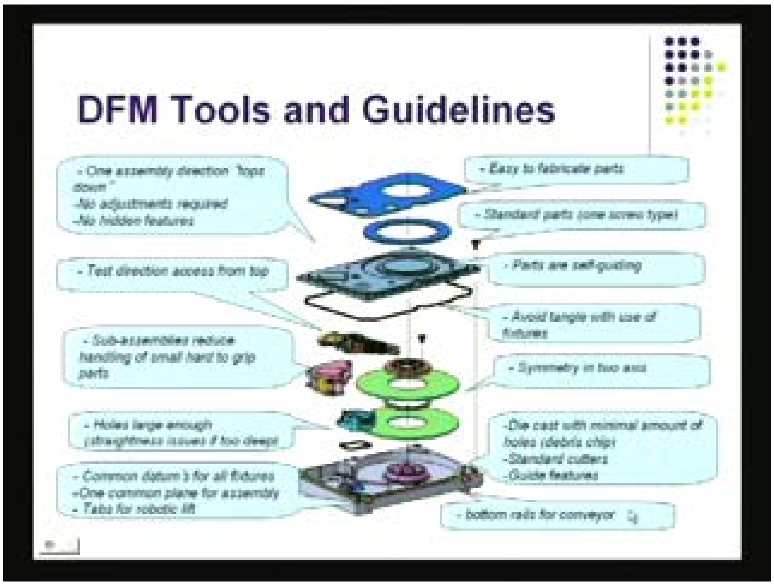


Let us again take a look at that that disk drive and if you take a closer look the screen you will be able to read a few things. For example, the assembly is to be done in a top down manner so that no adjustments would be required, no hidden feature would be required, the test reduction access also is going to going to be from the top. These are guidelines given to the design for manufacturing specialist. Some assemblies are to be done in order to reduce total handling, holes have to be large enough to make sure the access is there and of course, you got to make sure all the fixtures and so on so forth they come together properly.

I have got to look at the parts we got to make sure they are easy to fabricate their standard parts to the extent possible for example, one screw type used throughout the assembly. Parts are self guiding if you put them there there you put a screw in place it goes right in exactly where the thread is supposed to be. That is like something that is part of a good design and it really helps in manufacturing. Avoid avoid tangle with the use of fixtures. This helps lot when you are doing when you got wire harnesses and so on so forth you got to make sure things are easy to fix, things are easy to you know kind of isolate and so on so forth. That is something that is done a lot when you are trying to for example, put together a motor cycle. At the design stage itself they try to figure out how it is going to be put together then they try to make sure it is going to be easy for the person who is going to be doing this. The same thing what apply for electronic electronic devices like such as this drive drive there.

And we have got some some other considerations like in this particular I guess symmetry die cast material and the bottom rails for conveyers. You got to make sure that the product is able to right container that is like something that happens a lot. If you look at a bottle for example, if you look at a bottle right at the bottom of the bottle you will find some grooves and those grooves are of no use to the user. The the person is going to put in some liquid in this bottle but, this a great, great great aid when it is going through that filling line and the bottle has to turn or it is ti stay secure so that, the cap can go on. For that we need those little studs there. That is something that is always done.

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It is done in a way that makes manufacturing easier. Design for assembly I have got a list of guidelines here and I will let you read this at your own time so you can actually stop your your your your play of the video and you can actually read of some of these things. You can also of course; you can find them in design books they are there there.

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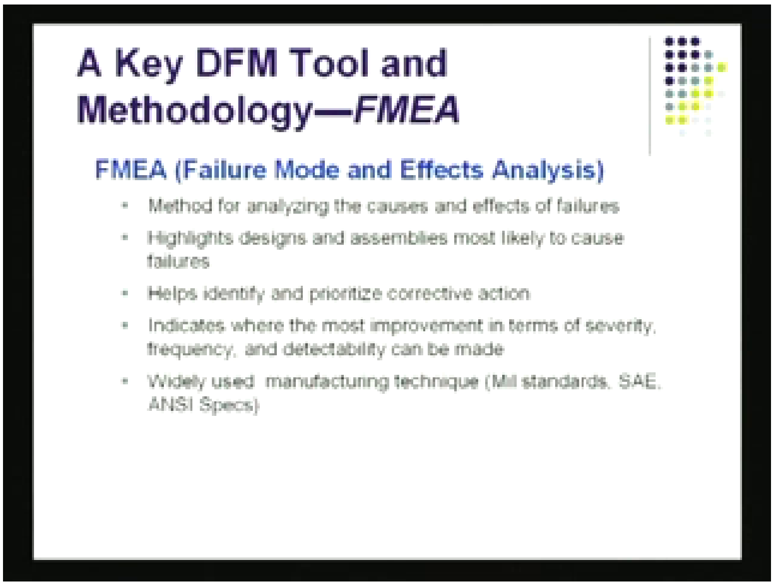


I just want to make sure that you keep some of these things in mind before you go before you finalize your design because eventually the design is to be done such that the final assembly can be done conveniently. This is something we require then of course, you move slowly into FMEA. FMEA is really failure mode and effect analysis. What is what is this approach? You try to actually try to predict failure and you try to look at the first form the different modes by which you can fail; what are the different ways a disk drive could fail for example, then you try to identify what would be the impact in that thing if that particular thing failed or what is the likelihood for it with this. You try to find out the seriousness of the problem itself and you workout something that I am going to tell you a later about called the RPN or the risk priority number. This helps you prioritize the different action. The different action can be prioritized if you do this RPN calculation. With the RPN calculation you end up with getting getting kind of a sorted situation.

When the items which are likely to fail, highly likely to fail for example, and that will have a big impact, that will end up with a high RPN and these these are the ones that you got adjust firstly before you go into any of the other details this is what is done very systematically using the FMEA worksheet and I am going to be showing this to you as we go into this. We will be showing this to you.

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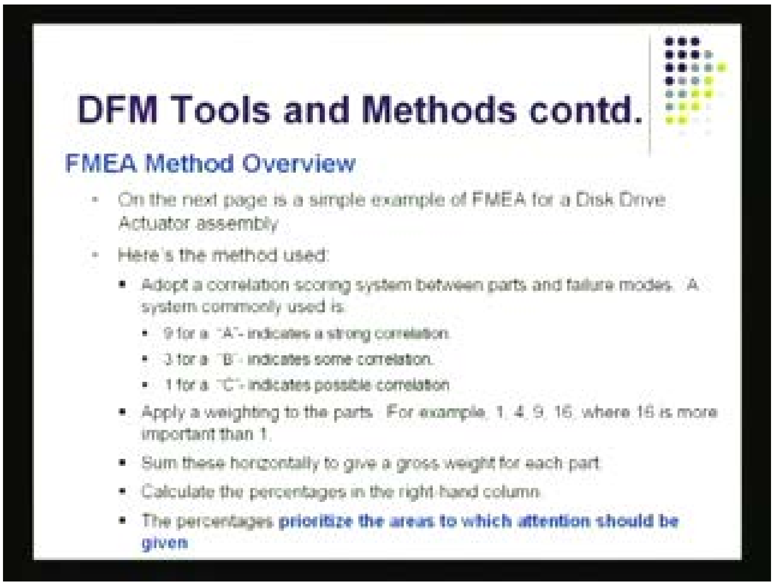


Just the overview of the method itself I have an example in the next page when I am going to be showing you how exactly a disk drive is put through this FMEA process. you will see certain cells, you will see certain columns, you will see certain entries there and those are done eventually to make sure that for every mode of failure that you identified you go down to the root cause and you try to make sure you either reduce the likelihood of that failure or you reduce the impact of it. And you that by addressing all those items that end up with high RPN, has a high risk priority number. Those are the ones you will attack first you try to reduce either the likelihood or the impact. Then you go on with the other set of the lower RPN. That is what you would be doing.

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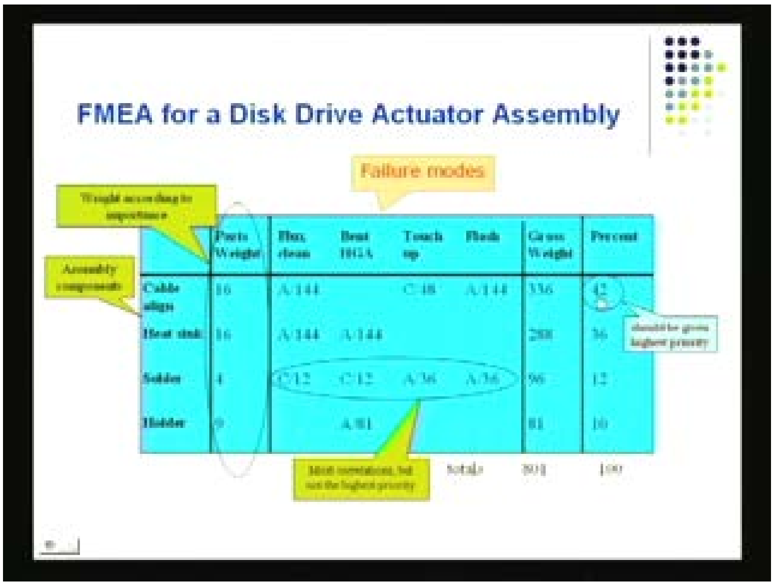


Here is an example the same disk drive, it could pay lane you know, many different ways some of the parts that can actually cause problems is the table alignment or the heat sink or soldering or the holder. These these could these could from cause problems.

In what different ways could it cause problems? The flux may not be clean, there will be some bent component, there some touch up may be required in certain places and flashes may be there because some injection molding and so on. And with that you end up with a high high likelihood of a failure taking place as far as cable alignment is concerned. And of course, the next one is the heat sink that may give you also trouble and the other one is tend to be lowers. Now, here I have got a priority sorted out for me. The total weight is 142 is the weight given to the problems associated with cable alignment, heat sink picks up 36 which is like one third of the problems are expected to go there and the others are about ten twelve percent. So, they are not much of the thing. So, we should be giving the highest priority in terms of tackling it to this issue about the cable cable alignment not being proper.

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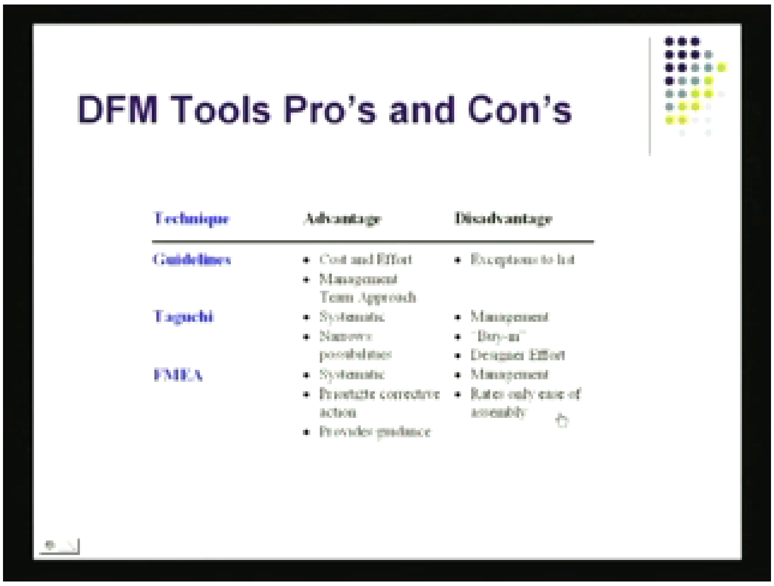


There are certain guidelines which are also used and certain tools are used. Guidelines of course,, are there to try to make sure you got cost minimum you got to have minimum effort in doing your design and certainly finally, the finally, the final manufacturing you would you you will be using the management team of course, these are some of the advantages directly coming out of the guidelines that you have got. And the disadvantage that sometimes you got to got to have a exception which are not covered by the guidelines. This is like if you are doing DFM you might be using guidelines and these would be the things that you should be doing in addition to just following the guidelines. Then you got Taguchi methods and the Taguchi method actually is a very systematic method these are some of the advantages and it narrows down the possibilities of things going wrong because you already got a robust design. And what are the disadvantages of the Taguchi method? First of all management you not really understand what you are trying to do and it will deploy special effort from the designer to be able to do this so these are going to be some organizational challenges if I try go the Taguchi way.

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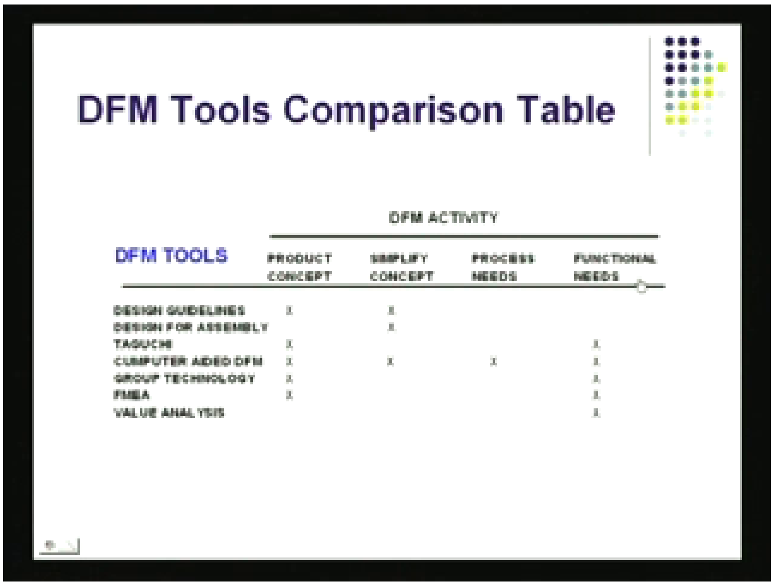


As far as FMEA is concerned; it is a very systematic method. So, this is also an approach that you could use in DFM. It will help you prioritize corrective actions and it will also provide guidelines. What are some of the problems? You got to make sure you manage this whole effort properly and make sure that you worry about the ease of assembly. This is something you got to be able to do when you trying to do FMEA and here is a little chart that gives you a comparison of the different approaches to try to these different approaches or the different activities which I utilize to try to make sure you do your design for manufacturing. You got the product concept you got you will be simplifying some of the concepts, you got to look at the requirements of the processes that you need and you got functional requirement which is like where actual actual and it is going to be. That also will be there. So what is the summary of DFM?

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If we summarize this very quickly; it is design considering manufacturing because the eventual goal is to be able to manufacture that product there. What are some of the advantages? We will end up with shorter development time, lower cost, higher quality. These are some of the things coming out of this and there will be fewer engineering changes which will not be there if you do not do not go the DFM route. The approach itself is integrated and of course, this is this is not deigned in a vacuum. You got constant dialog going with the manufacturing unit. So you got to make sure that you maintain this so that problems are not found when manufacturing gets into the act. Problems are designed problems are not discovered when you get into the act there. Tools and methods: These are actually pretty standard now and I have gone through some of those tools and methods there those are the ones you will be using and please remember FMEA is a very important tool and we will be using FMEA as we go into this.

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I have provided you with some references which again if take your time you would be able to probably find most of these in your library.

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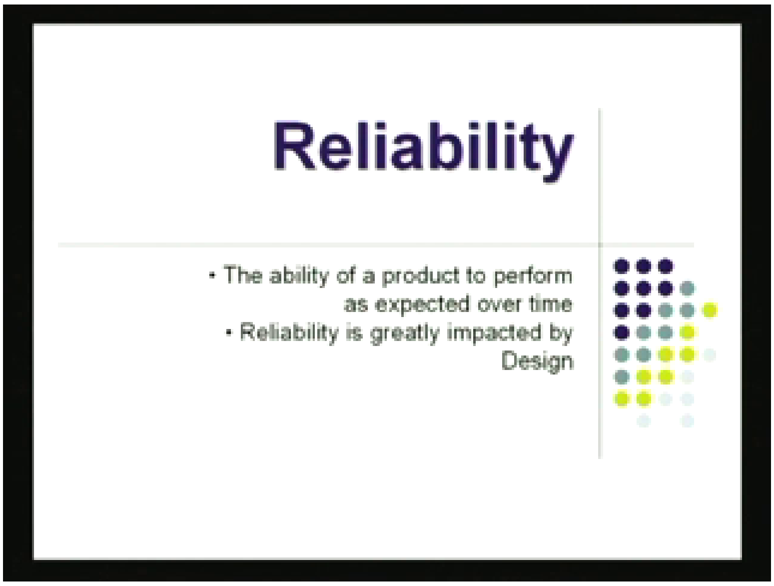


I move on now to this great area called reliability and reliability basically is the ability of a product service in fact to perform as expected over a period of time. So, this is not quality exactly when a when I unpack the item. It is actually not the not the thing that is like the quality of it or the performance as of day zero. It is the performance of the product over the life of the product, over the useful life of the product itself and this is of course, something that is greatly impacted by design. You can make a very big impact on reliability if you design things right.

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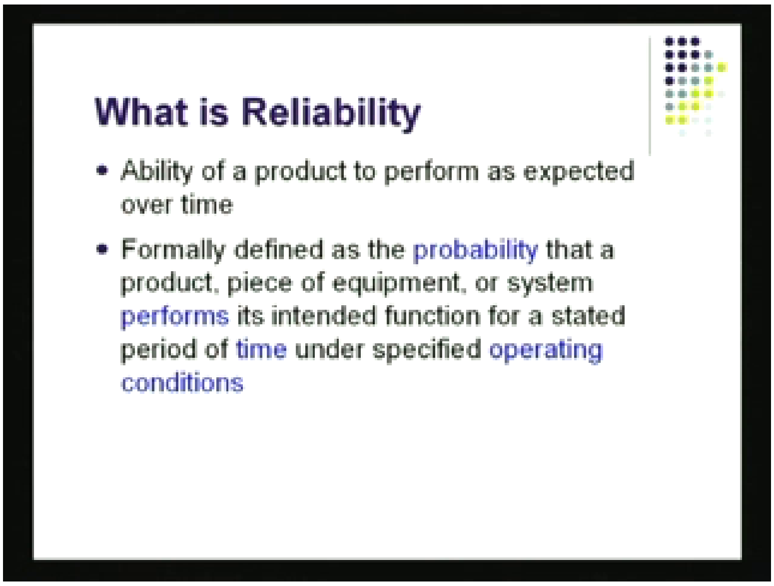


Let us take a look at some of these things. First of all what exactly is reliability? It is like I said is the ability of the product to perform as expected over time. Reliability is also defined as a probability that the product will perform over a specified period of time under specified operating conditions satisfactorily.

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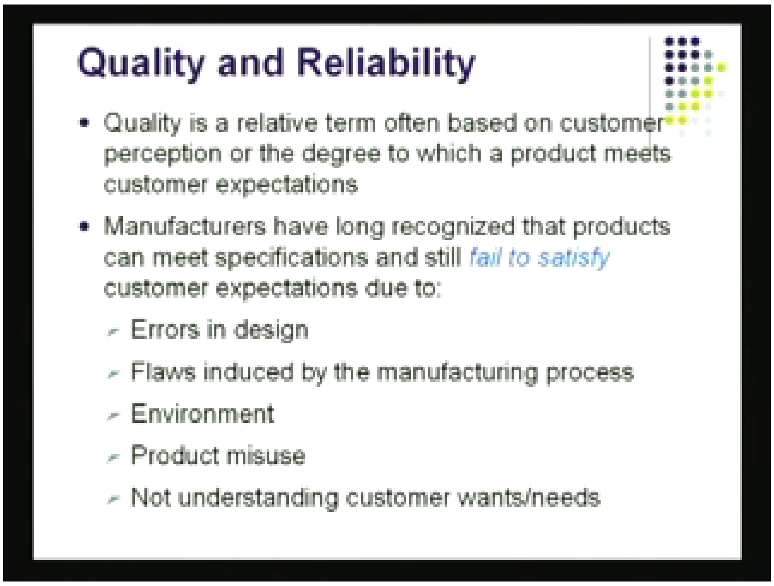


This is something this is if these features are there that product is I would call it a reliable product there. Quality is a term that is also sometimes when you say it is a it is a confused reliability. You got to make sure customer really quality is a term that is basically a customer perception term and reliability is a is basically related to performance. Reliability looks at the chance of preventing failure to satisfy the customer's requirement. So, there could be errors in design that could be lead to reliability questions, there could be flaws introduced by the manufacturing process, the environment could impact and reduce reliability of a particular product, product could be misused that would reduce your its reliability and many times because we do not completely understands the customers wants and needs I could end up with a unreliable product.

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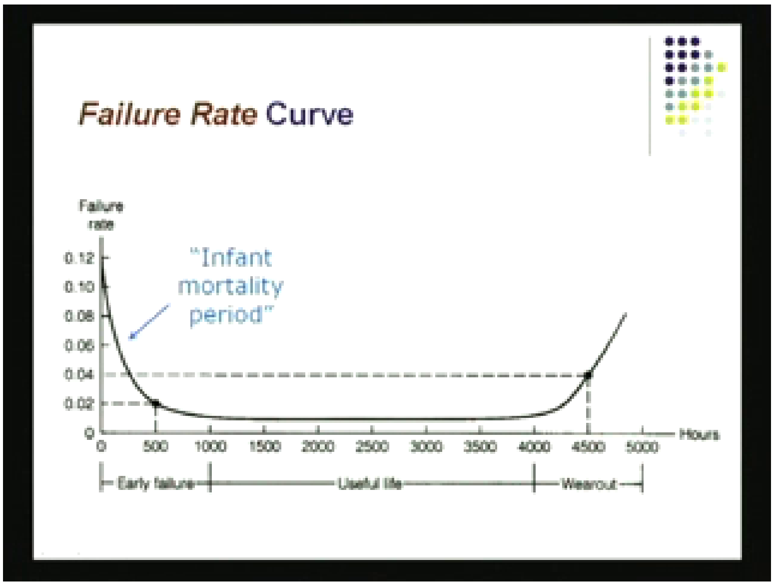


How is reliability presented in by by professionals? Well they say, take almost any product. You take something as simple as a CD which is you know, something that we will be we will be hopefully using without any trouble at all we we just open the pack and start using it. If you look at a thousand of these a few of those will have problems.

And these are the ones that die early. These are called the infant mortality products and this is a small period of time a few product die there and these are generally because of manufacturing problems. And those sneak in they get into the package stuff and you end up with you know with these products when you when you take them home and so on and so forth. So this is, says there is cure for this and that is done by doing this burnin before the product is shipped. Now, this is so the failure rate is pretty high early on and this is the infant infant mortality state. Then you got this service rate, service range and this is exactly this is a this is a region of operation for the product that is got low failure rate and this is exactly why we buy a product. We buy a product to be able to use it like for example, this pen I brought, I hoped to be able to use it for two weeks without any trouble at all because it is life is expected to be couple of weeks when I start using it. I i i use it may be for three four hours a day, it should last me something like couple of weeks. That is like expected. That is going to be this this time there. That is the useful life time.

Then of course, things ware out. For example, the the ink will be gone or the tip the tip itself may become little fuzzy and so on so forth. So, the tip may not be as sharp as it was when I bought when bought bought the pen when I opened it up. Now, this is the ware out period, this is the ware out period failure rates increase here as you notice there. This curve by the way looks like a bath tub. So, it is actually called the bath tub curve.

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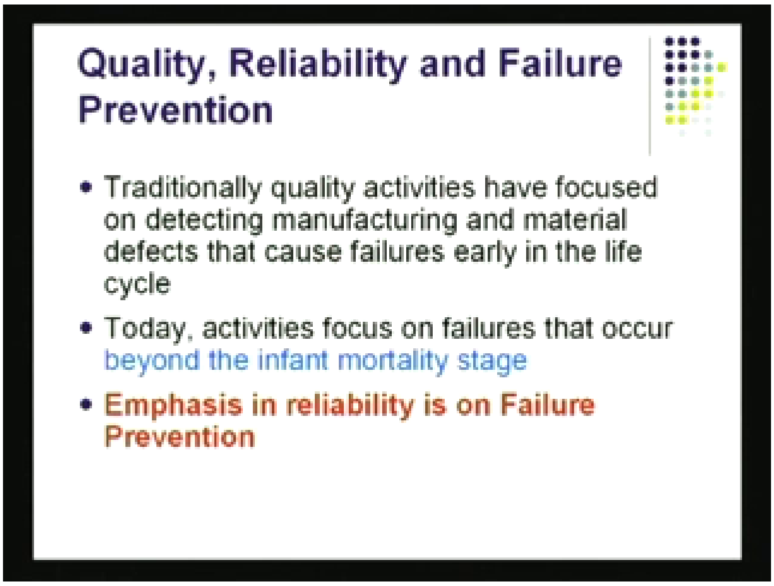


The job of reliability engineering is to try to prevent failures, is to try to do whatever you can to try to reduce failures. This is a mission for this and this is to done beyond the infant mortality stage. We understand that infant mortality is because of manufacturing defects just as you are getting products straight of the alike. Many products who actually will have these problem just a few percent perhaps even if even that. But is the period of use over which I have got to make sure that failures are rather few and next to zero if possible.

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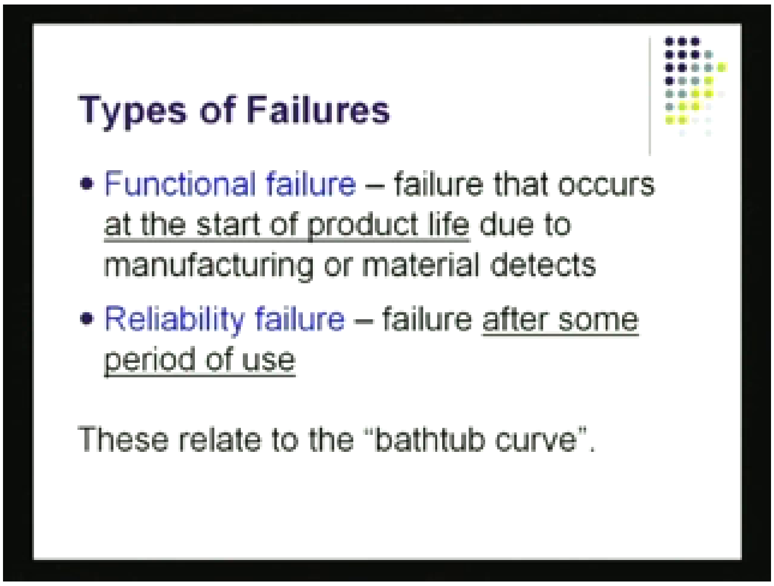


Two types of failures could be there; reliability failure that is like after sometime of use and functional failure takes place almost immediately. As soon as you take it out out of the box there may be functional failures. Like you bought a fan or you bought computer or a laptop or something and it does not function you know, within a within a few days of using it, it does not seem to function right that is a functional failure. A reliability failure is after you used it for six months or a year then it begins to act up. That means the the product is not reliable.

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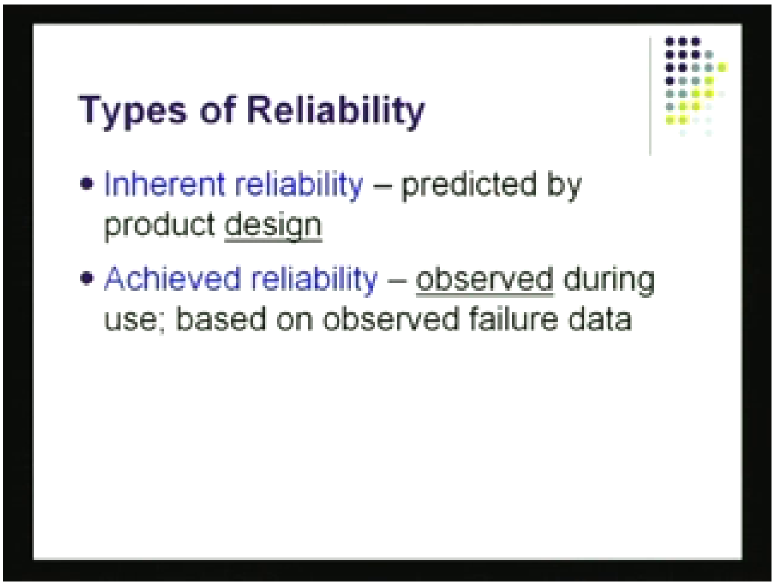


This again is showing by that bath tub curve and there is something called inherent reliability. Inherent reliability can be predicted by looking at the design of the product. There are some approaches by which you can predict the inherent inherent reliability of the product itself and of course, there is something called achieved reliability which is like in the actual site of use the actual location of use.

Therefore example if I start using a laptop or if I start a particular portable disc drive for example, what is going to be the history of its breakdown? Or even something as mundane as bicycle or perhaps a scooter or a vehicle for example, there there will be a designed reliability condition which would be the inherent reliability of the product and of course, there is going to be the achieved reliability and of course, we want to make sure that the achieved reliability is at least as good as the inherent reliability. This is something we would like to be able to do because then customer satisfaction is going to go up.

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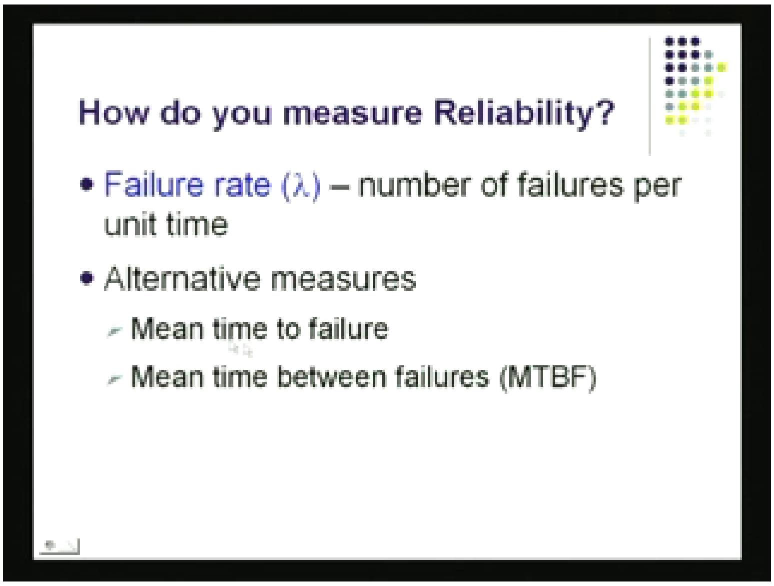


How do I convey this notion of reliability? It is done always by number of failures over time. So, this is this is called the failure rate which I have called lambda here. Notice here, the Greek letter lambda. This tells you the mean mean failure rate which is the number of failures per unit time which could be per year and sometime it could be per month and hopefully it will be over a decade or for large construction project it could be over perhaps one hundred years. How many failures would take place over a hundred years? That is like something you would like to keep your eye on.

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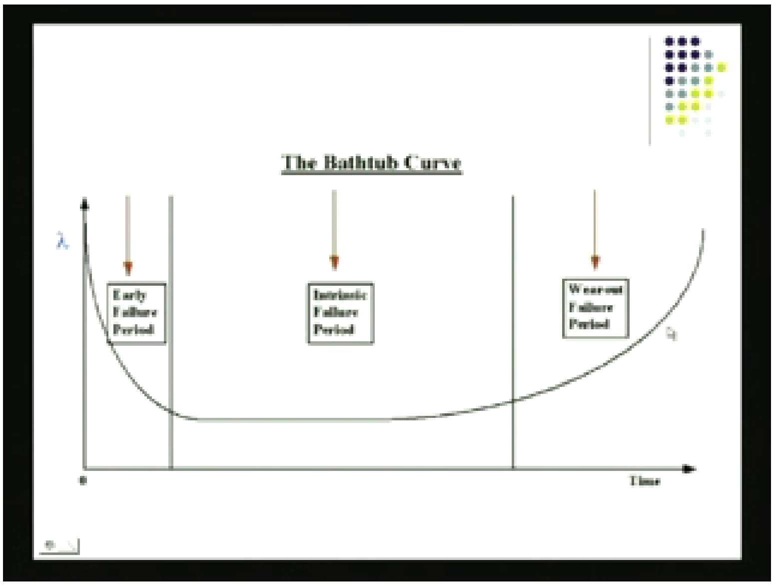


So failure rate is one great indicator of how good or bad reliability is. Some other measures are there; mean time to failure and mean time between failures. These are also measures that are used and getting back again to the bath tub curve again I have got early failure which is when lambda is high. Then lambda becomes quite low in the intrinsic failure period. This is like the service period and then of course, lambda begins to rise the rate of failure begins to rise when you come down to what we call the ware out period.

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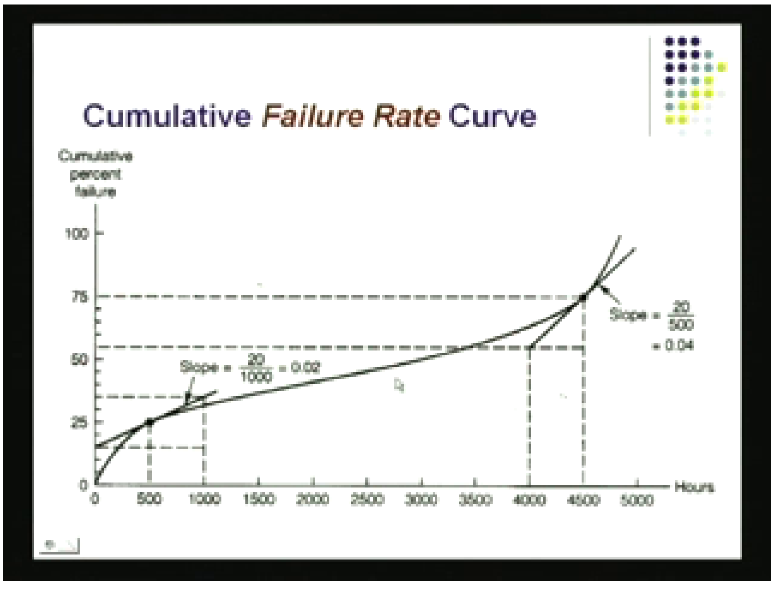


If you look at the cumulative time, the curve turns to flatten out in the when there is not much change in reliability over the service period. Initially there is some decay in decay and reliability begins to improve and then of course, as the product begins to ware out again reliability begins to change. What we would be interested for most most part in the service phase of the product itself that is the part where where this slope is smallest and therefore, there are a number of failures per unit time is also going to be smallest. This is something we would like to be able to do.

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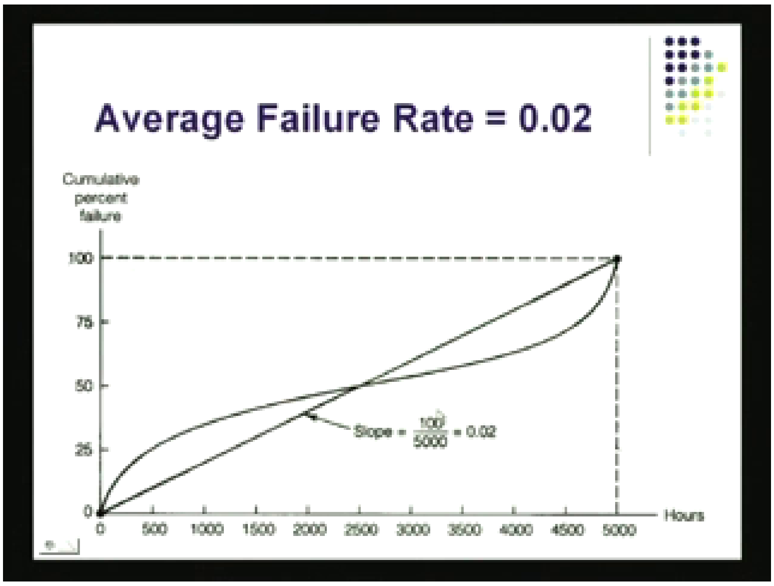


And as far as average failure rate is concerned you span the full spectrum the full life cycle of the product and that will be starting at, in this case starting at zero hours going all the way to five thousand hours when everything completely failed. And that that slope will give you the overall average failure rate. My new the failure rate improve situation would be higher in the beginning and higher toward the end and in between you would be actually enjoy a failure rate that is going to be smaller than the overall average.

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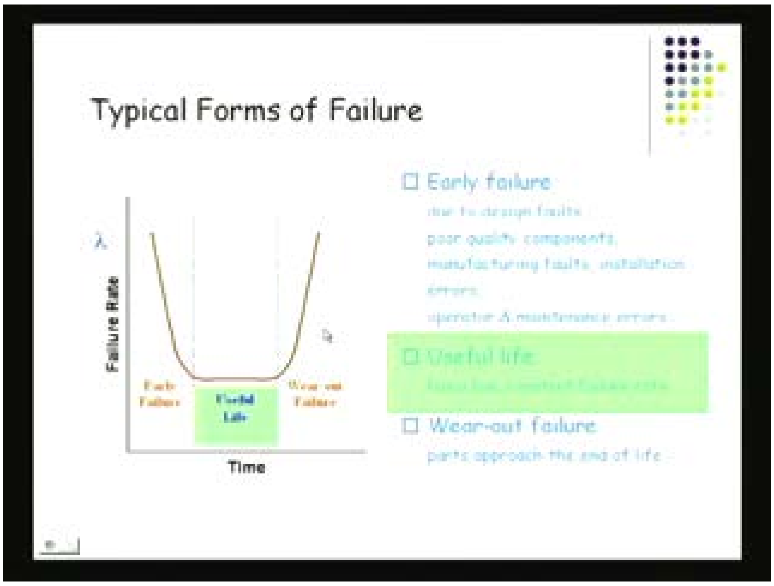


The same thing can be said again if you look at the bath tub curve. There is the early failure period phase. Then there is the useful failure rate, useful life then of course, the ware out period. These are the three phases in almost any product. What your goal should be? You you should a design a product in such a way that the useful life is as long as possible and the failure rate during that useful life is as low as possible. If you do these two things, you are doing good design; you are doing good reliability engineering. Of course, you got to use some strategies right early on to make sure there are not many manufacturing processes are good so that they are not too many early deaths and also you have got a replacement, a maintenance policy in place so that this decay toward the end. And it does not become catastrophic. This is also something you got to take care of but, for most part the reliability focus is on the useful life of the product.

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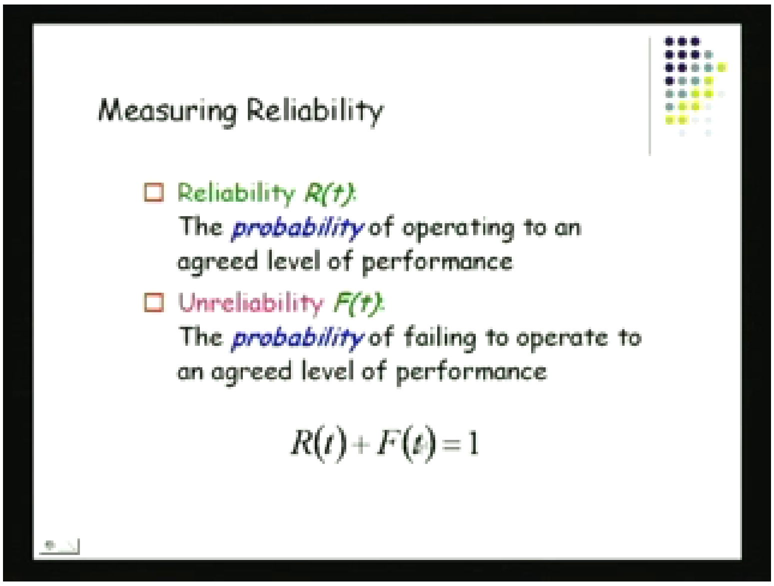


We will take a look at as we go into this measuring reliability. How do you do it? One great way is to look at the probability of operating to an agreed level of performance so were the period of time. This is like r t. r t is the reliability. That is a probability. Unreliability of course, is the probability of failing to operate over that period of time that you you would like it to be a functioning. You would like the thing to be functioning and if you add these two r t and f t that is obviously equal to one. r t is the probability of surviving and f is the probability of failing within before the time t, time period t is over and that is got to add up to one for sure.

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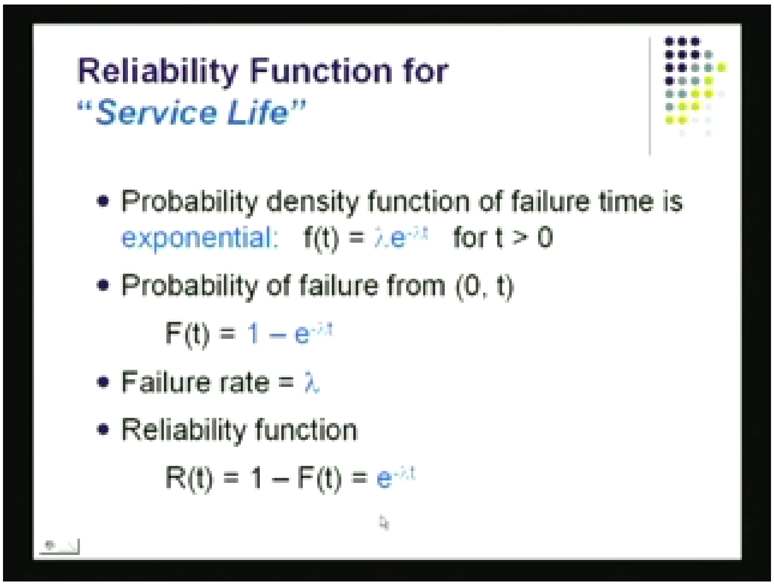


In the service life period; generally speaking your reliability stays the same and lambda becomes a constant there and there the failure time distribution turns out be something we called exponential. You notice here I have shown you the exponential formula there. That is the density that is the density that I actually control to distribution of failure times in what we call the service rates of period itself and the cumulative distribution is shown there. Failure rate is lambda. Lambda is constant in this service period there and the reliability function itself which is the length of time. The the the device operates before it fails that has this exponential distribution.

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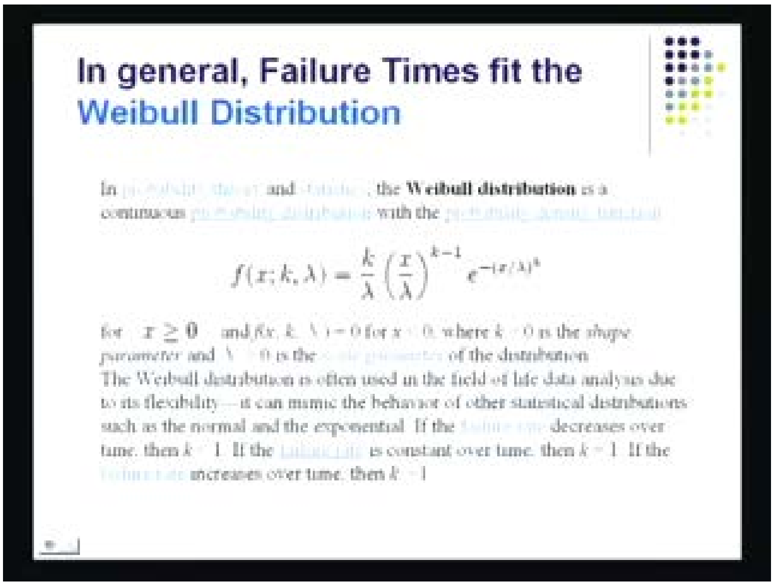


This is how it is now as far as the tail ends are concerned. Remember the two ends of the bath tub curve; they tend to rise. There are special distributions that are applied at the beginning which is like when the early early life, early deaths are there and also when the ware out deaths are there. Then these distributions are different these statistical distributions of failure times are different from that flat exponential part. These two ends they are governed by what we call the Weibull distribution and the Weibull distribution has shown peculiar formula. It also belongs to the exponential family.

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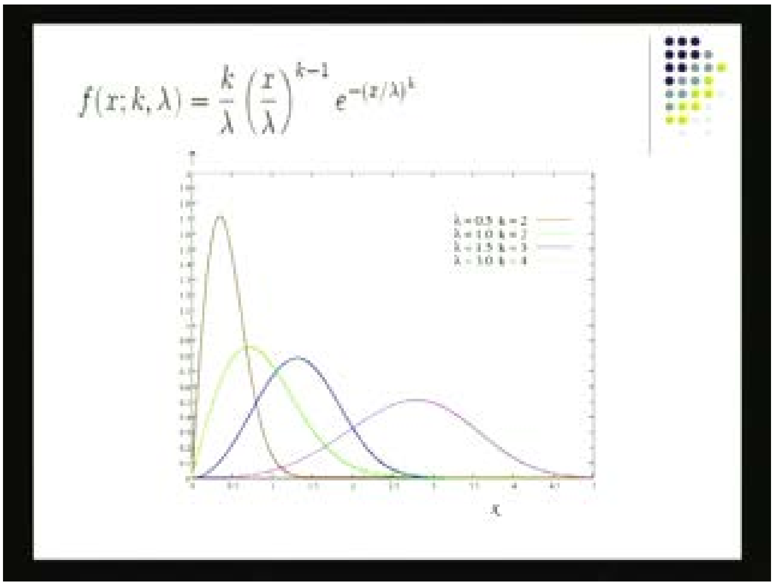


It is a very, very useful distribution. It is a distribution that can be specialized to to a curve that is coming down. It also it can be specialized to a case when the curve is flat the density probability. Density is flat it also can be used to show a arising or a deteriorating situation. All these three scenarios can be modeled by the Weibull distribution. So the Weibull distributions are very, very popular distribution in reliability engineering.

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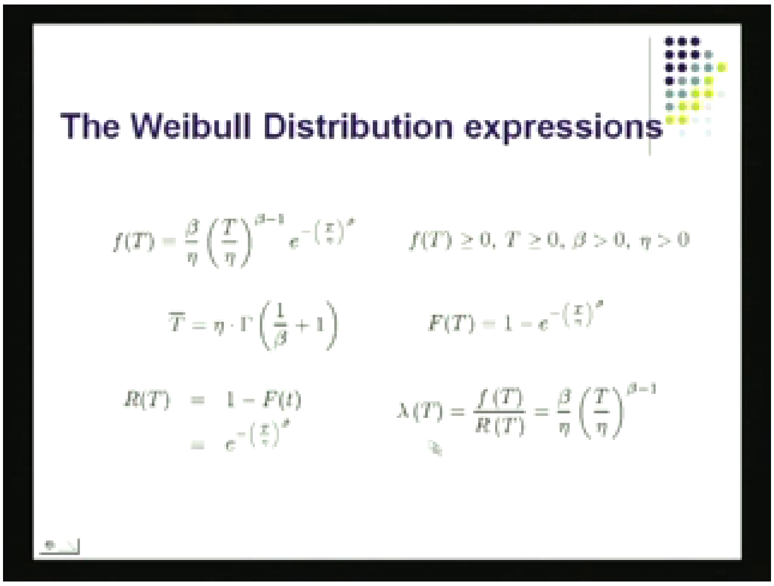


I have shown you the formulas I showed you the density and and also I show the average times and of course, I show you the completed values of the reliabilities. Those are those I showed and I show you the meantime to, I i show the meantime to failure distribution and also I show you the the rate of failure.

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Those are all shown here. If you got real data if you got life testing data which means if your listing starts with a total of two thousand products and these could be a light bulbs and you would like to establish this bath tub curve for it. What you really have to do is, get these two thousand lamps and at some point in time, light them up. Put some power into them and light them up and then you just make till the first one fails, the second one fails, the third one fails and so on so forth and keep a count of this as time goes along.

So let us say if you are doing this by an hour and you are doing this by an hour and you are keeping track of how many failed. So in the first period six hundred and fifty of those lamps went out and the next three fifty went out and the third two hundred and ten went out, forth hundred and sixty six went out fifth, one thirty one went out and so on and so forth. And toward the end again it begins to rise now this if you can actually see this is kind of like your bath tub curve it is kind of like that bath tub curve there. Initially you got you got to coming down, coming down then it becomes this somewhat flat, then it begins to rise again. You you are able see this bath tub curve business there and then I show here the different columns. If you come towards the end of the table here, you will end up finding the reliability and you notice there reliability test will become flat and low at a certain point in time. This is something that you can see very, very easily you are able to see that as you as you look at look through these numbers there. You will be able to see that and f t is of course, the cumulative probability that that an item would have failed by this time. And then of course, when two thousand hours are up; everything dies and all the components are gone, all the lamps are gone. So, this this mode of collecting data by doing life testing is a is really a big tool to try to establish reliabilities some products that you produce in large quantities. If you could do life testing on them you'll be able to come up with for example, warranty warranty period estimates and so on so forth. That something you should be able to do this.

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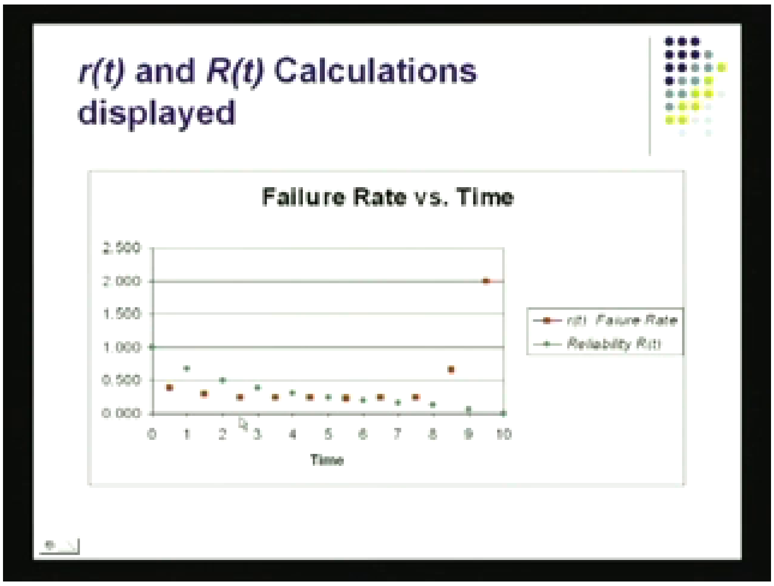


If you look at this pictorially; I have these red dots here and that tend to show you the failure rate. The failure rate is shown here and the green line, the green dots they connect their reliabilities. So notice here the reliability begins to come down and down and down of course, reliability in the end nothing survives so that that thing is gone there. So these two show these two show how failure rate changes. It was somewhat how in the beginning then it become low then it began to rise again. This is something you should be able to figure out by looking at the life testing data and of course, the other things which you should be able predict reliability also with this. Most of the time the period in which you have interest is the middle middle period which is like the flatness on that bath tub curve. That is you would like to able to do.

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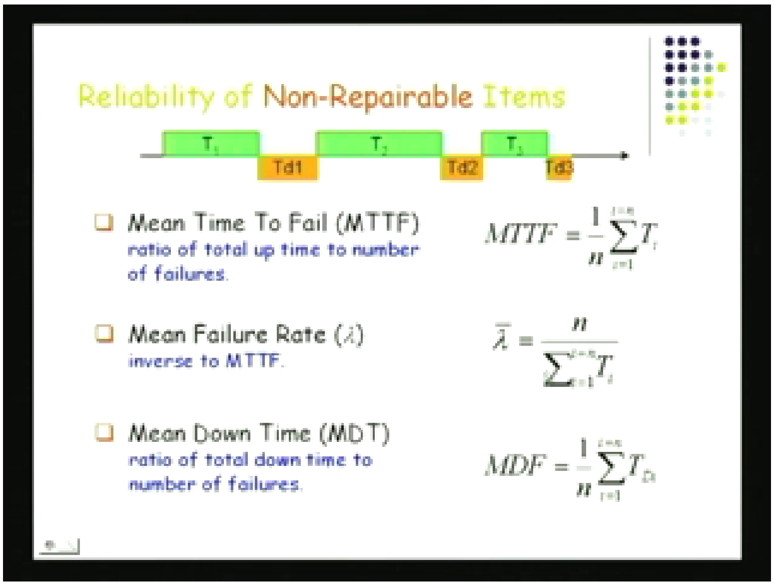


The mean time to failure for non-repairable items those are shown by the formula which is here. t one is the time period over which is the working, t d one is the down time for that then you are replaced that for another item which is item number two. And it operates for t two period of time. Let the time and t d two is the period for which it is done. Now, these are non-repairable that means I am not doing repair but, I am procuring other item there. If I do this i am I am able to end up with something that I call mean time to failure which is like the some of these t i's divided by the total number of failures to impress. And mean time mean failure rate would turn out to be just basically the inverse of this. That will turn out to be mean failure rate and that means down time that we would like the period over which the thinks have been down because I am i am procuring a new product there. This is a non-repairable product.

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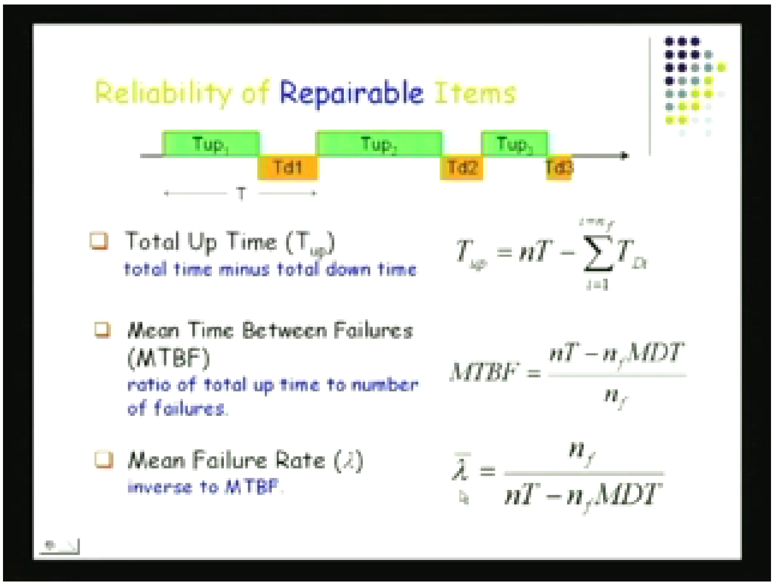


If I have got repair repair repairable items there, repairable item basically means that I am repairing and putting back the same item again and again again and the the formulas are giving here. Again I have got mean time between failures the formula is shown here and the failure rate that also is shown here, the mean failure rate is also shown here.

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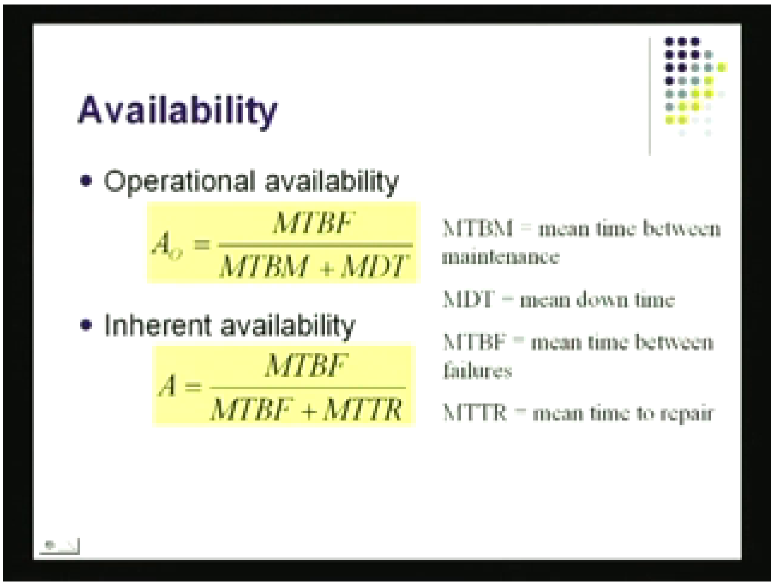

These are matrixes which are used quite often in doing reliability engineering. Then you got something call a variability which is like the period of time over which a product is available and you can actually utilize this and that is m t b f divide by m t b m. That is the time between maintenance plus the mean down time. These are together, that covers you the total time covers the total time them of course, you got m t b f mean time between failure this is actually your availability time. Then you got something called inherent availability which is like m t b f divided by m t b f plus m t t r .m t t r is mean time to repair because here we are repairing and putting the back for a putting the system back get a zero and a naught and a these become our availability figure and these basically should be pretty high. For example, if you got a generator, if you got a standby generator that produces electricity when power is out you got to make sure the availability is right there and same thing would go for almost to anything that comes along comes along as a backup. You got to make sure the availability is right up there.

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Design for reliability: This is something you got to keep in mind and this influenced a lot by element selection. The components that you buy, components that you put together, the environment, the complexity of the product itself and any kind of redundancy that you would like to be able to do. Let us see how this is brought together in a system.

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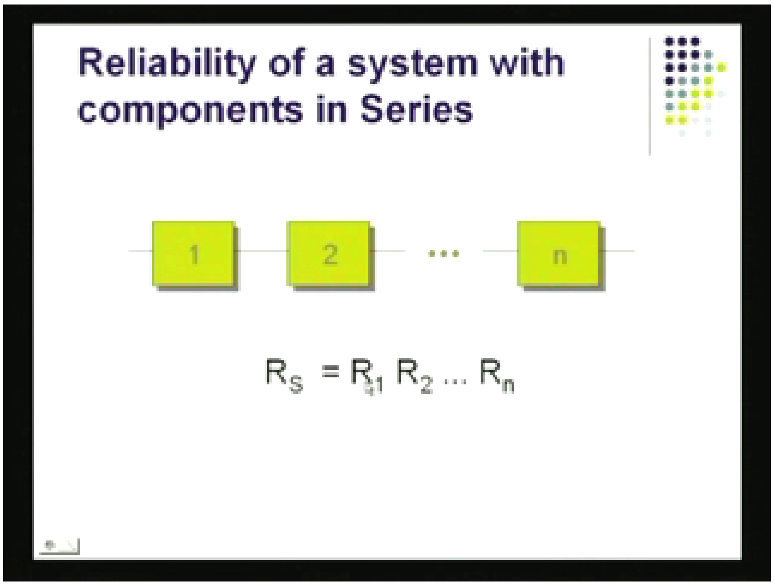


The reliability of a system really depends on how it is configured so that configuration could be either in series; you got the components all laid out in series. If any of those components fails; the whole system comes down. So if any component fails and the whole system comes down most likely the components are connected in series. That is like the picture that I show here. Here the reliability of the system which is the probability that the system is going to survive, is going to be up and running for period of time over which you are doing the evaluation. It is going to be the product of every one of them surviving for the period of time. So reliability of system is equal to r one times r two times r three and so on and so forth.

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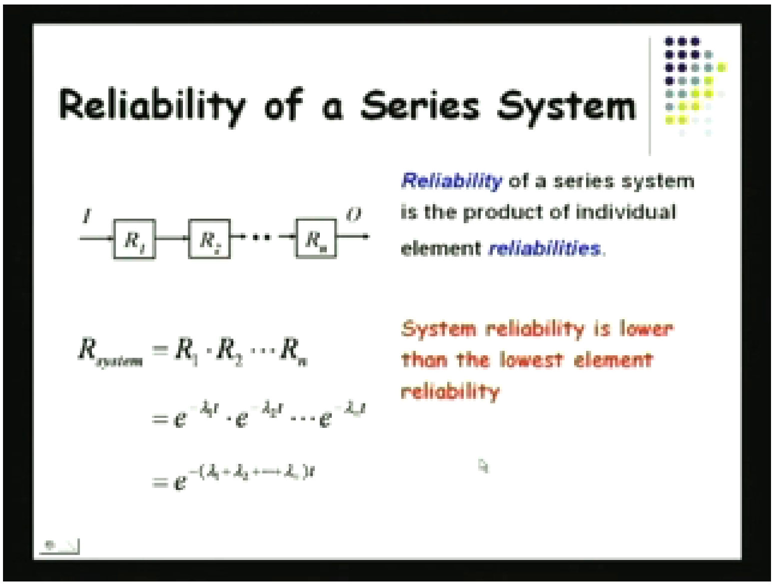


Any of these r’s of course, are what we call one minus the probability of failure. If I do the same thing there let me show you how it works out. Let’s say the component themselves have failure time distributions which are exponential. Then the reliability turns out to be one minus f t and let us let me just write a little formula here for you.

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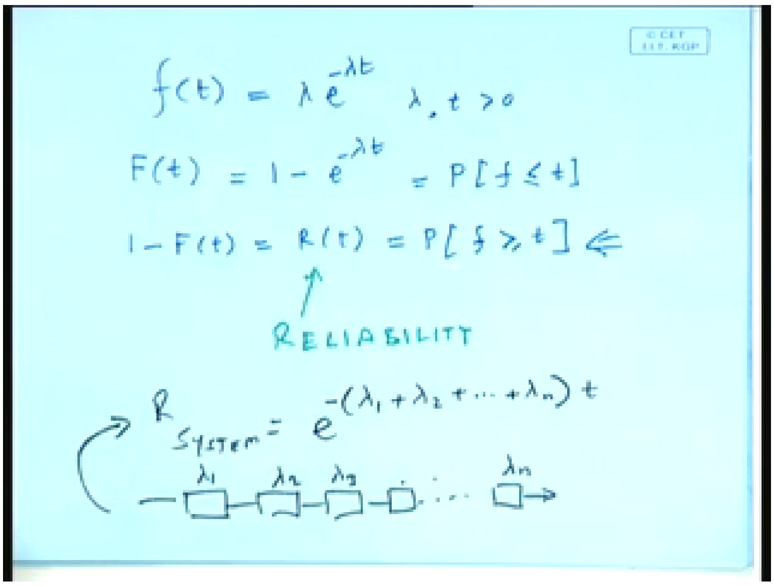

F t is lambda e minus lambda t. Well lambda and t are greater than zero. This is the distribution of failure time. If that is the distribution of failure time then the probability that the item will fail before time t is up. This is one minus e minus lambda t. This is the probability this is the probability that a failure will take place. Therefore, time t is up then therefore, what is the probability that the product will survive? It is basically one minus f t. This is the probability of this is called reliability, this is the probability. Then the product is going to fail beyond t, beyond time t and this is exactly what we want. We want this to be as high as possible this is my reliability, this number is reliability. And if a system is in series, if a system is is in series then this reliability turns out to be this r system. This turns out to be e to the power minus I have got lambda one plus lambda two plus and so on and so forth plus lambda n multiplied by t. And this is going to be for a system that has got component which are like this. They are connected in a series and thus the full system, this is lambda one. Failure rate here is lambda one, lambda two, lambda three and so on and so forth and this is lambda n if this is the picture the reliability of this total system is going to be this.

This is a clearly simple easy to remember formula when every component must survive in order for this system to survive and this system is the full system. This total thing is the full system. This is what you see on the screen there. I have got I two o connected provided all of them are surviving the picture is slightly different when you got things in parallel. Then of course, any one of the components they are parallel. Any one of the components surviving would actually need that you got a reliable system. Any one of the components surviving, any of the components surviving would mean that you got to reliable system there and there of course, the failures will takes place if all of them fail. Therefore, the chance that the system will fail is the first one fails and the second one fails and the third one fails and so on.

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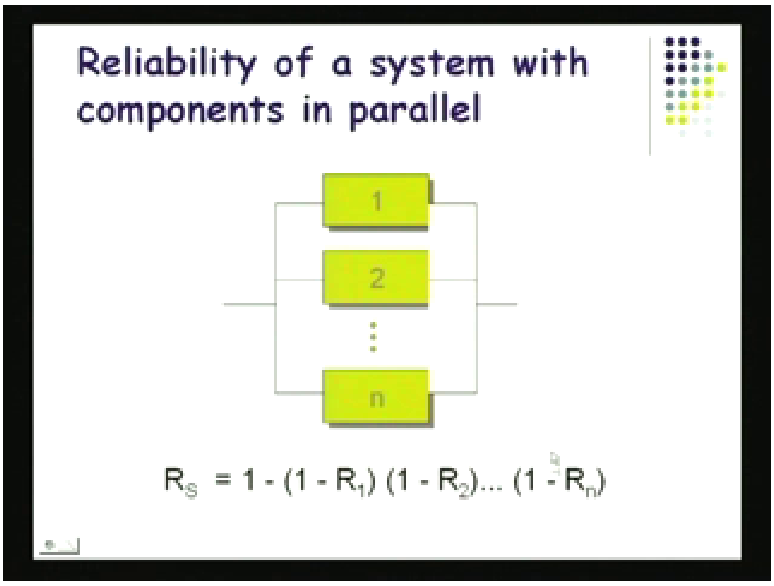


So here it is going to be a slightly different formula. Look at the look at the probability here. System probability is equal to one minus the chance that the first one failed and the second one failed and the third one failed and so on so forth all the way. If I convert this into our exponential formula; it gives us this expression it gives us an expression which is like this. This gives us the system reliability.

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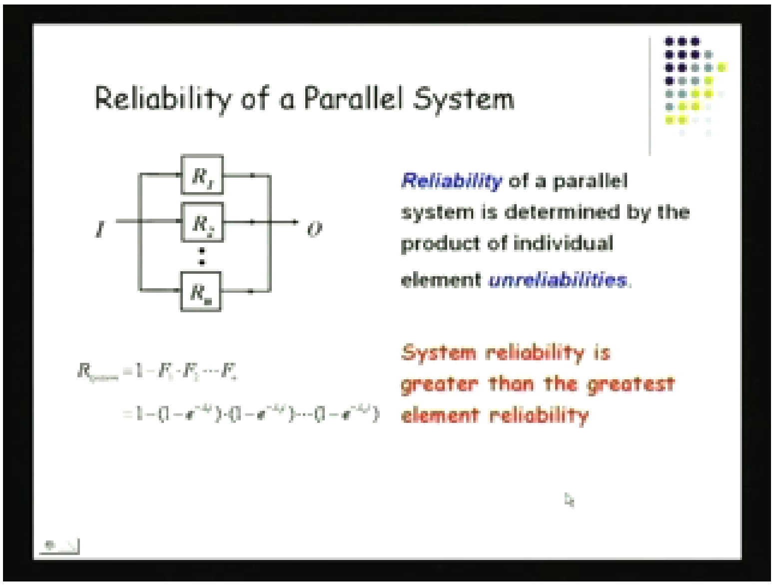

So it actually says the more components I have in parallel; the higher will be my system reliability when systems are in parallel. And this is why we provided redundancy. Whenever we provide redundancy in the system we make sure that system the additional component they come in parallel and they are they are really at standby situation or they might be even be functional but, they are still in standby situation. So, if the main component breaks the second main is going to come kick in and he is going give the the reliabilities I want. If I have got a complicated systems such as I have got a mixture of some parallel and some series components, if that is what a configuration like the rule of thumb is convert everything; convert all the parallel items, calculate the, compute the total reliability of all the parallel systems, replace that total parallel system by one component now which is equivalent of that parallel system there. Then put things the rest of them is in series and this exactly what has been done here.

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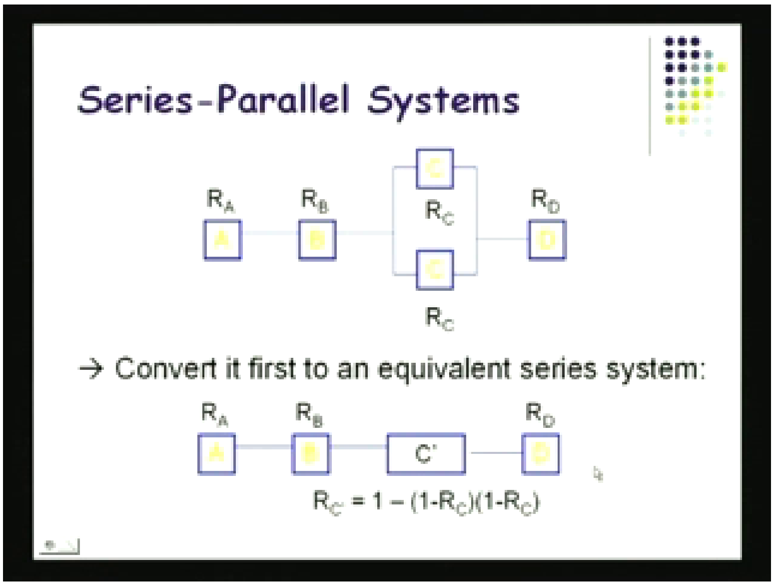

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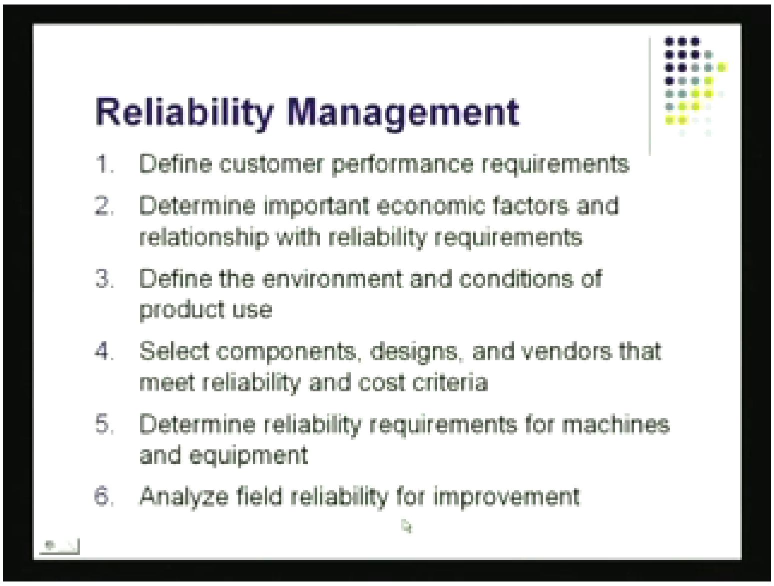


These two components they are in parallel so they have been replaced by this c prime. c prime is the equivalent of this guy there and the rest of them they are in series and therefore, I have got now my probability of the total thing coming like this and this is what it could be like. Reliability management how do you end up managing reliability? Start with your customer performance, start with customer performance determine the importance of the economic factor that might be like for example, down time what it is going to cost you, define the environment and the condition of products use, select components designs and vendors as that you you really meet your reliability criteria and the cost criteria. Both of those you got to be able to take a look at. Determine the reliability requirement of machines and equipments. This is something you got to be able to do. If I am trying to manage reliability and analyze field reliability, you take a look at actually performance and just see is that good enough for me.

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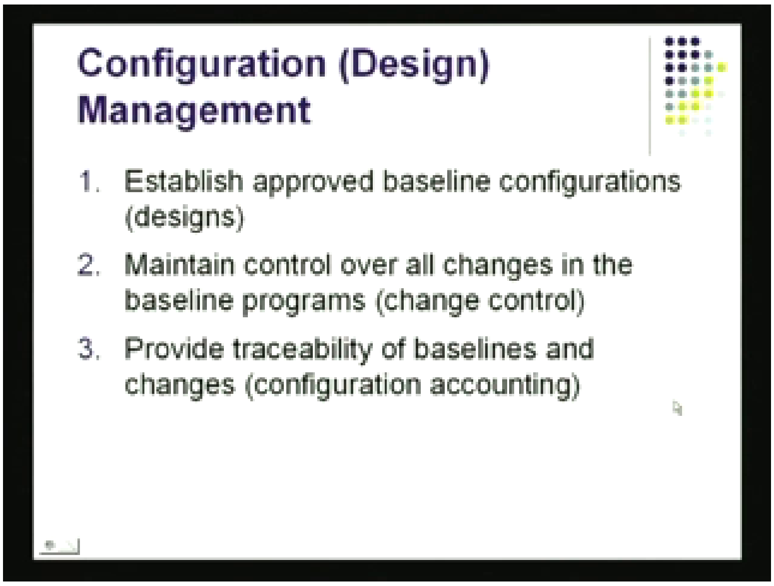


Configuration is design management basically certain things are done which is like establish procedures. This is something you should be able to do and I have listed them out here and I have listed out some more things.

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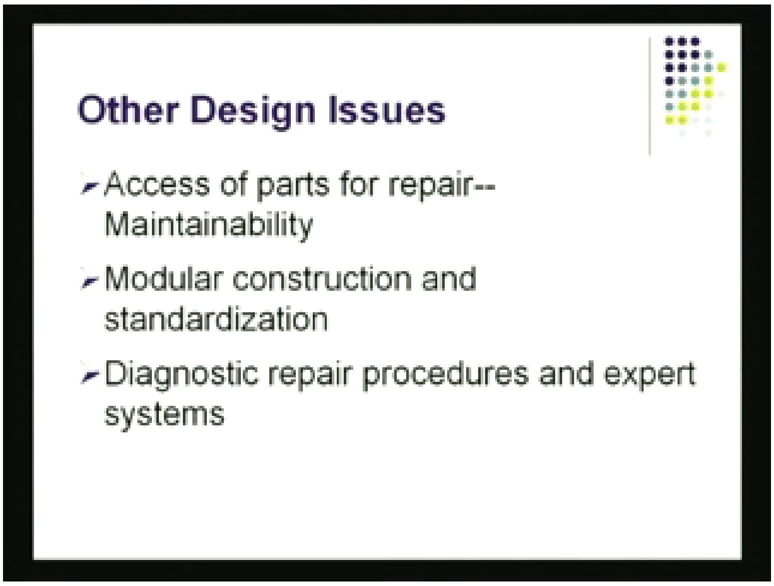


Other design issues also are there for example, maintainability that is like a big huge issue in a design.

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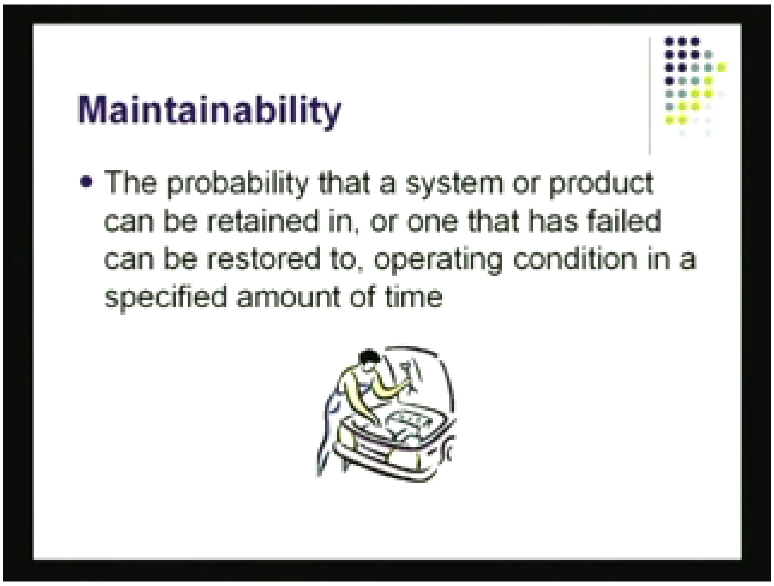


If I put a system together; I should be able to repair it. I should be able to reach in to the parts, I should be able to do it. So, you are trying to change a oil filter for example, you should not have to hide the car, you should be doing do it from the tap. You should be able to do it reach reach there and do it many times. What is happening now is you got jumbled of wires and tubes and pipes and everything else and it does not really become easy to maintain. And certainly modern cars they have they have really gone over board. This way and the older cars I must admit they were very easy I mean, the most of the thing parts were easy to access. May be the performance was not as good boundaries, the the layout was such that you could you could do it quite easily. This is something you got to keep in mind.

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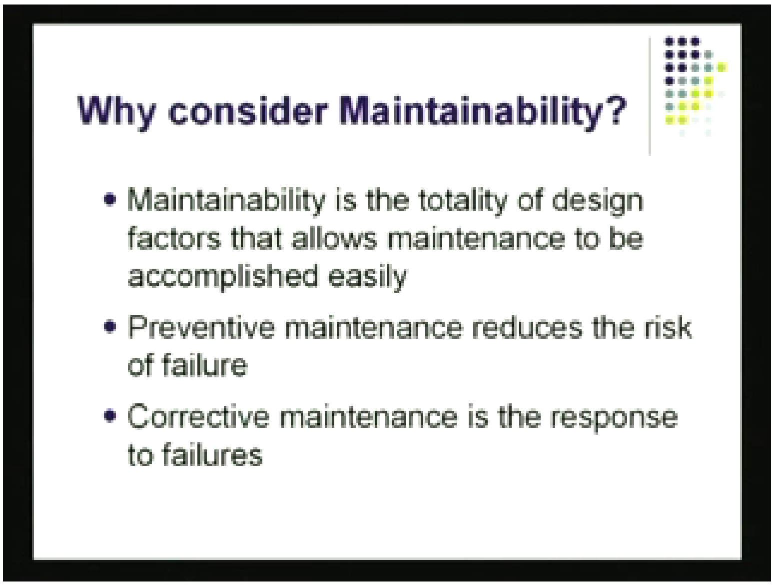


Why consider maintainability? If you do not do that, the total cost of down time is going to go up and if you are not able to maintain the car then, you will be doing less preventive maintenance and its going to raise the risk of failure. Corrective maintenance actually is done in response after the failure is taking place. Then you will do corrective maintenance.

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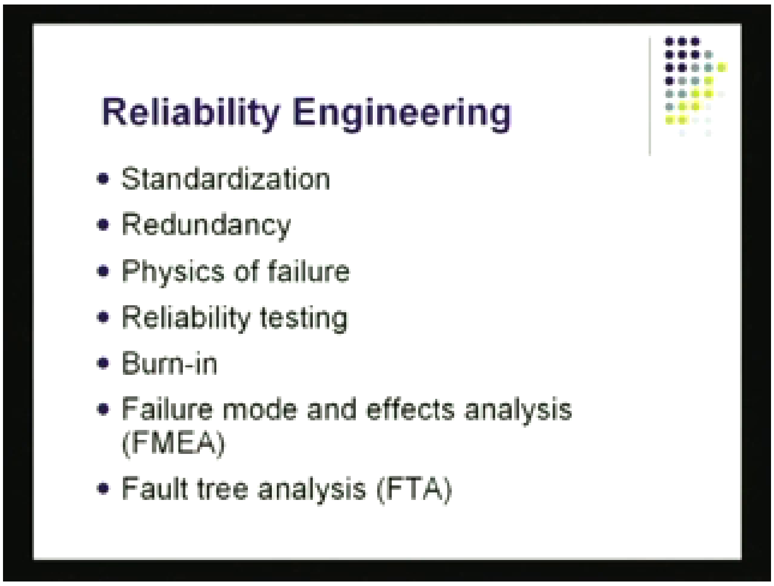

This is something you should not have to get into when there is some other tool called FTA.

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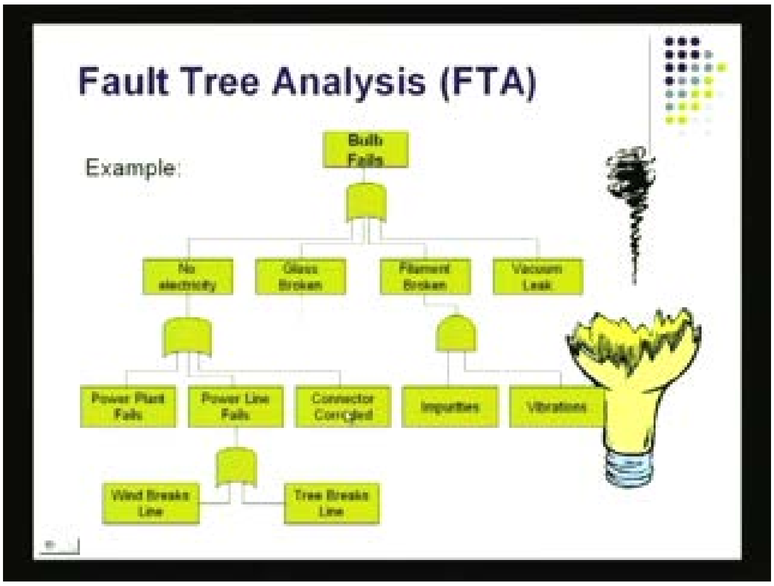


FTA is a fault tree analysis. If something fails; take a look at its component and see how they are configured together. The the if the bulb fails as an example the bulb fails, if there is no light it could be because of no electricity or the glasses broken or filament is broke or vacuum leakage there that is why the bulb failed? There is there is no light then you look at filament. Why did the filament break? Maybe there were impurities or there was a vibration. There was some vibration that caused it. No electricity. What could have caused this? Power plant had a failure, power line had a failure or the connector got the, connector got corroded. Many times this happens. When you got a got a vehicle and you have really looked at the battery cables for a long time, the battery electrodes for a long time and they may began to corrode because the acid is there in stuff of and you may not be washing it cleaning it and so on and so forth.

So that will lead to that. A power line of failures what could it what could have caused it? or tree could have fallen on the line or perhaps wind probably led to that. So this would this will lead what we call the FTA.

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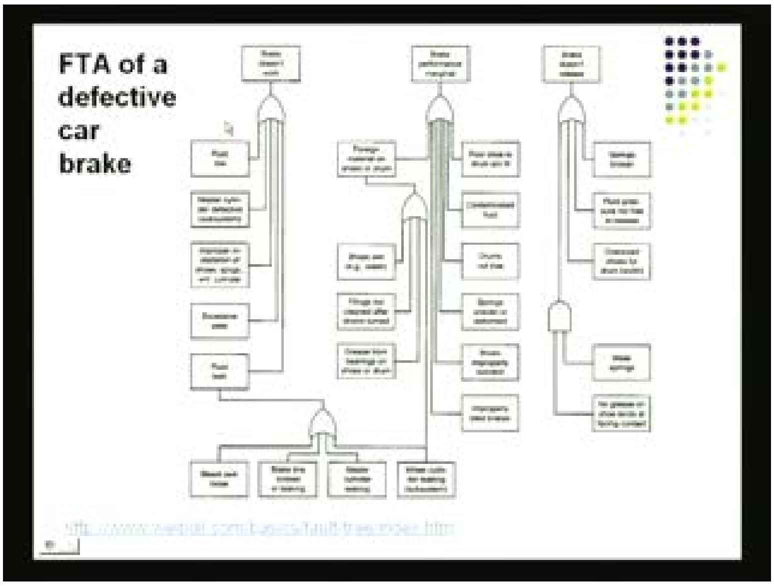


A car break for example, it would not work because of many things, any of these things. Brake performances marginal or brake does not release or the brake does not work, any of these things could have been caused by any of these components there. So this is what we call a fault tree. A fault tree is is a tree built of various thing that could go wrong and either they kind of work in parallel or the work in series. So you could have a or situation or you could have a and situation which is like something you know would not be functionally if all the components are not working. That means all the component means none of them is is working and then if the system fails of course, you got one particular situation and if anyone coming down brings the whole system down that means things are in series you got to approach it differently.

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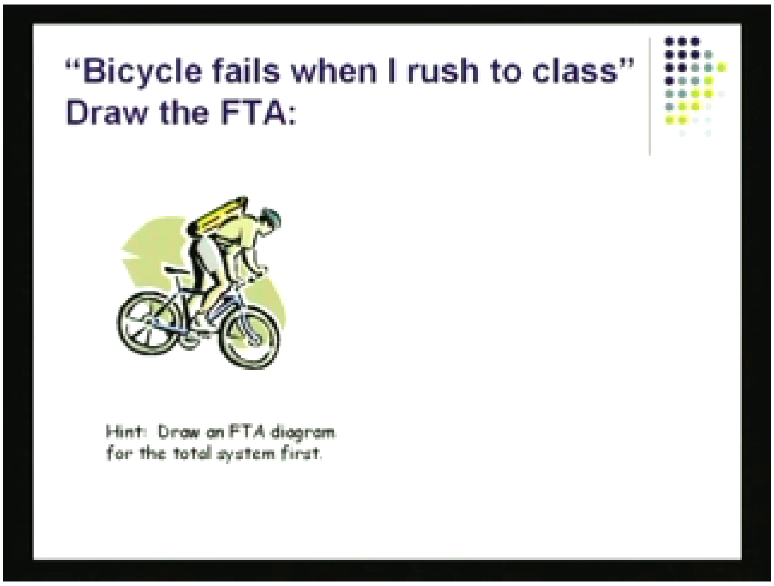


So this were fault trees become very, very handy and what I would like to able to suggest is that you take a look at your bicycle. And you try to draw an FTA diagram using that and this is an exercise you should try to complete before you move on to the next class. So please you know think of the bicycle, try to construct your FTA from it. I said for some reason I wanted to rush to the class but, I could not do it because my bicycles stopped functioning. Well, something went wrong and you will start with different ways, it could fail different modes by which you could fail and then see what what could have caused it. Either the the the another I had puncture or the chain broke or something broke or something jammed and so on and so forth or perhaps the ball bearings have gone or something; you got to figure that out. So try to do an FTA before you go further and we will continue with our discussion of FMVA in the following following lecture. See you in a few, see see you in a little while. Thank you.