Introduction to Reliability Engineering
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Lecture 01
Introduction to Reliability Engineering

Good morning, everyone. I welcome you all to the first lecture of the course introduction to reliability engineering. During this eight-week course, we will cover the fundamental concepts of reliability and emphasize their significance. Specifically, we will explore how probability and statistics contribute to assessing reliability indices. So, in this first lecture today, we will be discussing basic terms, definitions, and why they are essential.

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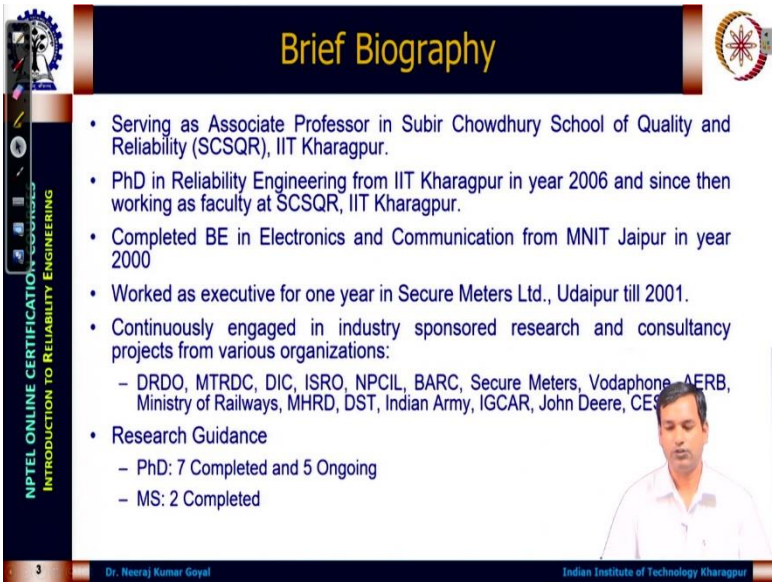

Allow me to provide a brief introduction about myself. My name is Professor Neeraj Kumar Goyal, and I hold the position of Associate Professor at the Subir Chowdhury School of Quality and Reliability at IIT Kharagpur. I earned my PhD in Reliability Engineering from IIT Kharagpur. In the year 2000, I completed my BE in Electronics and Communication from MNIT Jaipur. Additionally, I worked at Secure Meters Limited in Udaipur for one year, from 2000 to 2001. I have done various research and consultancy projects for multiple organizations like DRDO, MTRDC, DIC, ISRO, NPCIL, BARC, Secure Meters, Vodaphone, AERB, Railways, MHRD, DST, Indian Army, IGCAR, John Deere, CESC et cetera.

I have guided few students like 7 PhD has been completed, 5 are currently going and 2 MS have been completed.

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Publications

- Books:
  - Early Software Reliability Prediction: A fuzzy logic approach
    - Authors: Ajeet Kumar Pandey and N.K. Goyal
    - Publisher: Springer, 2013
  - Artificial Neural Network Applications for Software Reliability Pre
    - Authors: Manjubala Bisi and N.K. Goyal
    - Publisher: Scrivener Publishing, WILEY, 2017
  - Interconnection Network Reliability Evaluation
    - Authors: Neeraj Kumar Goyal, S. Rajkumar
    - Publisher: Scrivener Publishing, WILEY, 2020
- Papers
  - International Journals: 44
  - International Conferences: 13

Consultancy Projects

#	Project Name	Sponsored By	Period
1	Reliability Work Package of LRSAM	DRDL, Hyderabad	2007-08
2	RAMS Model for Project ASTRA	DRDL, Hyderabad	2007-08
3	Shutdown PSA of KAPS	NPCIL, Mumbai	2007-08
4	Accelerated Life Testing of 30-pin Connector	BARC, Mumbai	2008-09
5	Flood PSA of KAPS	NPCIL, Mumbai	2009-11
6	Assessment of Residual Reliability of Armored Fighting Vehicles through CBM	MCEME, Hyderabad	2010-11
7	Advance Studies on Human Reliability Analysis	NPCIL, Mumbai	2012-13
8	Reliability Modeling and Prediction of Process Control System	DRDO, Panagarh	2012-13
9	Reliability Assessment and Improvement	Secure Meters, Udaipur	2014-15
10	Preliminary Risk Analysis of Hypersonic Technology Demonstrator Vehicle	DRDL, Hyderabad	2014-15
11	Flood (Internal and External) Probabilistic Safety Assessment of MAPS	MAPS, NPCIL, Madras	2015-16
12	Application of RAMS concepts for HHP (4500HP) Diesel Locomotives	DLW, Varanasi	2015-16
13	Reliability Assessment and Reliability Improvement of Products Designed	Secure Meters, Udaipur	2015-16
14	Reliability Work Package for Project LR-SAM	DRDL, Hyderabad	2015-16
15	Reliability Assessment and Reliability Improvement of Products Designed	Secure Meters, Udaipur	16-17
16	Standard Based Reliability, Prediction of Submarine Degaussing System	L&T Ltd., Mumbai	17-18
17	Software Quality and Reliability	John Deere, Pune	
18	Reliability Study of RUSTAM-II	ADE, Bangalore	
19	**Resiliency Modeling and Analysis with Recommendations for Overhead LV Distribution Network of CESC Ltd. in Kolkata Region**	**CESC, Kolkata**	

Research Projects

#	Project Name	Sponsored By	Period
1	Design of Minimal Cost Backbone Network Layout for Given Capacity and Reliability Requirements	VICET, IIT Kharagpur	2009-13
2	Reliability Assessment of the Large Complex Computer Code	AERB, Mumbai	2009-11
3	Reliability Assessment of L40 Stage Assembly and Integration Process	ISRO, Bengaluru	2016-19
4	Reliability Studies on Electronics Power Conditioning (EPC) of Microwave Power Module	MTRDC, DRDO, Bengaluru	2015-16
5	Developing a Reliability Engineering Framework for Indian Railways Rolling Stock	DST	2016-20
6	Reliability Studies on Electronics Power Conditioning (EPC) for Space Application	MTRDC, DRDO, Bengaluru	201
7	Quantification of Software Reliability for Computer-Based I & C Systems of Prototype Fast Breeder Reactor (PFBR)	Indira Gandhi Centre For Atomic Research (IGCAR), Kalpakkam	2
8	**Design, Development, Verification and Reliability Analysis of Prototype Control Room HMI Software for Fast Breeder Reactors**	**Indira Gandhi Centre For Atomic Research (IGCAR), Kalpakkam**	

I collaborated on a couple of books with my scholars. So far, we have authored three books, the first one is on software reliability and early software reliability prediction utilizing a fuzzy logic approach. The second is on artificial neural network applications for software reliability prediction. The third book is on interconnection network reliability evaluation. Then I have also written a few papers, around 45 journal papers and 13 conference papers. Here is a collection of consultancy and research projects we have done.

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So, before we begin this lecture and delving into the details of reliability engineering, we will first go over some basic words and definitions that will be utilized throughout this subject.. There are four basic terms which are used for performance evaluations like reliability, availability, maintainability and safety. We will discuss these one by one.

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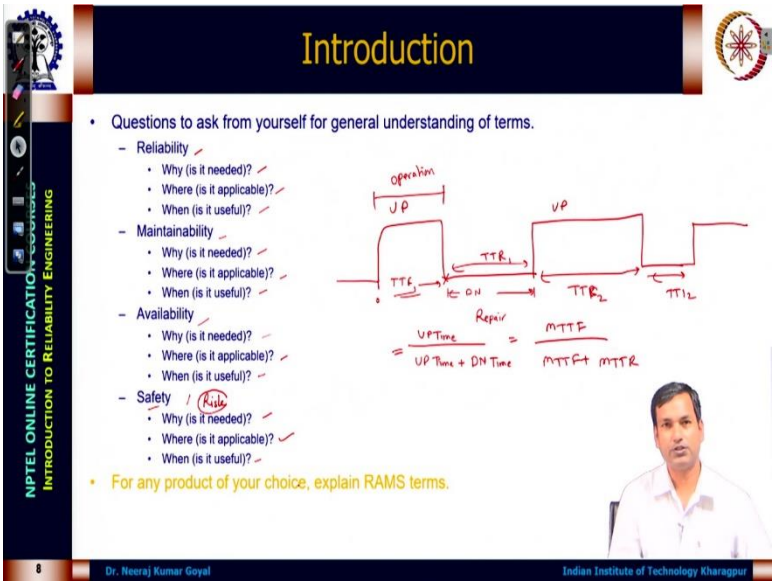

Before going into detail, we will first discuss what is meant by these terms. So, here we aim to develop a general understanding of what are these terms and how they can be used for our purposes. Before going for these terms, let us also discuss where these relevant engineering concepts are applicable. Reliability engineering concepts are generally applicable to most of industries as well as general life. In industries, we need to apply this concept of why the reliability concepts of becoming more and more beneficial for the industry people like nowadays we have a demand for RAMS engineers. RAMS means reliability, availability, maintainability, and safety.

We also have a high demand for reliability engineers. Now, what do these engineers do? These engineers try to evaluate the product, their life, and the possible problems the product may face during their lifecycle and try to predict them. We also try to address those as much as possible during design, manufacturing and operations or the maintenance phase. Here knowledge of reliability engineering helps any organization to grow. Nowadays, like earlier we used to have systems which have been very robust, which have been very simple. So, dependency on the human being was also not very high.

These days systems are complex. That means they have multiple devices; they have multiple components, and they are interlinked together. Nowadays these days we also talk about the multidisciplinary field because any system is not purely electronic or purely mechanical. So, there are not only multiple components, there are also different types of components that are coming together to do certain functions. Now, why reliability comes into the picture is that when these products are made by any organization, they can be sold to the customers.

So, let us have general electronics and general home-use products. If these products do not work correctly for a sufficient period, for example, if we get a TV at home and within three months, it fails. We will be very dissatisfied with the product and may not be using the same product again. We will also not be recommending the same product again. Therefore, it is essential that the product we are making are not only able to do the task but they are also able to do the job for a more extended period of the time.

So, the design life concept comes into the picture that the product is not only designed for doing certain things; they need to do those things for a certain period. Hence, reliability comes into the picture. Similarly, other concepts like maintainability, availability and safety come into view. Mostly these terms are considered to be customer-oriented, like, who is demanding reliability, the customer is requesting this or the users or even the general public, like let us say if we are talking about the reliability for nuclear power plants.

So, we are talking about the reliability of the traffic systems, or we are talking about the railway systems. Now, these systems have safety consequences. Even if we are not using them, we want to have them safe because of their wrong effects, we may be influenced like we may be exposed to radiation and crushed on the road even though it is not our mistake.

So, all these systems where safety concern is there, their high losses are there, we need to make sure that they are reliable; if they are not reliable, those systems will become useless. We will not be able to use them if, let us say, we purchase a TV every 6 months it fails, we are not going to purchase a TV every 6 months. So, that is going to be highly costly for us. So, either because of cost or because of safety concerns, we may have to ensure that these products are able to not only do the job, but they are also able to do their job for a more extended period and for the desired time period or the general time period which we expect as well as they are safe.

So, let us discuss some terms we will use during all these lectures. The first term is reliability. So, reliability as we see reliability, why do we need reliability? Reliability we need so that we can understand the product's performance in terms of duration the product works without failure. So, if a product is working for a longer period without failure, it has better reliability.

So, are we using this measure or this measurement we are doing from the data to see how long a product will work? Where is it applicable? As we discuss that reliability is applicable generally everywhere. Everything we are using, have a certain life, we want them to work for

that life without failure. But as we discuss like for safety cases, wherever safety is essential or wherever the product is having a high cost or the product is being used in a high volume.

So, consumer products produced in high volume also need to be reliable, because if a cstomer comes to know that they are failing fast, the company will lose the market. So, reliability is something which the people demand for longer duration of work, but it is supposed to be met by or ensured by the supplier or the manufacturer. When is it useful? So, whenever we have now like high consumer products, if we talk about high volume products are there so unless there is a competition there may not be high for much focus on the reliability.

But all these products have multiple manufacturers there is fierce competition. In this competition, the product that is unreliable or less reliable will soon be phased out from the market because customers will not pick up. So, we need to make sure how much reliability we are expecting from our product. Accordingly, we can decide our warranty policies, maintenance requirements, etc. Similarly, for maintainability, in maintainability, we talk about the time required for maintenance, primarily repair time or other types of maintenance.

So, here we need to ensure that the failed product goes to the maintenance. So, after the failure maintenance is being done sometimes, we are doing maintenance to stop the device from the failure or to predict that if condition is going bad for the system, we can repair it before it actually fails. Especially that is done for cases where high consequences in terms of losses or safety or human life are considered.

So this is required to ensure that maintenance time is optimized so we do not take much time in maintenance. So, if we do not take much time in maintenance, for example, if we are using refrigerators in our home. Now, if our refrigerator fails, by chance then what happens? Because of the failure directly, we cannot use that refrigerator. So, the purpose of a refrigerator is to ensure that our food items, mostly food items or other, ice etc., are not wasted and remain usable.

Now, when this refrigerator is failed, all of our functions will be affected, and we will not be able to use it for those purposes. So, since we are losing the function, I will be dissatisfied as a customer. But I can still tolerate that, okay that my fridge will be repaired within 1 day. So, 1 or 2 days, I can easily manage it. But if the fridge takes one week to repair, then what will happen? I will be highly dissatisfied. And I may not use the refrigerator from such a company.

So, that company which is giving can repair my fridge in the least time; I will prefer that company because that way, my inconveniences are short, and I am staying strong. And I am able to continue use the because that fridge it is failed. So, I am not able to use it. So, whatever the purpose and whatever my dependency is there on the refrigerator that is affected. So, maintainability comes into the picture.

So, the companies which design their maintenance procedures to ensure that in the least time your devices are repaired, the customer will be more satisfied. So, it is needed for those cases where generally this may not be required for the cases where use and throw items are there, this is mostly for little bit costly devices or the we have the engineering setups like nuclear power plants, like thermal power plants, we have chemical industries.

So, all these big, big industries, steel industries or whatever big setups, generators, etc. which we have all these need to be maintained. Because if they fail, we will not throw them we need to repair them. So, we need to ensure that the repair time is minimum as possible. So, where is it applicable? It is applicable to all cases where either item are costly, or they are having, they are big items So, most of the time it is costly, and infrastructure items, and that is the cases it is useful, we want to make sure that our maintainability is high. High maintainability means we are able to repair it in less time.

When we discuss, availability is generally for the repairable systems. So , we are also worried about the availability of the costly item you discuss for maintainability for those kinds of items. So, availability is telling us to see if we have a system that is up and down for a certain period. Let us say so, let us say this is our up period, this is up and this is our down period. Down period means system is under repair and here up period means system is under operation, it is working, functional.

Now, what is availability? Availability is how much time let us say this is time to failure. Generally, for a reliability we use time to failure, working time is how much? It started working from here that it let us say time t =0 and it worked up to here and then it failed here. So, from 0 to there, this becomes time for failure. This is the time it is taken to fail, but that is the same time it has been operating. So, TTF is the operating time, while downtime is the time taken for repair TTR.

So, we can say TTR for first instance, second instance we can say this is TTR 2, and similarly, we can have TTR 3. So, what is availability? Availability of a system is in two

states, either it is up or it is down. We want the system to be in upstate. So, what is the probability that system is in upstate? So, we can say uptime divided by uptime plus downtime. That means in one cycle this can be the average value of uptime and average value of downtime.

$$\text{Availability} = \frac{Uptime}{Uptime + Downtime}$$

So, we can say the average value of uptime is MTTF (mean time to failure), an average of TTF that is mean time to failure. An average downtime we can say is TTR. So, the mean time to repair is how much average time it is taking to repair. So, if we want high availability because this is the period for which we are using. So, high availability we can achieve either by having high reliability which means, over time to failure is high, or we can also achieve by having high maintainability, which means TTR is less time to repair is less, if the time to repair is less or time to failure is high, we will be observing high availability.

So, the system we want to be available, if that is available, then only we are able to use if it is not available, then we will not be able to use it for the functions like we took the example of the fridge. So, we want it to be highly available. So, first, we do not want it to fail. And if it fails, it should be repaired quickly if it is repaired quickly my availability will be higher. So, availability is a performance requirement that is there and useful. Almost all systems here we have high-cost involvement where we have the safety involvement, where we have the bulky systems.

So, we need to ensure and tell this so, that we are able to understand how much, how on overall life, how much time the system will be useful. Generally, for safety requirements, we may be looking for high reliability, but in further cases where the consequences of failures are not very high. Consequences mean whenever there is a failure, then whatever happens after failure, mostly we are losing money, if we are only losing the money, there is no threat to the life then it does not have safety consequences it is having only the loss of function or loss of money.

So, loss of money kind of scenario, we will be working on the availability. Because if availability high, that means, we are able to use it more we are able to generate more money or we are able to satisfy our function for a larger time. But for safety kind of requirements, because if it fails it is going to harm the people which is not permitted. So, for safety kinds of

requirements, we have to meet high reliability, high reliability means the time to failure is high we do not want it to fail.

So, for those kinds of case we are more interested in reliability, but for cost kind of scenarios, we are more concerned about availability. It is applicable to the repairable systems, wherever repair is applicable, we are able to use it. If such a system cannot be repaired we cannot talk about maintainability or availability. Let us see if we talk about satellites. So, satellite repair is very cumbersome, and most of the failures may not be repairable. So, if they are not repairable, we will not be talking about maintainability or availability, we will be mostly talking about reliability.

Then comes safety, safety is also measured in terms of risk. So, safety is like reliability all failures are considered to be unreliable, but all failures may not lead to harm to people. So, safety is concerned with the cases where people may be harmed, people can get injured, people can get there is a possibility of death. So, those kinds of scenarios or those kinds of failures, whenever possible, then there is a safety concern for the system. So, wherever such possibilities exist, we must ensure that safety is kept high.

So, we need to evaluate the safety, how do we evaluate safety? Safety is a subjective term. So, we cannot directly evaluate. So, we evaluated it in terms of risk, the risk is opposite of safety that means unsafe means risk, and here this risk is again a miserable term where we try to estimate what is the probability that the system will be unsafe. Then, this is applicable for scenarios like, let us say, railways, aircraft, nuclear power, thermal power, and chemical plants. So, all these cases where there is a possibility of harm to the human being, safety, or risk have to be analyzed. And in all these cases, we find it useful also.

So, like for RAMS terms, if we want to explain likely if you take an example of let us say train, passenger train. So, for passenger train reliability would mean that when we sit on the train and when we reach our destination. So, from one destination to another destination, there is no failure, without failure we are able to start and reach the final destination.

Maintainability means, like, whenever this journey is completed, then the system will go for the maintenance. So, and during the journey also, if it fails, sometimes we have observed that when you are travelling during the train using the train, then in between there is something happens something goes wrong and then it got stuck. So, maintainability we will deal about

how to address these failures? That means calling support and how quickly they are able to fix it, because if they take more time, then we will be stuck on the way for a longer period.

Availability means that since this train can be unavailable, either due to the failure or when we are traveling, this may also be unavailable because this is a vast system to keep it running, we have to maintain it. So, it goes to the maintenance, there are some general regular maintenances is carried out like cleaning, some repairs, some replacements and that takes time. So, that train is not always available. So, it takes some time to maintain regular maintenance is there, than periodic maintenance is there.

So, some time is lost in that. So, how much is the time it is going to be available to us that means, how much time it is not spent on repair or that is either due to the failure during its travel or to ensure that this is in good health? Similarly, whenever we are talking about the risks, then we are talking about those failures like brake failures like we are talking about wheel failures, or we are talking about accident chances.

So, in all those cases, what will happen and how the system will behave, and how much harm is possible that we are evaluating in terms of risk? I hope this is understandable. So, we will continue to next slide.

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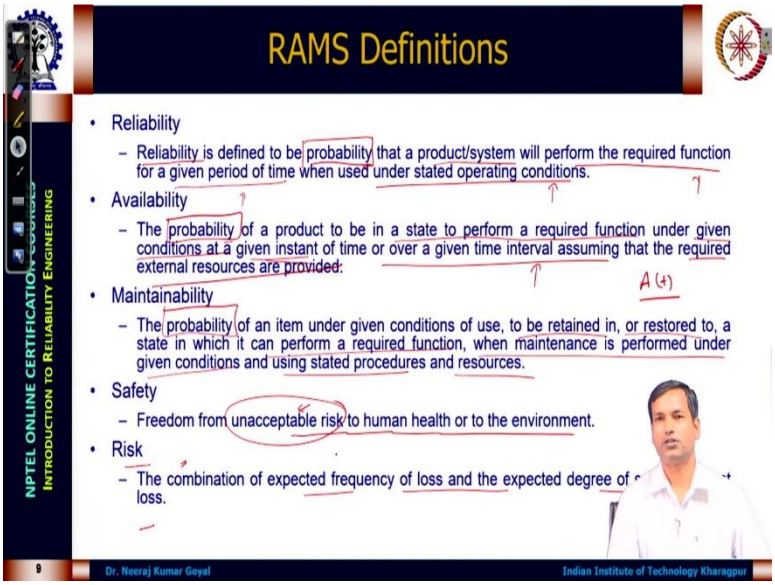

Let us go through the definitions of each term. What is Reliability? Reliability is defined as the probability that a product or system will perform the required function for a given period of time when used under stated operating conditions. So, as we see, reliability was initially defined as the ability but later on, in this definition was changed, and it was made a probability. So, how do we measure reliability? We measure the reliability in terms of probability.

Probability of what? Probability that the product or system, whatever is of concern product or system, will perform the required function. So, we need to know what are the functions of the product, these functions the product should continue to function and should for a given period of time, it is not like it just worked and then failed. And why we also mention here operating conditions, we are making sure that this system should work under the stated operating conditions like environment like what kind of uses, and what way people are going to use it.

Because if the environment is harsh if people are using abusing the device, then the probability will change and the probability of big failure may become higher. So, reliability becomes poorer. So, whenever we are promising reliability, we are also telling them under what conditions this reliability is valid. Then comes availability which is similar to reliability. It is also the probability that the product is in a state to perform the required function. So, there are two states that we discuss either it can be a working state or it can be under repair.

So, it should be a working state, what is the probability that the system is in a working state under given conditions? So, at this condition what is the probability that at any particular time

or at any given time, that system is in the operating state. Sometimes we may discuss about given time, but this is not used frequently. The most used term is the instant of the time, like availability at time t when we are talking. Then at that time t what is the probability that the system is in the working state not in the failure or the repair state, given that required external resources are provided, as we see here for availability the maintenance may be there.

So, maintenance may have a requirement for external resources. For maintainability, it is a probability again as we see, all these terms are being measured in terms of the probability, that is why we have to understand probability for this. So, here the item under a given condition of use, we want to retain it in that condition the excellent condition or it is from a failed condition, it is restored to the good condition where it is performing the required function.

When maintenance is performed under given conditions again we cannot assume that maintenance will be done like this like that, whatever is the defined way of doing maintenance that should be considered here using the standard procedures and resources. If there is a lack of procedure and resources, we cannot assess the maintainability because then it sometimes it may take very huge time sometimes it will have high variability in that case, maintainability assessment will become challenging.

So, here whenever we say so, like for engineering systems, there are maintenance crew that availability of resources, resources in terms of both spare parts as well as the equipment required for opening and using them and correcting the machines. Then comes safety, safety is freedom from an acceptable risk to human health or the environment. So, anything which can damage the human health or the environment, those are having the safety consequences. So, the probability which is given in terms of risk that is the combination of expected frequency of loss and expected degree of severity of the loss.

So, here we have to ensure that the probability of a certain type of loss is within certain limits. So, after if that probability of loss becomes high that means, our risk is high, that means, risk becomes unacceptable. If the risk becomes unacceptable, then the system is considered to be unsafe, but if the system is lying within the acceptable risk. In that case, we will consider that system is safe and usable because nothing can be made perfectly safe. So, but we have to ensure or we cannot say that risk free or zero risk.

That kind of scenario does not exist. So, what we have to make risk as low as possible, as low as practical and practically possible that in that case, we will ensure that the system is considered to be safe.

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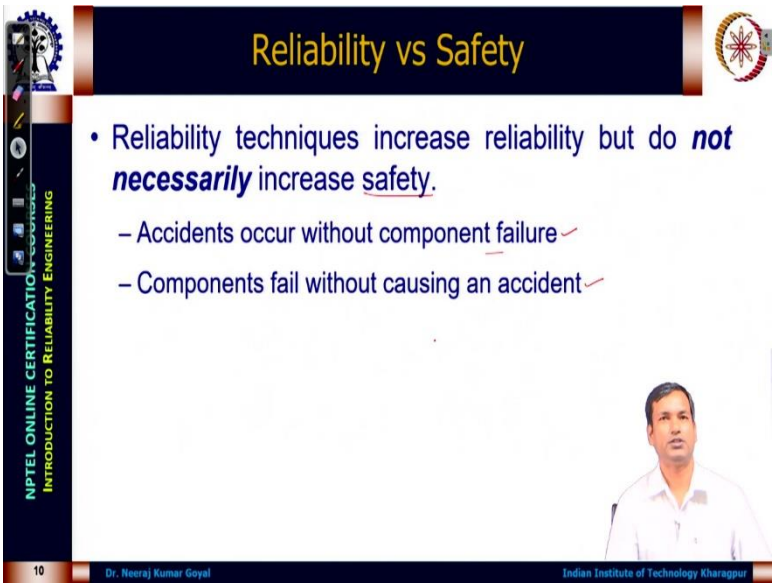

Let us discuss reliability versus safety. So, reliability techniques increase reliability but may not necessarily increase safety, why? Because while increasing the reliability, you may increase the reliability of some certain functions, but to increase the safety you have to work with those functions or those consequences which are having the like all the failures may not lead to harm to the environment and people.

So, if you work on the failures, decreasing the failures which harm the people and environment, then you are increasing safety. But if you are working on other aspects of failures of the devices, then it may not be improving the safety, but it may improve the reliability. Because reliability is all failures, safety failures, or some failures out of that. So, an accident can occur without component failure, a component can fail without causing the accident. So, even though there is no failure, you may have met an accident or two vehicles that can collide.

Similarly, a component can fail without causing an accident, even if the accident is not there, but the component can fail on its own. So, this is mainly about the reliability concern and this is our safety concern.

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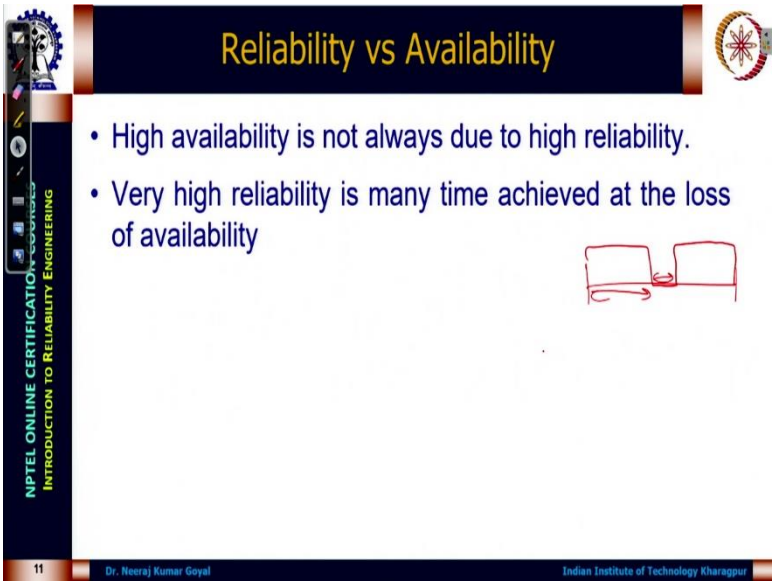

If you compare reliability and availability, we have discussed this. So, high availability can be achieved by reducing downtime. If we increase reliability, we can achieve high availability, but if we decrease downtime, we can also achieve high availability. So, high availability is not sure that we always do high reliability, but we can also do high maintainability or reduce the repair time.

High reliability, similarly, may sometimes be at the loss of availability, what is happening for repairable systems, is we are doing preventive maintenance if we do preventive maintenance, our availability is decreased because now the system is in downtime, while high reliability is there because the system is ensured in good health. So, we discuss these terms in detail in the following lecture, lecture number 2. So, we will stop it here today. Thank you.