**Industrial Safety Engineering**
**Prof. Jhareswar Maiti**
**Department of Industrial and Systems Engineering**
**Indian Institute of Technology, Kharagpur**

**Lecture – 60**
**Summary of the Course**

Hello everybody. Very good day and welcome to the last lecture of Industrial Safety Engineering. Today I will Summarize the Course, whatever you have learnt so far in the previous 59 lectures will be summarized, linked so that, a rational conclusion of the subject can be made.

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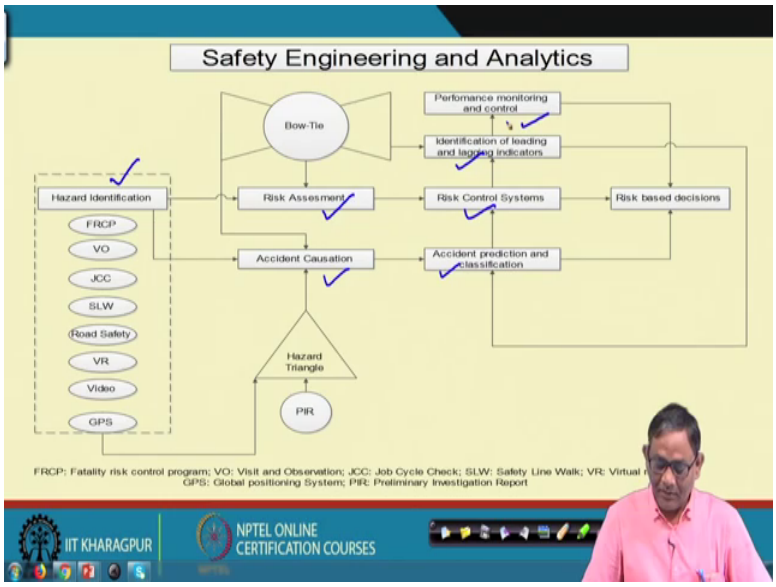


All of you know that safety engineering is a multidisciplinary topic or other way I can say, it is a multidisciplinary subject involving several issues related to hazard identification, related to risk assessment, related to accident causation, related to risk control system, accident analysis, prediction, classification, identification of lagging and leading indicators, performance monitoring, risk based decision, prevention through design and ultimately you have seen the different application of different qualitative and quantitative techniques as well as different technologies like analytics like virtual reality.

I believe that you have got the elaborate discussion in terms of concepts, in terms of practice, in terms of mathematics, in terms of application. So, let us now see that, what are the different topics we have covered in different weeks and how they are related to

this slide, this is the big picture of safety engineering and analytics. And you know that your evaluation will be only when you will apply all those concepts, techniques, tools in real life's problem solving pertaining to safety engineering.

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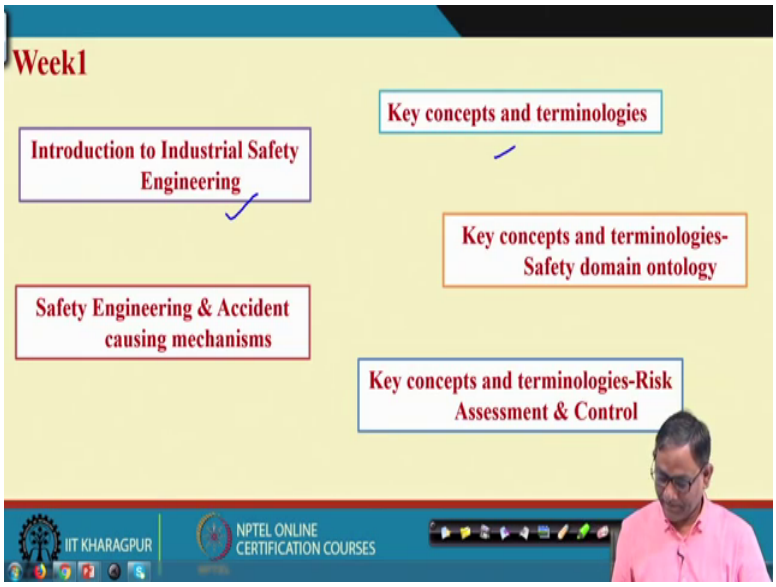


In week 1, I started with introducing the subject in terms of key concepts and then different scenario the accident scenarios taken from the accidents happened over the time in different industries. And, I am happy to share that you all have liked this lecture at least from the views, what we are seeing the number of views that is quite a large.

A like other discipline or other subjects, so every subject has its own language, so safety engineering also has its own language, so the terms, definitions all those things we have discussed in week 1. Then we have given you the concept like hazard triangle, safety domain ontology then, how accidents are caused from hazards and the total accident path. And finally, in that week you have seen that how risk control systems can be put in place conceptually from the prevention of accident point of view, as well as mitigation of the consequential impact point of view.

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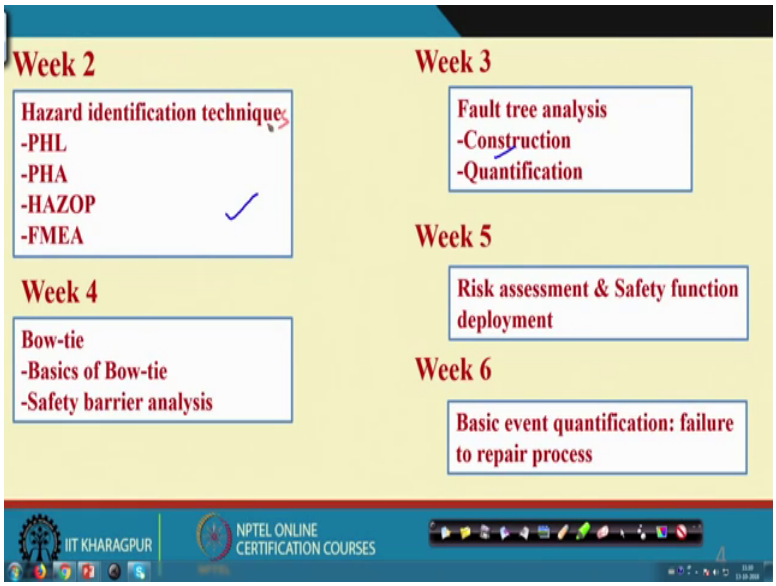


After that in week 2, you have learnt several hazard identification techniques, several hazard identification techniques like preliminary hazard list, preliminary hazard analysis hazard and operative studies failure mode and effect analysis with simple examples and some cases. And you have done several assignments related to these in week 2 as well as the topics covered in week 1, in week 1.

So, after that we have you have gone through fault tree analysis in detail and I have told you this is a wonderful technique which has both mathematical as well as graphical representation and we have in fact, developed further discussions or further concept or further models based on fault tree analysis. For example, bow tie which was discussed in week 4. So, week 3, you have seen the fault tree construction and please understand fault tree construction is the most important part.

It is possible only through team work and you must have domain knowledge and there must be having a good team so that, the team will ultimately brainstorm and find out the different top level incidents or top level accidents that could take place at your plant or the systems you have considered and then you dig down the in the causes. Means from the top level event to finally, the basic level event and in between there will be intermediate events and all those events will be linked with different logical gates like AND and OR gate primarily. You can use boating gates in a with gate other gate like exclusive or priority and gates also.

Unless the fault tree is constructed properly, then you will not know that, why the top event is occurring, what are the different issues involved and they are those things are discussed in karts sets principle through, that mean the karts sets links the basic event with the top event in such a manner that in a minimal kart set all the basic event must occur for the top event to occur. And then the quantification of the fault tree provided the basic event probabilities are known also discussed in week 3. So, my suggestion is that, if you are not confident enough for the quantification, but you must do the construction. So, constructing fault tree is 70 to 80 percent work in fault tree analysis and quantification helps you prioritizing the action area ok.

If you cannot do that you can rely on expert opinions in terms of linguistic probabilities or subjective probabilities and then using fuzzy logic or fuzzy concept you can convert the linguistic or subjective fault tree values to objective fault tree value or so. That also we have discussed, but not in week 3, in later stage. Then we have discussed the event tree analysis. Event tree means one side the accident has taken place, so what next or what will happen or what the system should be configured or a what way should be configured so that the consequences can be minimized. So that means, given an accident what way your system behaves so that, the impact can be minimized was discussed through event tree analysis.

And then in week 4 what happened, we combine the 2 and we developed bow tie, where bow tie is having a centre event which is basically, the top event for fault tree or initiating event for the event tree. So, the centre event is linked with faulty tree and event tree and the entire combination is bow tie. So, bow tie is basically the I can say the one of the best thing that happened in safety engineering because, faulty tree and event tree two are most very important techniques and they are combined together, in fact, bowtie mathematics is still under development.

So, we have discussed bow tie from the basic development point of view, as well as we use it for the safety barrier identification analysis point of view. So, the researchers should work in this particular area, particularly in the development and quantification of bow tie and it is still open research area. Then after bow tie analysis, in week 5 we have given the detail of risk assessment considering all those tools and techniques and their associated risk and individual risk calculation was also given to you and please

remember for plant risk assessment point of view individual risk as well as associated risk is very very important.

We have given example with reference to fatality risk, but that is not the ultimate you have to compute risk from the basic definition point of view and if person is exposed to risk or a property is exposed to risk or an environment is exposed to risk, so what is the quantity of or value of that risk you required to be quantified. The assessment process what is given to you, this is a generic one applicable to all situations, but if you want to make you customize risk assessment process, you can do that and I hope that the knowledge you gathered from this subject will help you in developing risk assessment framework from for your company or for your organization or for maybe your dissertation from the master from the bachelor and from the PhD point of view.

And in that week 5, we also discussed safety function deployment and this is what is our own creation, we have adapted the adapted the philosophy of quality function deployment and we have seen that how safety can be integrated into the design of the system. So, we have given starting from the stakeholder concern to ultimately design solution with several steps safety function deployment. It is conceptually or philosophically equivalent to quality function deployment, but from if you see the component it is not exactly like quality function deployment, it is the philosophically quality function like quality function deployment.

We have adapted the hazard identification risk assessment techniques as well as we have adapted hazard control hierarchy and also we have adapted some (Refer Time: 14:08) ranking mechanism for in the safety function deployment and it is a handy tool and I think it should be applied by industries by practitioners. So, after safety function deployment, so we started with basic even quantification, so I can tell you that the from week 1 to week 5 this lectures are more on concepts, more on philosophy, more on models more on functional aspects. Then week 6, we have shifted from these qualitative aspect to the quantity part.

So, in a up to week 5, we were more stressing on qualitative aspects of safety engineering. Although in between we have given you in some of the quantification, but our focus was more on imparting knowledge on the concepts, on the models, on the theories, on the practice our application point of view. So, in week 6, you have seen

some probability, reliability, availability then ultimately survival function then failure distribution, so many mathematical issues. And I know if you are a practicing engineer, then you have faced little problem in accepting these or understanding this, but nevertheless these are very important concepts.

And if you are a student from any engineering or science or other discipline, so you found this one more interesting because, you like mathematics. And because, it may be very not that was sound statement but, more or less the young students they like mathematics whereas, when you grow up we like more on concepts. So, basic event quantification, we started we will liability then failure and failure probability distribution and then there we have created lot of other parameters and we have seen that how those parameters can be determined when data is available through graphical method, through multical loop sorry through maximum likelihood estimation method. And once you know the know the basic event probabilities then using get by get method you can find the top event probabilities.

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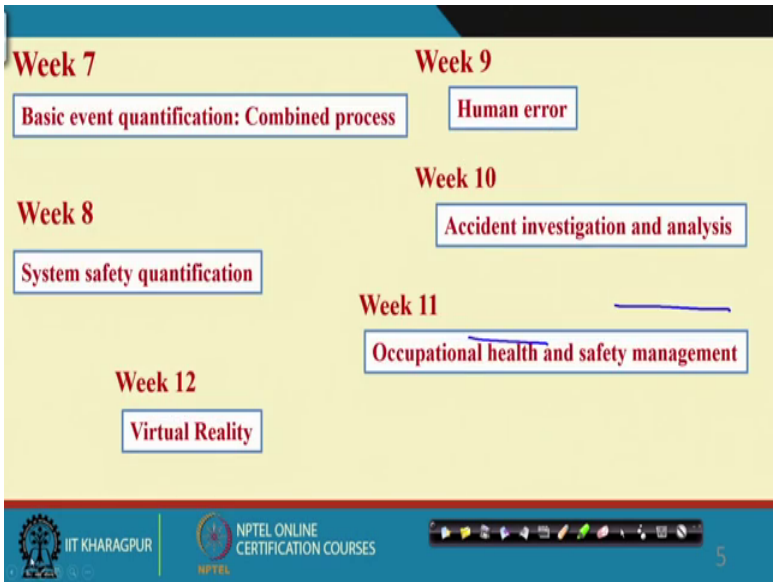


So, in week 7, week 6, we concentrated more on the non repairable components and week 7 we concentrated on the repairable component. In repairable case, what happened once if component fails it we it is repair and then the again it fail, something like failure, repair, failure, repair process. And there are you find out the parameters related to repair rate, repair intensity all those things.

An interestingly in week 6 and 7, we have given you also some of the basic engineering mathematics like Laplace transformation like a Markova chain analysis and to quantify the ultimate leader system component safety using few applications or few examples. So, week 6 and 7 you have seen good amount of mathematics and week 8 also it is basically from system safety quantification point of view, so it is also a mathematical issue and you have seen that different a concept like that how cut sheets along accident sequence can be generated.

You have seen that structure function approach, you have seen truth table approach, you have seen so far I can you let that common cause, cut sheets and also a good amount of treatment related to identification of or handling of common cause So, that means, if I talk about the quantification part then basically, basic event quantification and system level quantification we have discussed. And, interestingly we have taken all though the lecture materials primarily from the book of Kumamoto and Henley probabilistic these cases ment and management for scientists as engineer and we followed that book almost for weeks 5, 6, 7 and 8. And, to keep the keep the parity and we sure that you will not face difficulty in an in the flow and understanding of the things.

So, if you have this book, it is good if you do not have please have this book and it will help you in the quantification part. Then we have shifted to another important topic of safety engineering which is known as human error. Ultimately if you analyze accidents, you will find out that you will one way or other human involvement is always there. So, so that human error cannot be eliminated completely. Human error will be there and it is to me and engineering issue, it is not a issue only time can for behavior point of view. Human error has its root in the definitely in the psychology, but when we are talking about human error and it is quantification from safety engineering point of view, so it is very much a engineering issue.

So, you are seen that what is human error, you found out that there are classification given by psychologist in terms of slips, in terms of lapses, in terms of mistake, in terms of intentional violations, in terms of unintentional mistakes. And then there are knowledge base there are rule base and there are skill base task and corresponding errors and we have given you some techniques some classifications related to human errors; for example, Tharp for example, Sherpa. And they and we you have seen the systematic way of way of identifying human errors and then quantifying human errors.

Here human error quantification in terms of fuzzy theory also discussed. This is very important topic for everybody. It has huge potential from research point of view also. For example, cognitive modeling of human during accident, what when human is involved human maybe is responsible, so this is very important issue. Then in week 10, we have discussed that what is accident investigation. Accident investigation means when an accident taken place, what will be the investigation process, who will be doing investigation, what kind of data been collected and in this week the analysis part from descriptive and predictive analytics point of view we have discussed.

I have given you some with some examples that what is the different charts, what are the different tables that are related to descriptive analytics. And then under predictive analytics regression and classification and regression tree both were discussed and but, the discussion was mainly on the concepts and applications point of view given a data, but not in the mathematical underpinning on mathematical day point of view. But please remember each regression classification and cart they have very good mathematics behind they are behind the scene.

So, if you are interested to know those mathematics it is available particularly, in any data mining book you will get it. It is not that it is used in the accident data analysis only, it is used everywhere whenever there is data. In accident investigation, many times we basically we analyze the investigation reports, which are basically in the text form and you know that text analytics can be applied there, but we have not discuss this analytics, we are only discuss that excel based data. And another important issue is that, when you talk about large plan you will find out that the accident data are collected from different sources including the video also.

So, a huge amount of data from the velocity variety and volume point of view are generated, which can be termed as big data and big data in safety is a big issue and it is purely it is it still is a is a area completely almost completely unexplored. So, people may be interested to work on and it will be it will be a good investment for all of you. Then after week 10, in week 11 the lecture was taken by very eminent safety expert Professor O B Krishna who has spent almost 40 years in industries and developed lot of lot of I can say other way implements a lot of safety related programs measures. And they are the primary a discussion what he has made where, what is occupational health and safety

management and then what is that for safety performance indicators, primarily leading and lagging point of view and then he also discussed on energy isolation.

So, it is a huge thing. So, only with 1 week of time all those things could not be completed in totality, but a if we have very good amount of that is knowledge is imparted to you all of you by professor O Balakrishna. So, I am really thankful to him. Then in week 12, that is the a final week where 3 lectures were given on virtual reality by 1 of my research scholars, Mister Karthik Aditya Dharmaputra.

And you have seen that, this technology is an important technology and the accident research as well as this practice for accident prevention and mitigation cannot be completed, unless you add up this technology. You cannot know industry particularly, now can rely on the traditional way of hazard identification and safety education and training and other way I can also prevention through design principles cannot be without virtual reality.

So, in virtual reality although we have not giving you the detail elaboration with a particular accident scenario that what is it how it is developed and ultimately what it is used but I can tell you that, this virtual reality lab what we have developed in what we have established IIT in the department industrial and systems engineering under the leadership of Professor Parthoprothin Chakravarthi our director it is unique facility and impact we are developing that different accident scenarios which are in some developed some are in the process. We can not disclose all those things because of confidential that clause but it is a good technology and particularly for the safety engineering point of view for all industries including that process industries, including manufacturing, including coal, including transport, including healthcare.

So, this virtual reality has in other applications also. So, but nevertheless in virtual reality the concepts that differ, a how the virtual reality models should be created and ultimately different applications of virtual reality not necessarily with accident and accident or hazard identification point of view, for some other aspects also we have discussed, we have discussed in this class what can they has done. And you have seen that, the fuzzy logic part particularly fuzzy mathematics I have that one research scholars say Shobik Das he has taken and that was also another interesting one.

And. In fact, the human error and human cognition modeling in and in during or pre accident during accident post accident time a period can be model through virtual reality and I tracking methodologies. So, that part he is doing and all those things we may discuss in some other advance of in advance objects, in a advance subject of safety engineering but these are upcoming areas and I am happy to share with you all those things. And I hope that you have enjoyed that 60 lecture series and I am sure that you have gained a lot and what you have expected, I think maybe more than that, but you are the right person who will be able to tell this.

This subject based on my knowledge and my work in this field I know is still it is in the developing stage. Because and also material related to for these subjects are hardly available on internet also. So, we have tried our level best to give you the best possible materials lectures related to industrial safety engineering, it is applicable to all industries. And give your feedback in the discussion forum, we will definitely look into it and we will try to improve our effort, improve our put more effort put more technology, more time in this particular area which is upcoming, but it requires many more people to work together.

I welcome all of you in this venture that to make people safe at workplace, at the public place means safety is very very important one and it is not possible by one individual or one industry, it should be everybody's job. So, the first law of for working for safety and then definitely you all will win, that is what is my message to my dear participants for this course.

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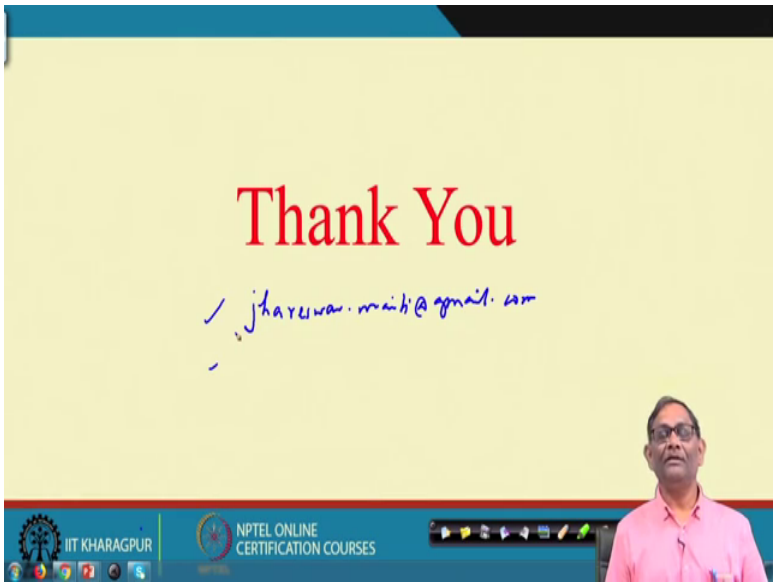


And we are available always, if you have any query, you please put a mail. My email ID is jhareswar dot maitiat gmail dot com and you know the email id of Kanti and Shobik also. So, you please share your views your requirement and we are happy and we will be happy also to come to you for your and our for everybody's development.

Thank you very much.