Industrial Safety Engineering
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Lecture - 23
Consequence Assessment

Hello everyone, today we will discuss Consequence Assessment, the contents of today's presentation.

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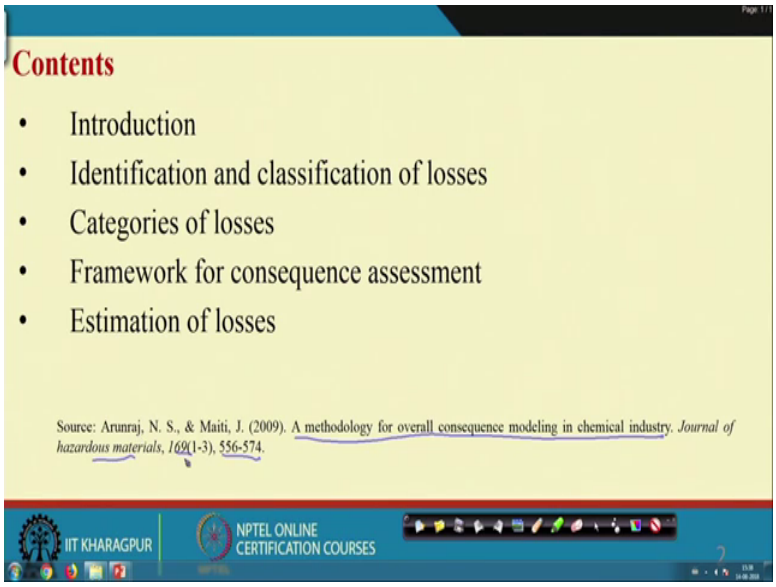

We will start with what is consequence assessment and then we will discuss different kind of losses, how to identify and classify the losses. Then all the losses we will be put into different categories for quantification and then framework for consequence assessment and finally, estimation of losses. So, all those things are available in the paper a methodology for overall consequence modeling in chemical industry. Journal of hazardous materials volume 169 page number 556 to 574 which was developed by myself and my PhD students N. S. Arunraj.

So, there can be variation of this approach, but we have tried to incorporate all most all of the important loss categories. And, we assume that this will give you some idea and that how to get identify categorize and estimate losses.

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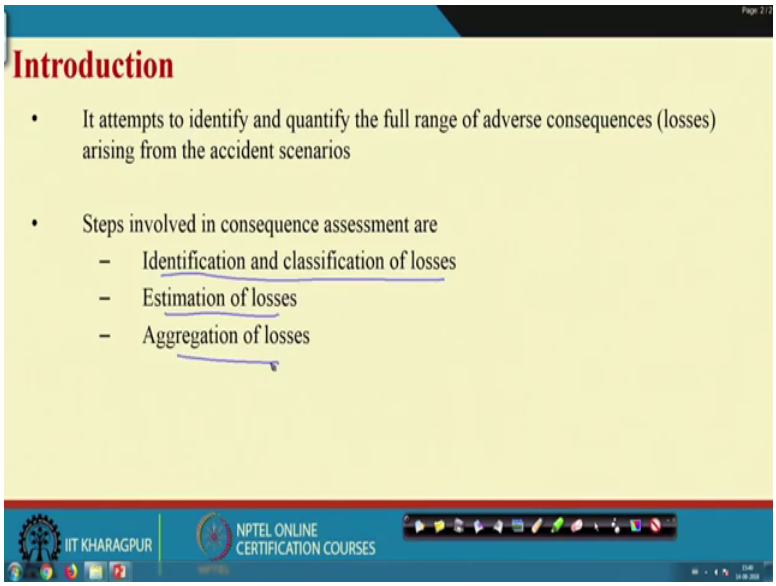

So, what is our intention? Our intention is we want to identify the full range of adverse consequences. We are discussing safety, we are discussing accident scenarios. So, every accident scenario ultimately will lead to different kinds of losses. So, our aim here is to find out the full coverage of the losses and; obviously, also estimate aggregate losses.

What are the steps involved, steps identification classification and losses, estimation of losses and aggregation of losses. The aggregation is needed because, you may not be able to find out loss calculated from different classes of loss in same unit of measure. It may not, if it is possible to find out or compute the losses in terms of money everywhere then it is fantastic, but it will, it may not be possible.

It may so happen that you required to rely on sometimes the some experts opinion, some qualitative assessment, sometimes some kind of probabilistic assessment, sometimes some monetary assessment, sometimes some kind of fuzzy assessments. So, all things may require. So, under such cases aggregation is very - very important.

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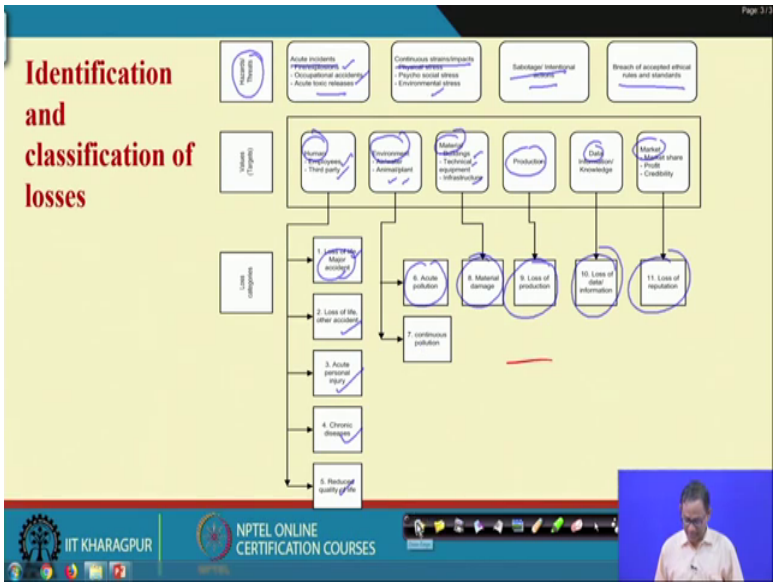

So, let us see that what are the (Refer Time: 03:13) loss categories. So, here under hazard and threats, different categories are given and if you look into the slide minutely you will be able to find out. First is acute incident, what happened in any in work place or shop floor or a search in industry and then continuous strain and impacts, then sabotage and intentional actions and then breach of accepted ethical rules and standards. So, these are all threats I can tell you and these are threats because of different kind of hazards.

Now, under acute incidents like fire explosion, occupational accident, toxic release under impact or strain that a physical stress ratio psychological stress, environmental stress. So, then sabotage and sabotage and intentional actions that you know and breach of accepted ethical rules and standards, these are also quiet known to you. So, now when we basically write down the values associated with those threats with reference to the threats to the targets so; obviously, we have seen that targets are human, then environment, material, now production, data, market, all those there would be the rule threats will be there.

So, the values and targets, when we are talking about human; that means, any kind of threats or accidents ultimately leads to the loss to employees third party. From environment point of view air, water, animal, plant. From material point of view building, technical equipment, infrastructure and you all know that loss of production

and these two are very important now a day's, one is the data information and knowledge another one is the market share profit and credibility.

So, now you know that a an accident can create bad image in the market and there maybe situation when the customers will refuse your product produced if your safety performance is not good. And, the other end the data is so important now because of this industry 4.0 and you are, you get the data from every sphere of your work, every equipment, every workplace, every human, every movement those data are available and this data is the knowledge now. So, the data loss also may happen because of your accident.

So, that is why they are, these all are very - very important loss categories. So, now, when you talk about the human loss, it can be further classified into that loss of life due to major accident, loss of life with other accident, acute personal injury, chronic diseases, reduced quality of life. So, you have to find out all those losses. So, there are models for accident, cost of accident, but it is it may not be applicable to all the organization, all the industries. So, organization specific industry specific cost of accident model is very - very important. Here, we are not interested to give you the cost of accident model rather I am giving you the component which may enter into the cost of accident model.

So, when you talk about environment, environment particularly environment pollution point of view, it may be air pollution, water pollution or soil that is also very important one. And then the population can be acute pollution can have continuous pollution. So, the quantification scheme will be different for acute and continuous pollution. So, then when you talk about the material that building technology these are basically that material damage. So, we can say these are basically equipment damage asset damage so, asset loss something like this.

So, any accident ultimately may lead to the temporary or long term or short term stoppage of production. During accident and after accident there is quite likely to have loss of production and accident may lead to loss of data or information and loss of reputation because of accidents. So; that means, you see that what are the different loss categories. So, there are 11 loss categories. So, we hope that these 11 loss categories are quite exhaustive one and there are scheme for quantification of each of the loss categories.

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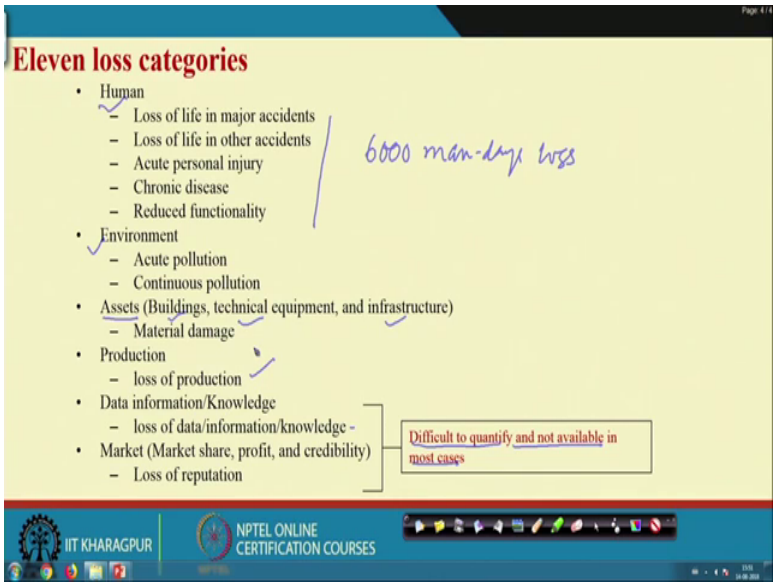

So, what are those 11 categories of loss? Human already explained, environment explained. Now, when we talk about material damage, this is basically assets, building, technical equipment, infrastructure all these assets. From production point of view loss of production, data information knowledge point of view loss of data information and knowledge, market point of view loss of reputation and accordingly the market share profit and credibility will go down. So, these 2 particularly data information loss and market share loss or profit and credibility, these 2 loss they are difficult to quantify and ultimately I have not come across any cases where they are quantified.

There are other cases I have some references, some that human loss category, environment loss and other things some references, but these 2, I am not come across. Definitely in today's context they are important and definitely some kind of quantification is already there which I have not come across. So, what I, my suggestion to you that when you do a case study on loss calculation and when you try to find out the budget for safety so, if you do not consider all the loss categories then you may find out that the cost of accident is much less than what is actually to be.

So, when you calculate cost of accident, it is recommended that you consider all the 11 categories of losses and find out (Refer Time: 10:32) to calculate each of the categories and then aggregate or sum up the all those categories. And finally, the resultant loss will be used for some kind of safety budgeting or when you do cost benefit analysis. For

example, the cost benefit analysis for safety is that in order to improve the safety, you may required to invest in terms of, in terms of intervention implement design and implementation which will cost you.

But at the same time you may be in if you, you may think that intervention cost is too high compared to the cost of accident and accordingly you may not go for that costly intervention. But it may so happen that actually you have computed the cost of accident with, with incomplete information or other way I can say with inadequate information or data, we have not considered the total loss categories, you may be you might have considered a partial loss categories.

Most of the time we find that the human, the health and safety, health and safety loss, this one, this is in terms of your that some categories are there any fatality lead to 6000 man days lost, loss and similarly when there are some kind of permanent disability. So, equivalent man days lost is considered. And then the man days lost and multiplying by the, by the employee salary or wage whatever may be that may be the compensation or the loss to the, loss to the company that way it is also calculated, but this is not the total this is a part of the loss categories.

Environmental loss in terms of accident, it is really calculated, asset loss is calculated and then production loss I will or might be calculated, but actual in plant I do not know exactly that how much it is done. But, please remember that these all those cost components if estimated and summed up, it will be a large one, it will be huge one and you will find out the cost of accident is always less than the cost of required intervention.

So this is what is our different categories, now we will go for the estimation of loss, but it is not possible to compute all the categories. We will show you some of the calculation and rest of the calculations either you have to find out from the that published literature or you have to create by your own you quantify it, still cost of accident or loss calculation is a debatable issue and it is an incomplete one.

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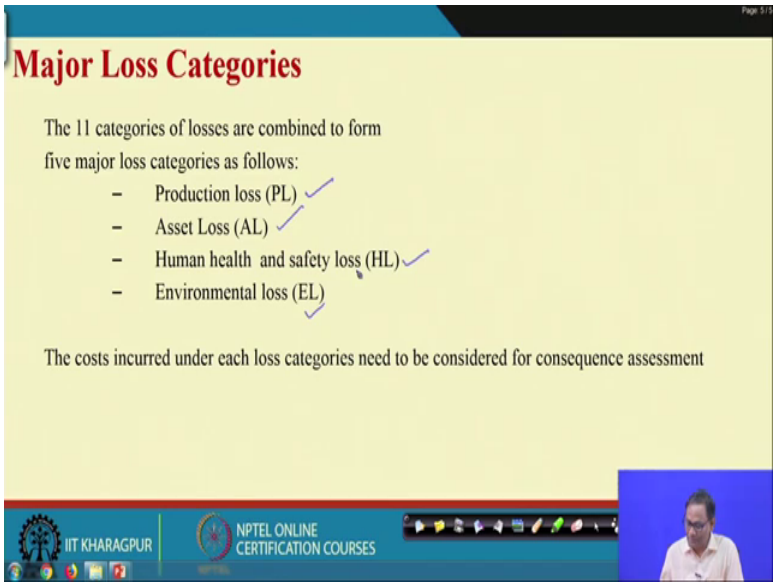

So, we will basically discuss here this production loss calculation asset loss human health and safety loss and environmental loss. And what I will do basically, I will give you some idea that how do you calculate all those things. It is not that we will calculate everything all the every aspects of human health and safety loss or environmental loss, but we will give you some idea how to calculate it?

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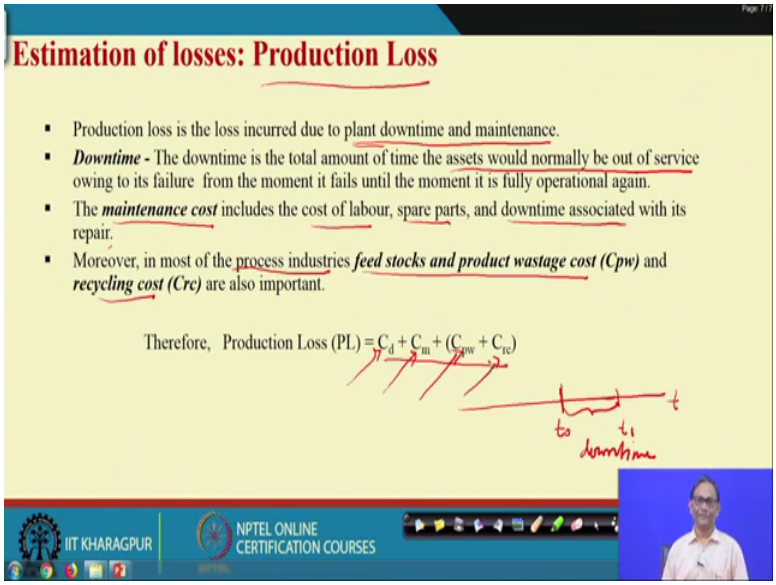

So, first production loss, production loss calculation; now production loss incurred due to plant downtime and maintenance; what is downtime? The downtime is the total amount

of time that asset would normally be out of service asset, would normally be out of service owing to failure from the moment it fails until the moment it is fully operational again.

So, if I say that you this is the time here the something that t 0, it is fails and here t 1, it is operational again. So, during this is the downtime, downtime, so out of service, the equipment out of service. So, now, during this period there will be loss of production. So, that you required to compute. Then when the equipment fails you, you required to repair it so, that lead to maintenance cost. This includes cost of labor, spare parts, downtime associated with its repair. In some industries particularly in most of the process industries feed stocks and product wastage cost and recycling cost is also important when an accident has taken place.

So, as a result we are saying if you want to estimate the production loss, you have to find out all those 4 components, one is downtime cost maintenance cost feed stocks and product wastage cost and recycling cost, all those cost you have to find out compute it and add it then that will be the production loss. So, what I will do? I will give you some idea of how to compute C d C m C p w and C r c.

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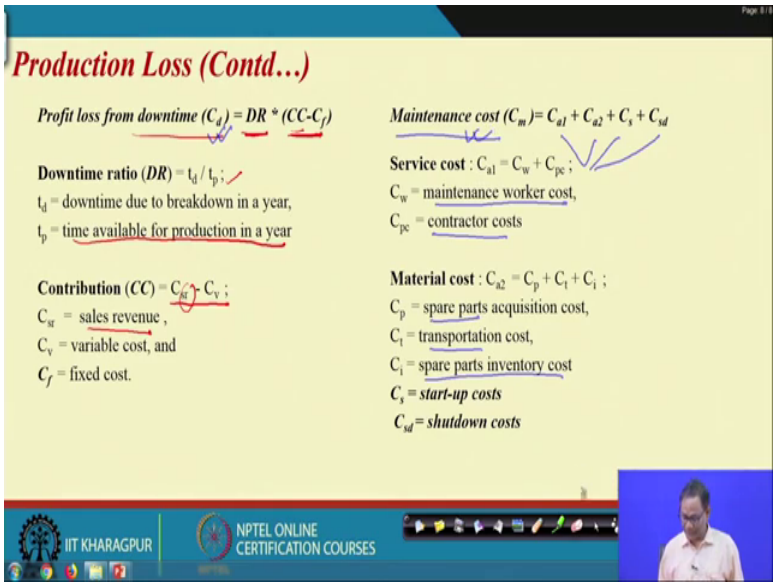

So let us see that, what is downtime? It will be basically the profit loss from downtime. So, this is downtime ratio contribution minus fixed cost. So, what is downtime ratio? Down time ratio is t d by t p where t d is the downtime due to breakdown, the t 1 minus t

0 is the downtime and then: what is t p time available for production in a year. So, you have to compute it annually ok? So, one you will find out that there may be several accidents in the sense that several times the stoppage of production or failure of equipment. And then in a year you have a stipulated schedule for production in terms of time. So, that you find out and downtime due to the down and particularly related to accident that you find out the ratio will give you downtime ratio. So, downtime ratio when multiplied by that contribution minus that fixed cost you will get the profit loss from downtime.

So, what is contribution, contribution is C s C C equal to C s r minus C v where s r is sales revenue. So, what you, what a revenue you earn from the sales. And then the variable cost, variable of cost of the items produced and then C f is the fixed cost. So, I hope that you will be able to quantify this from your organization point of view or the system for which you are interested to find out the production loss. This is a idea and some contribution scheme given to you. Now, there is another cost is called maintenance cost. So, maintenance cost has again the 4 component. So, you see that the C a 1 is the service cost and C a is the 2 is the material cost and C s is the startup costs and C s d is the shutdown cost.

Because you require you may required to do shutdown and you and again then you also required to start up. In addition the maintenance service cost will be there and maintenance material cost will be there. So, that is why there are 4 four component of maintenance cost. So, what is the service cost, that is maintenance workers cost C w and contractors cost C p c. What is the material cost? One is spare parts; another one is transportation cost spare parts inventory costs. So, all those costs will ultimately go to the maintenance cost, then startup cost and shutdown cost that you have to find out.

So, then production loss or profit loss from production, that is the productional downtime cost it is found out and you requirement to do maintenance and repair because of accident that whatever damage taken place. So, these 2 cost in addition in a sorry in addition to that C d C m the C p w and C r c that is a feed stock and product wastage cost and recycling cost. So, all those cost you add up and then you will get the production loss.

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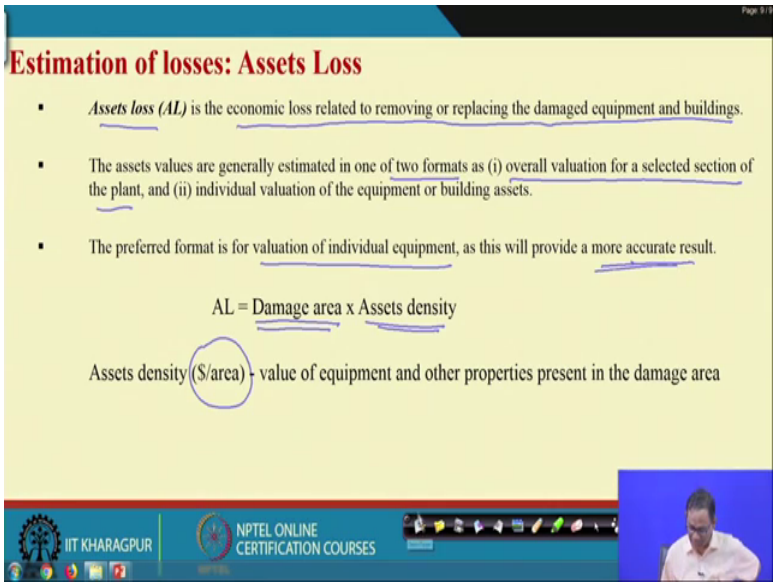

Now, we will go to see the concept of Asset Loss, how we will calculate the asset loss. So, what is asset loss here, the economic loss related to removing or replacing the damaged equipment or building. So, that mean of what is the asset? Asset definitely all equipment infrastructure that the asset. So, because of your accident so, there can be removal as well as replacement of the damaged equipment or infrastructure. So, what is the economic loss that is our asset loss.

So, now the asset loss calculations can be done by 2 formats, 1 is overall valuation of a selected section of the plant where the accident taken place and where the removing or replacing the damaged equipment and infrastructure is necessary that is that section or individual valuation of the equipment and building assets are of the infrastructure assets. So, that you find out the damage area and then find out within the damage area what are the equipment and related other infrastructures, the infrastructure that is that is located then find out the cost of each of the equipment and other infrastructure and then sum up the cost that is your asset loss. So, individual valuation is preferred and obviously, it is more correct also.

So, what you required to do to go for individual equipment loss calculation, you have to find out the damage area and then you, you also required to know the asset density. What is asset density? Asset density actually in terms of dollar per area that is value of equipment and other proper properties present in the damage area; so, if you know

monetarily, if you know that what is the asset density and then if you know the damage area, multiply the asset density with damage area you will straight away get the value that is the asset loss. We will show you the approach and how to get good computation related to asset loss.

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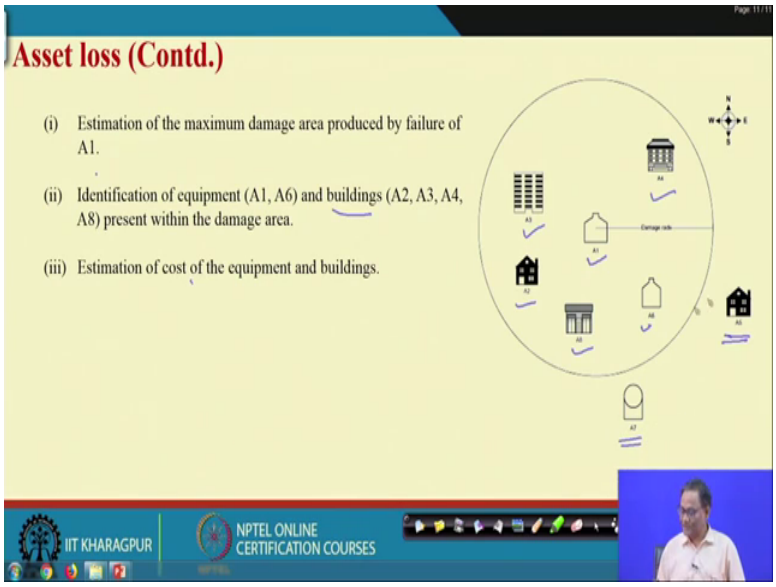

What is this? First one is find out the damage area, now this is our damage area. So, any accident that take place that that may suppose the you know what the accident scenario the scenario ultimately leads to this much damage need not be that it will be just always the circular, it may be something like this. So first is you have to find out the damage area and this circular concept that is better one because we know the center of the, the center of the hazard and if it occurs at the center and it is quite likely many most; that means, the it will affect the entire periphery and as a result what happened the circular damage area will be a good approximation of the damage area.

So, now once you know the damage area, there at techniques in chemical industry there are many software are used to find out the damage area ok. Even dow fire and explosivity index is also used to fire used to find out the damage area the formulas are available, I think in my paper I have using the dow fire and explosivity index how damage area is computed it is given there, ok. So, that mean first find out the area, then identify the equipment building present within the damage area, we are saying building

not necessarily only building maybe other infrastructure that also you required to compute and then estimate the cost of equipment and the building.

So, if I consider these is the damage area. So, then you see that A 1 then your A 3, A 4, A 2, A 8, I think A 6 these are the equipment and assets which are available in the damage area where A 5 and A 7 are out of the damage area. So, these 2 will not be considered, others are we required to consider. So, that mean what you required, you required to know the damage area and also you required to know that what are the equipment building and other infrastructure that present within the damage area.

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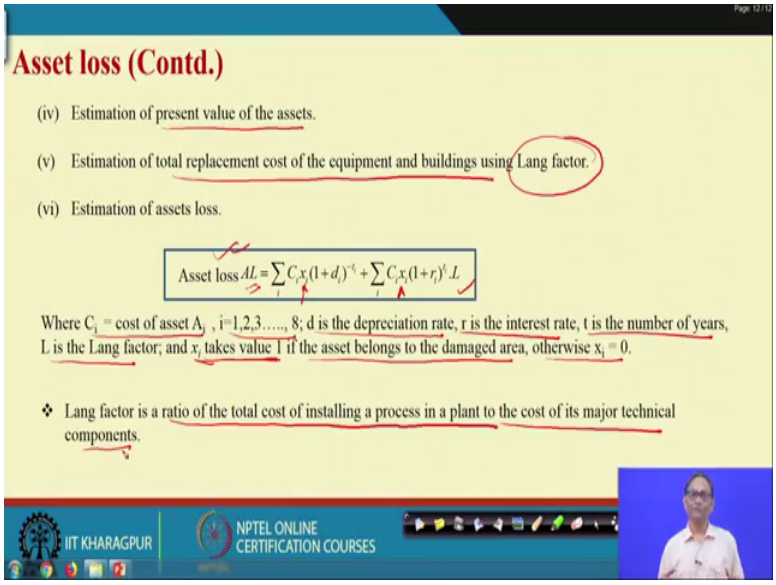

So, then what you do you, you, you calculate the Asset Loss. In order to compute the asset loss you required to know the present value of the asset, then total replacement cost of the equipment and building there is 1 factor called Lang factor which is used for the evaluation and then you use this formula. What is asset loss? A L equal to C i x sum of C i x i 1 plus d i to the power minus t i and then plus sum of C i x i 1 plus r i to the power of t i into l l is the Lang factor.

What is C i cost of asset A i i equal to 1 to 8 with reference to the previous damage area and d is the depreciation rate because we required to know the present value of the asset, r is the interest rate and t is the number of years, L is the Lang factor, x i here x i this is a value these takes value 1 if the asset belongs to the damaged area otherwise x i 0 basically. We are interested to consider all the assets which are within the damaged area

and why Lang factor is used? Lang factor is the ratio of total cost of installing a process in a plant to the cost of major technical component it will give you more accurate result ok.

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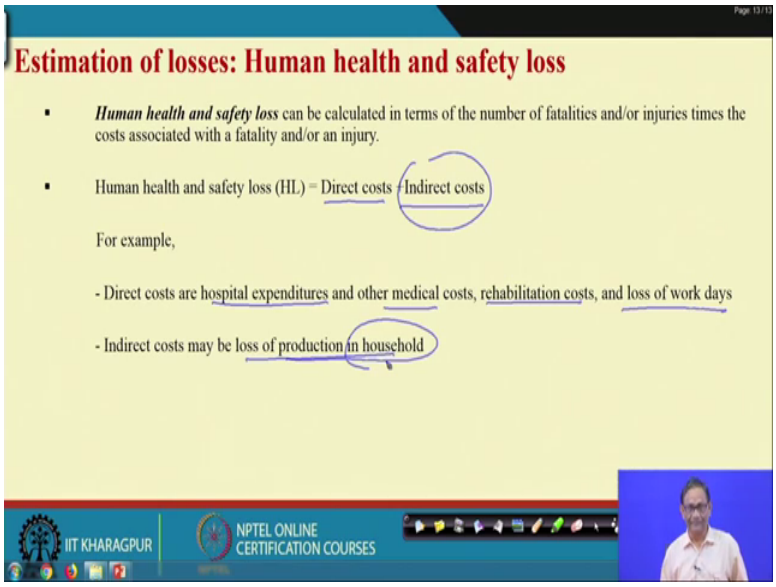

So, you have seen that how production loss is computed the formula we have given; now asset loss computation formula is given to you. Then comes to the human health and safety loss, please understand it is a very - very difficult one. So, health and safety loss, there will be direct cost and indirect cost. So, there, there can be fatality, there can be serious injury, there can be reportable injury, minor injury, first aid medical cases, so many things that would happen.

So, there will be direct cost means that immediately that compensations insurance other related things you will pay, indirect cost will be many, indirect cost will be basically the victims family will be suffering the, the ultimately you may lose a competent person. So, it is indirect cost is much more than the direct cost.

So, although I have not given much of computation issue where human health and safety loss so, but in the, in the paper what I have, I have given in the (Refer Time: 28:27) shows. Please go through, you will get little more treatment of these, but, but there are many many papers available where health and safety loss calculated different sense, direct cost and indirect cost are also identified.

So, for the time being you please understand that direct and indirect cost both to be considered. Direct cost maybe hospital expenditures, medical cost, rehabilitation cost, loss of work life, indirect cost of this loss of production in household.

So you required to true sense you required to compensate all those things and it is really very difficult and if someone dies so, there is I think no compensation is possible because you are not able to give back the life to that person ok. So, typical very - very that is sentimental as well as typical what I can say it difficult calculation then the last one what we will discuss today is estimation of estimation of environmental loss.

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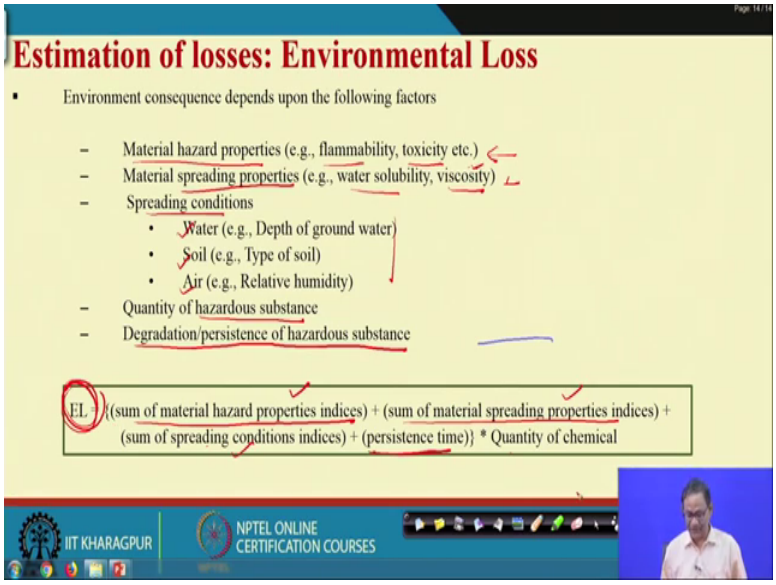

So, please understand it is again another that complex one and in order to calculate the environmental consequence, you required to have some knowledge of basically of the nature of the accident. And, how the during this accident environment particularly the water, soil and air they are going to be contaminated or polluted.

And how long the pollution will sustain? So, there are many factors. In fact, I have given in reference another paper which I published in journal of hazardous material this is Varunraj and myself has written this. So, that paper we have given elaborate treatment of all the factors and from different sources we have collected, we have taken data and then using fuzzy mathematics we have also quantified the loss. So, as those things are again little complicated in the sense you required to know all those mathematics.

So, for that, for the industrial safety engineering point of view that much detail things are not required. So, I am just giving you some of the that when a factors that you must consider while you go for environmental loss calculation. One is material hazard properties, flexibility, toxicity, etcetera. Then material spreading properties, water solubility, viscosity. Then spreading condition water, soil, air then quantity of hazardous substance which is basically going to be going to pollute this one going to be released; then degradation and persistence of hazardous substances ok.

So, what is degradation and persistence of hazardous substances, it requires a some kind of science behind the basically the spread of the; that means, that chemical or hazardous substance, ok. So, how long it will basically persist in the environment either it is soil water or air. So, then the environmental loss will be some of the material hazard properties indices. So, all those material there could be there are, there are many material hazard properties. So, there are material spreading properties. So, all those cannot be just directly quantifying in terms using some scale or some kind of your weight, it is not possible it requires some kind index because flammability is kind of measure, toxicity will be another kind of measure again in water solubility it will be another kind of measure.

So, you required to create some kind of dimensionless quantity which is called index. So, some of the material hazard properties index then some of the materials spreading properties index plus some of the material spreading condition index. So, all those index plus persistence time into quantity of that where we are we have developed it for chemical plant for that quantity of chemical which is basically the hazardous substance. So, if you, if you use this formula and all those indices, what I have given already in our paper.

So, then you will be able to quantify the environmental loss. But please keep in mind this will be in terms of index ok? Similarly the health and safety loss also may be quantified in terms of index where as production loss may be quantified in terms of rupees and your maintenance cost also may be quantified in terms of rupees. So, that mean different losses in different kind of measurement.

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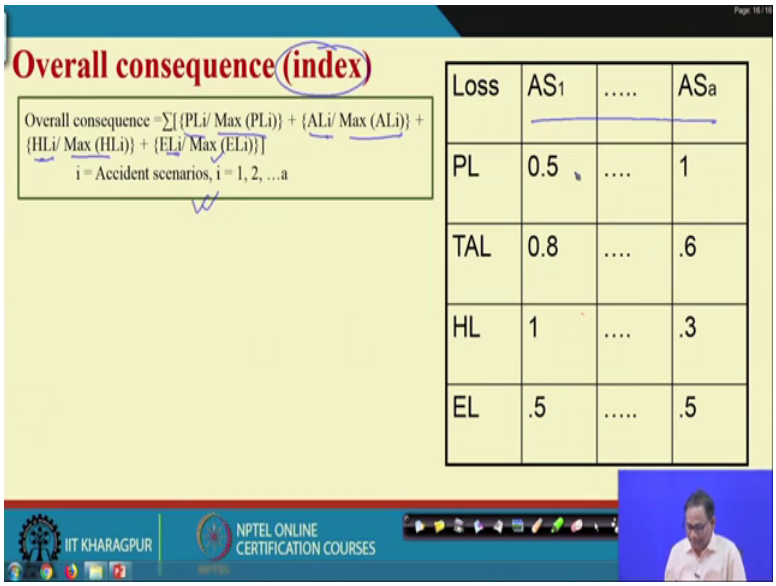

So, as a result what is the overall consequence? Overall consequence is your sum of production loss, asset loss, health safety loss, environmental loss, you can add other loss categories what we have discussed at the beginning in the beginning, but we have computed this 4. But as sum they are computed in different units, we are saying that you have to create an index. So, that production loss index is production loss by maximum production loss, asset loss by maximum asset loss, health and safety by maximum, this by maximum loss because you will be having different scenarios. So, for every scenario you will be having the all the 4 kind of losses.

And then if you calculate production loss in rupees and divide it by the maximum, maximum loss scenario then you will be getting index in the same manner index also all those indices will be added up and then whatever consequence value you got that is the overall consequence from accident point of view for your plan there are several hazards. All hazards ultimately lead to several accident scenarios. So, you have different accident scenarios and for every accident scenarios you have loss and those losses potential loss is, when you summed up as you have computed loss L i. So, that overall consequence L i consequence will be complete, ok

So, this is what is the some qualitative treatment of that is accident loss calculation; that means, what is the procedure, you know the scenarios, accident scenarios that is what earlier we have discussed and then for every scenario you find out the damage area then,

find what are the production loss will be there, what are the asset loss will be there, what are the environment loss will be there, what are the human safety and health will be there. And you can add the data loss you can add the brandling or the image loss or other important loss categories which are applicable to your organization or to the system for which you are interested to find out the consequence assessment ok. So, this if you compute loss in this manner, it is basically the I can say that exhaustive way of looking into the losses and its computation.

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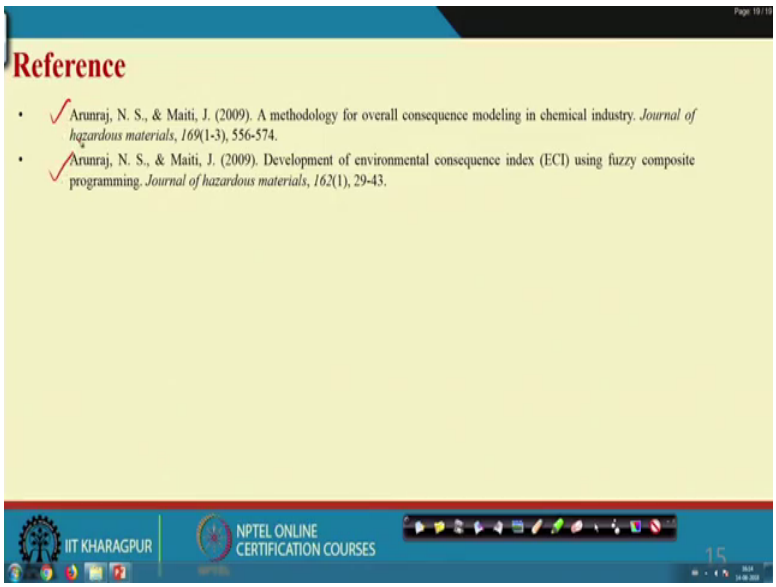

So, two papers in fact, both fortunately I am also the author. So, the second one environmental consequence index, here we have considered all those factors that material properties spreading properties, all properties in appendix all those index indices are given and from where which reference you found out that are also given and the first one which is basically in a short form I have presented today.

So, if you are interested to have a high better assessment then you may go through the paper and you can find out some more information, some more way of doing things. Because, we have used simulation and other things in order to quantify the overall consequences with reference to a chemical plant.

Thank you very much.