Urban Land use and Transportation Planning
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Lecture - 50
Vehicular Emission and Pollution Modelling

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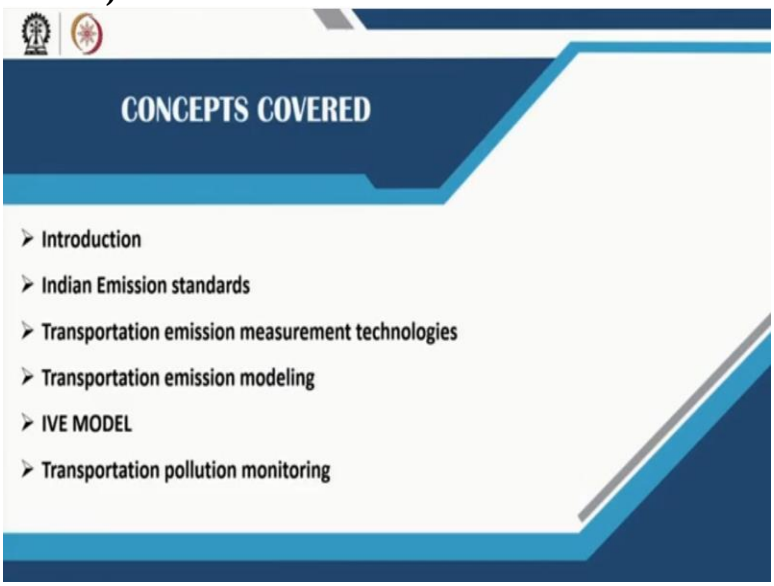

Welcome back. In lecture 50, vehicular emission, pollution modeling, Indian emission standards, transportation emission measurement technologies, transportation emission modeling, IVE model, transportation pollution monitoring etc. have been discussed.

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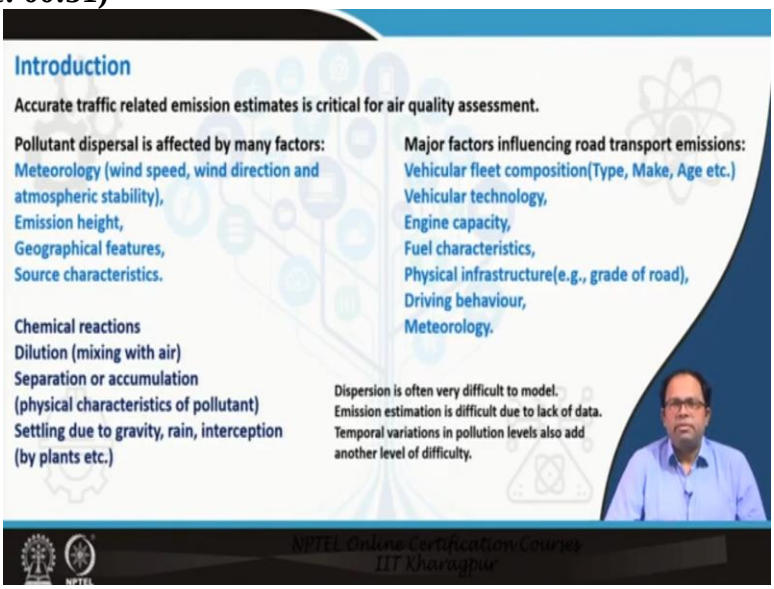

Accurate traffic-related emission estimation is critical to air quality assessment and is also required to understand the impact of traffic air pollutionand its health effects.

Emissions are the tailpipe emissions from passenger and as well as goods vehicles. When this emission gets diluted in the air, different concentrations of pollutants are found in the air whch is measured and is known as air quality assessment. There is also a need to determine what kind of health impacts does different levels of air quality has, but it is very difficult to measure. Hence there are air quality standards and different policies are designed to limit emissions to such a level so that the ambient air quality standards are not exceeded. The major factors influencing road transport emissions are vehicular fleet composition i.e. the different types of vehicles made by different manufacturers and their age.

The vehicular technology involved i.e. the technologies used in vehicles also play a big role. For example, all passenger cars may not follow the same technology as some maybe having a hybrid power train/ technology and some may use a certain kind of motor which is different from another particular vehicle and so on. The difference in technologies lead to different amount of emissions. Similarly, engine capacity (i.e. the size of the cubic capacity of the engine) also have a role in the total emission. Hence, we need to understand the vehicular technologies in use in a particular country or for a particular area. The amount of sulfur in the fuel is another issue. Physical infrastructure also plays a big role. For example, the amount of fuel consumption depends on the kind of road space, the grade of the road etc. which leads to different kinds of emission as well. The driving behavior in different areas and the metrology also varies from place to place. So, all these factors influence road transport emissions. A road with vehicles on it can be considered as a line source.

Once the pollutants are emitted, the next step is to understand how the pollutants are dispersed in that atmosphere, and this process is also affected by many factors. The main factors are meteorology which includes wind speed, wind direction and atmospheric stability. The boundary layer conditions and emission height also plays a big role. This is a much more complicated process than emission estimation.

Once the pollutants come out of the tailpipe it starts reacting since, these are chemicals. Thus, changes in their chemical properties, and their dilution or mixing with air also need to be considered. Thus, during emission measurement, it is important to note that dilution and separation or accumulation with different pollutants depends on their physical characteristics and these pollutants also settle due to gravity, rain, or due to interception by plants and other surfaces. Thus, these are the different issues that also need to be looked into during discussion related to pollutant dispersal. So, dispersion is often very difficult to model and it is even more difficult if enough data is not available. Emission estimation is not that difficult to model but it is difficult is to get the data related to different kinds of vehicles and different kinds of technologies that are in use at any point of time.Ttemporal variations in pollution levels also add another level of difficulty.

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Indian emission standards

Table 3 in the above figure shows the Indian emission standards which are currently adopted. For example, the first table on the left-hand side shows the 4 wheeler passenger vehicles standards. The standard followed now is the Bharat stage 5. Bharat stage 6 standard, is supposed to come into effect from 2020 nationwide. This follows the Euro VI norms which are very stringent. Hence, it is expected that, with the application of this particular standard the amount of emission will come down drastically. Standards are developed for 2 and 3 wheeled vehicles, heavy vehicles like buses and trucks, lightweight vehicles for passengers, goods carrying vehicles, and

so on. The emission standards are given in gram per kilowatt-hour for trucks and passengers because these are big vehicles. Different kinds of vehicles have got different kinds of emissions coming out of their tailpipe i.e. a car that adheres to Bharat stage 2 will emit different kinds of emissions compared to a car that adheres to Bharat stage 4.

Next, to determine total emission for a particular city or an urban area it is important to understand which vehicles belong to which category i.e. what kind of emissions, maximum emissions this kind of vehicle is likely to produce, and also the related technologies that have been used in those kinds of vehicles. Thus there is a need to determine the number of vehicles registered during a certain period in a particular area and under which emission norm it has been registered. This helps in understanding the kind of emissions that is possible to come out from those kinds of vehicles in absence of other data related to technology. However, emission also depends upon the wear and tear of the vehicle, the age of the vehicle, the number of kilometers driven, kind of technology used and the size of the engine, etc. This gives a very fair idea about what is the vehicular composition and what kind of emissions these vehicles emit.

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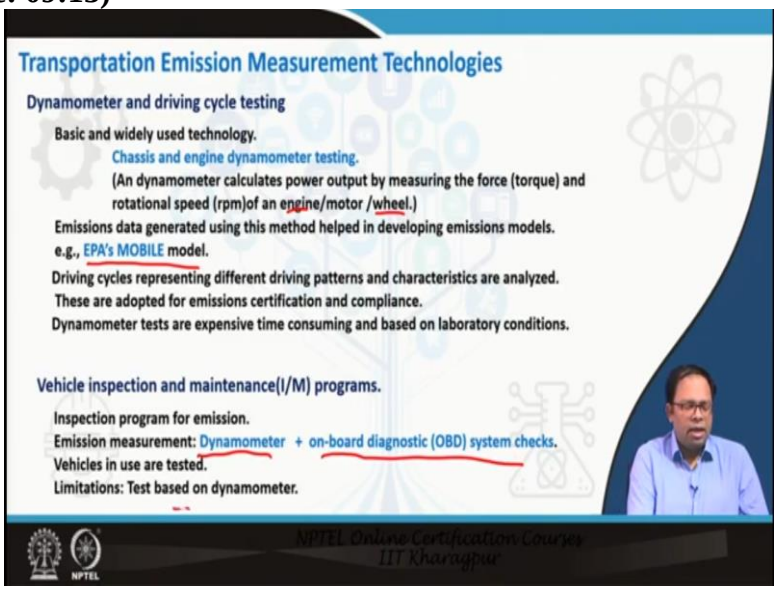

Transportation emission measurement technologies

Each vehicle emits differently and it depends on age and many other factors. So, it is important to understand how the transportation emission is measured and the model for determining emission is also based on that.

Dynamometer and driving cycle testing

The most common technology that is used is called Dynamometer and driving cycle testing. This is the most widely used and very basic technology. There are 2 forms of it. One is the chassis dynamometer testing and the other is the engine dynamometer testing. A dynamometer calculates power output by measuring the force or torque and the rotational speed of the engine motor or the wheel of the vehicle.

So, when it is wheel of the vehicle then it is chassis dynamometer testing and when it is directly the engine we can say it is an engine dynamometer testing. This kind of testing happens in the laboratory where the vehicle is accelerated or decelerated or moved in a steady state. The engine is run at a station and the emissions are measured. Emission data generate using these methods have been used to develop the EPAs MOBILE model.

Vehicle Inspection and Maintenance (I/M) Program

In any kind of emission model, the total kilometers driven and how it is driven i.e. what were the characteristics of that driving condition is measured. Emission factors for different kind of driving condition, for different kind of vehicle of a particular technology is determined. The engine RPM can be changed to see how the emission is increasing and so on. At first, this kind of emission models are calibrated which helps in determining the emission profile of different vehicles and how it changes with change in different charecteristics.

In the case of dynamometer testing, driving cycles representing different driving patterns and characteristics are analyzed and this is adopted for emission certification and compliance. But these are held in labs and requires a big testbed. Thus, this kind of testing is expensive and takes a lot of time and vehicle remains engaged as well. There has been a lot of criticism for this kind of testing but are still widely used and popular.

Then, there are vehicle inspection and maintenance programs. Each country has got its way to generate PUC certificates as in India, Pollution Under control Certificates are generated which is a vehicle inspection and maintenance program where the vehicle is inspected for emission.

Dynamometer testing is usually done when a manufacturer first produces a vehicle whereas, I/M programs are designed by authorities to test in-use vehicles based on the tailpipe emission coming out of them. For this measurement, usually onboard diagnostic (OBD) systems are used to measure rpm whereas, a dynamometer can be used as well.

The OBD systems are fitted with most vehicles nowadays. If it is plugged into the vehicle and the vehicle is revved, then automatically the RPMs and everything is recorded and the OBD system can tell what the engine revolutions were and this can be matched with the amount of emission coming out of the tailpipe. Thus, this is another form of testing or another form of emission measurement technology as well.

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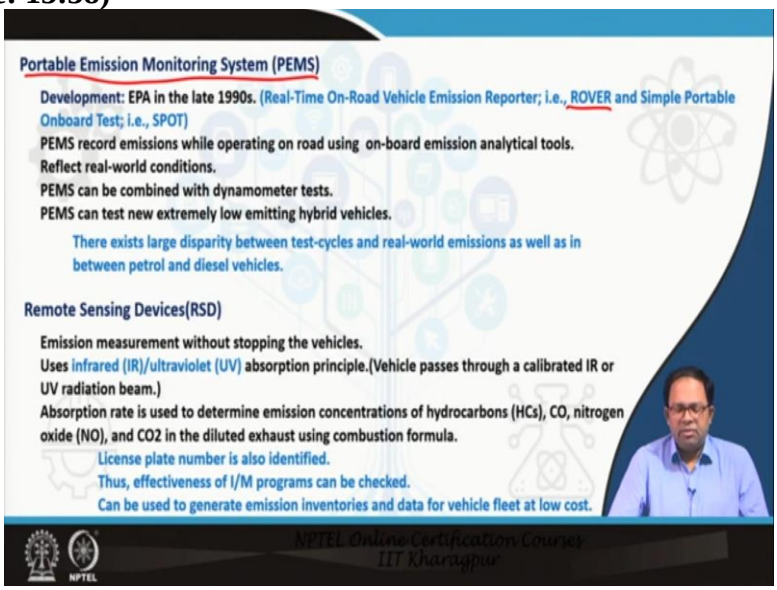

Portable Emission Monitoring System (PEMS)

This was developed by the environmental protection agency of the United States in the late 1990s. This is a real-time on-road vehicle emission test and initially known as Real time On road Vehicle Emission Reporter (ROVER) or Simple Portable Onboard Test (SPOT). PEMS record emissions while operating on the road using onboard emission analytical tools i.e. it is a real-world driving condition test and not a laboratory test and reflects real-world conditions. This kind of test can be done independently or it can be matched with a dynamometer test as well.

This can also detect very low amount of emission, particularly from hybrid vehicles. This kind of test showed that there is a huge amount of disparity between actual test cycles and real-world

emission i.e. the way vehicle has been tested in the laboratory and in the real world. These values vary significantly not only for different amounts of acceleration and deceleration but also between petrol and diesel vehicles as well. Thus, most of the models are currently shifting towards PEMS and many countries are also going towards this kind of monitoring system, which would be more stringent.

Remote Sensing Devices

This ensures that there is compliance with emission norms throughout the vehicles' drive cycle not only during testing but also during under operations. In remote sensing devices, instead of measuring tailpipe emissions, the test is done without stopping the vehicles. The setup is done beside the road with an infrared or ultraviolet beam and when the vehicle passes this beam, it can detect what kind of concentrations of hydrocarbons, carbon monoxide, nitrogen oxide, and carbon dioxide is there in the exhaust that is coming out of the vehicle. Thus, diluted exhaust coming out of a vehicle is measured based on the infrared and ultraviolet absorption principle and as soon as the vehicle passes, a reading from for that particular vehicle's emission is recorded.

This reading depends on many factors such as the environmental conditions, the concentration of other vehicles, the background concentration, etc. This kind of test is done, where not only the concentration is measured but also the license plate for this particular vehicle is recorded by taking a photograph. This kind of test is effective to test if our existing maintenance and inspection programs are being effective. While, most cars may have a PUC certificate, on-road, high levels of pollution may be observed. So, this is sort of a second check. This could also be used to generate emission inventories and data for vehicle fleet at a very low cost.

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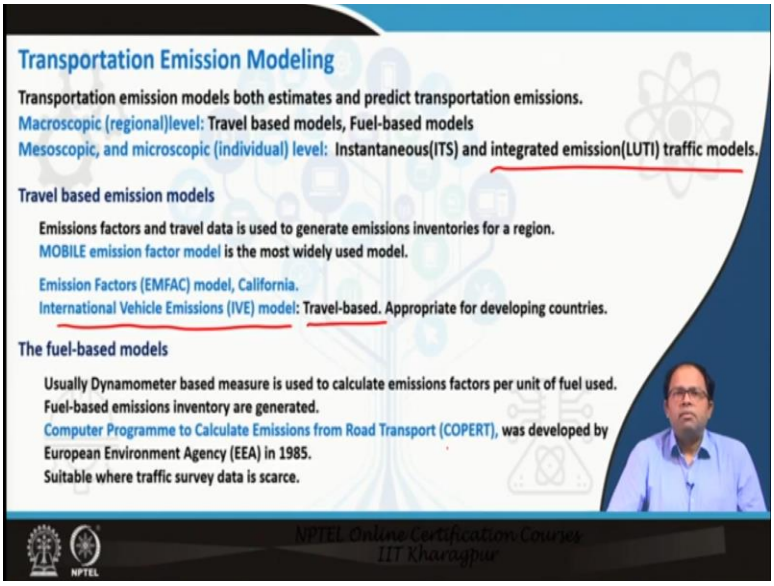

Transportation emission modeling

Data for the emission or rather the emission factors for different kinds of vehicles in different driving conditions are generated by using the tests discussed before and is used in transportation emission modeling. So transportation emission modeling is where transportation emissions coming out of different kinds of vehicles are estimated and predicted.

This model is done at the macroscopic level or microscopic level or mesoscopic level. Macroscopic level means regional level i.e. it could be at an urban level or for a zone level. It is measured how many vehicles are there in that particular zone and what is the total amount of emission coming out of these vehicles.

There are 2 ways to do this kind of estimation or modeling, one is called a travel base model and the other is a fuel base model. In the fuel base model, the amount of emission can be estimated based on the amount of fuel consumed. In travel-based models, the emission can be estimated based on the kilometers traveled. The microscopic models or mesoscopic cubic models are primarily related to individual vehicles or emissions for each car and are determined based on their particular driving patterns, their usage, age, and the other power characteristics of the particular vehicle.

Usually, there are 2 ways to get the data. First, it can be directly from the ITS which record vehicular flows and the different kind of vehicles passing through different points in the road as determined from the vehicle number plates. Next, it can be also determined as a part of the Land Use Transport Interaction modeling process, where from traffic assignment we can determine number and type of vehicles plying along a particular road along with other charecteristics like speed, congestion time, travel time etc. which helps in determining the resulting emission. These are integrated traffic emission models which are also used by many modelers these days. In travel destination models emission factors and travel data are used to generate emission inventories for a particular region.

The MOBILE emission factor model is the most widely used model. This is particularly used in California and the US. MOBILE is developed by EPA but used all over the world including India. These models have huge data requirements which are difficult to obtain in developing countries.

So, IVE model was also developed as part of an initiative where the entire process was simplified in form of certain emission factors and correction factors i.e., factors can be modified or kept as it is, and based on this emission can be estimated for developing countries as well. However, this also requires a huge amount of data. This model is again travel-based and it is appropriate for developing countries.

Different variants of this model have been used in India and many people have developed other emission models in India as well which primarily follow this particular international IVE model. In fuel based models usually dynamometer based measures are used to calculate emission factors, per unit of fuel used. Fuel-based emission inventories are first generated i.e from tax record or fuel sale record the amount of fuel that is being sold can be determined and then the dynamometer test can be used to determine emission based on amount of oil consumption. Different kind of cycles that a typical vehicle operates are determined and based on that, the amount of full usage can be estimated.

So, more or less the structure is similar to MOBILE model, but instead of travel, it is based on this fuel used. One of the popular oil-based model developed by European environmental agency is COPERT (Computer Program to Calculate Emissions from Road Transport). These models are suitable where traffic survey data is relatively scarce.

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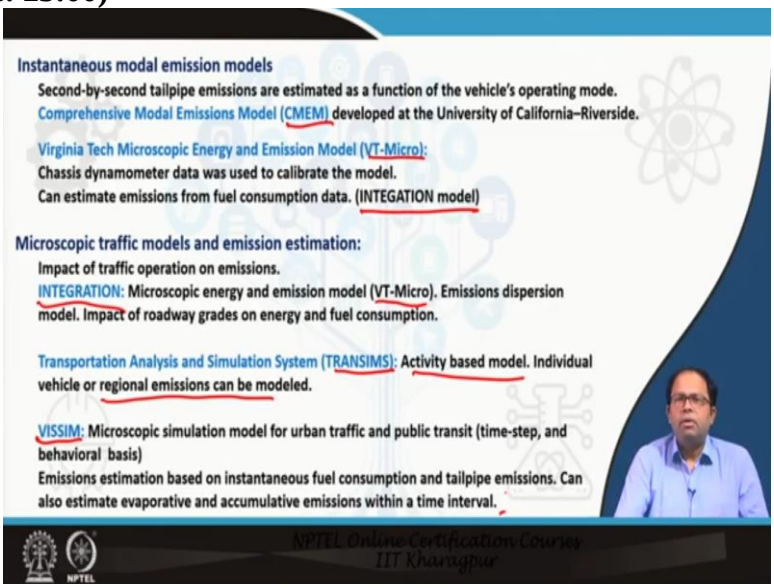

Instantaneous modal emissions model and microscopic traffic models and emission estimation are more or less related to more detailed calculation of emissions from tailpipes of vehicles. Instead of having an overall estimation, it gives us second by second tailpipe emission estimates as a function of the vehicles operating mode.

The amount of emission coming out can be measured depending on how the vehicle is being operated. One of the models of this particular type is the comprehensive modal emissions model (CMEM) developed at the University of California, Riverside. This model is based on chassis dynamometer data which was used to calibrate the model and it estimates fuel consumption and resulting emission in real time. This model is also integrated with another modeling framework which is named Integration. So, this integration model/framework is a microscopic traffic model. Another microscopic energy and emission model is VT-Micro developed by Virginia Tech which estimates energy and emissions at different conditions of traffic for of a particular vehicle and can be used with the integration model/framework. It is a fuel model that can consider impact of roadway grades on energy and fuel consumption. VT-Micro model is also calibrated

based on chassis dynamometer data and can estimate emissions at different kinds of traffic operation.

Transportation Analysis and Simulation System (TRANSIMS) model is an activity-based model (detailed discussed in module 12). In activity-based models, individual vehicles can be modeled to estimate its movement patterns which can be used to estimate vehicle wise emission or can be aggregated to estimate region-wide emission as well.

VISSIM is part of the PTV software suite where every vehicle (both passenger vehicles and public transit) in the traffic stream can be simulated. Then, based on the emission factors for each vehicle fraction, the total amount of emission generated can be estimated. Emission estimation based on instantaneous fuel consumption can be done along with evaporative and accumulative emissions within that time interval.

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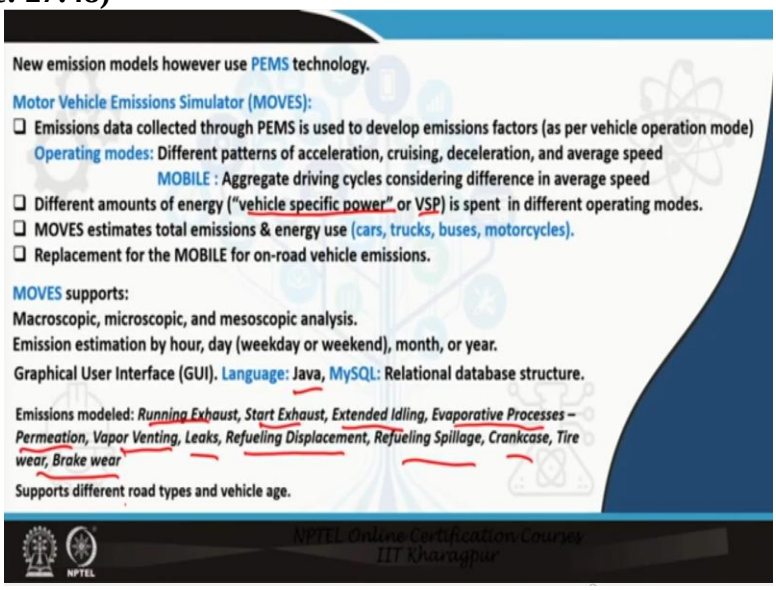

Additionally, new emission models are developed based on the PEMS technology. For example, the Motor Vehicle Emission Simulator (MOVES) is the latest model from EPA and is a replacement for the MOBILE model. This uses PEMS technology and the emission data is collected when the vehicle is in operation. Operation modes refers to different patterns of acceleration, cruising, deceleration and average speed. The types of emission generated can be determined based on an onboard emission monitor that can be used to determine the emission for that particular vehicle. MOBILE software uses aggregate driving cycles considering the

difference in average speed. However, in MOVES, acceleration, cruising, deceleration, idling of the vehicle etc. are considered which was not considered earlier. Thus, MOVES is also capable of estimating emission when a vehicle is parked but AC and vehicle engine is turned on. Different amounts of energy are spent during different driving cycles which also mean different amount of energy or fuel is being consumed. These are known as vehicle specific power (VSP) i.e. different amounts of energy spent in different operating modes. This VSP data has to be estimated. The VSP is calculated as an equation, which contains many of these factors such as acceleration, deceleration and gives a composite figure which can be used as a representation of that particular driving cycle or that particular operating mode. Thus, MOVES estimate total emission and energy use and it does it for different kinds of cars, trucks, buses, motorcycles and so on.

MOVES is gradually replacing MOBILE for on-road vehicle emissions as the most popular model. It supports macroscopic, microscopic, and macroscopic analysis. It can do estimation by the hour, by day, both weekday, and weekend, month, year or whatever is the desired period and it has a graphical user interface. It is built in Java and MySQL is the relational database (RDBMS) used. Database is required since MOVES use a huge amount of data which needs to be collected and stored. Similar to MOBILE and IVE, starting and running exhaust is measured. However, MOVES also measures extended idling evaporative processes and permeation, vapor venting leaks i.e. at certain temperatures the fuel vaporizes and a certain amount of oil vapor comes out which is also a type of emission, refueling displacement, refueling spillage, crankcase, tire wear, brake wear, etc. This is a very comprehensive model, but it is very difficult to get this kind of data for Indian conditions.

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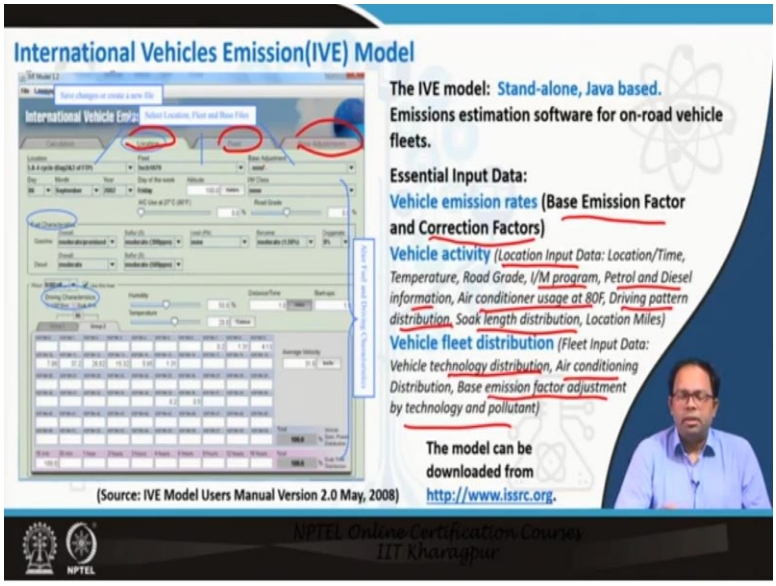

International Vehicles Emissions (IVE) Model

The international vehicle emissions model is a standalone model written in Java. Three essential input data has to be put in the model; vehicle emission rates, vehicle activity and the vehicle fleet distribution. The vehicle emission rate is the base emission for a particular technology of a particular vehicle type.

Different correction factors depending on altitude, technology, use of air conditioner, etc. are applied to the base emission rate in this model. Vehicle activity requires data input on location, time, temperature, road grid, the inspection maintenance program, fuel type used, air conditioning usage, driving pattern distribution, soak length distribution etc. Vehicle fleet distribution is the total amount of vehicles of different technologies with different air conditioning systems and base emission factors adjustment is done as per different technologies of the vehicle and the pollutant as well. So, these are the three basic input factors i.e., location, fleet, and base adjustments using which the total amount of emission that comes out from a particular vehicle fleet can be estimated.

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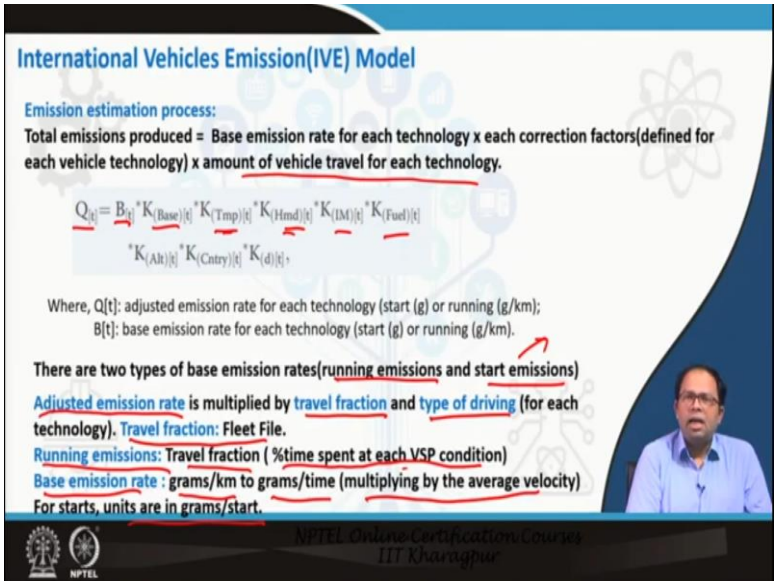

The basic formula for this model is the total emission produced for a particular area which is the base emission rate for each technology. There are approximately 700 technologies which are a combination of vehicle type, engine, fuel type, and so on. So, there are around 700 options to choose from. The base emission rate for each of these options and each correction factor are defined for each vehicle technology.

Then the amount of vehicle travel for each of this technology is also considered. There are 2 kinds of emission rates such as running emission rate and the start emission rate i.e. when the vehicle starts, there is a certain category of emissions, and then when the vehicle is running, another kind of emission happens. So, these are measured differently. When a vehicle starts it emits lot of emissions because of unburnt fuel and so on. If the numbers of starts are increased the emission also increases. There is a standard for running emission which depends on the speed in the IVE model. In the IVE model, the average speed of different driving cycles are measured and accordingly, the different emissions are estimated.

The emission rate will change as per the values of several factors such as temperature, humidity, inspection maintenance program, fuel etc. for a particular area. So, the adjusted emission rate is multiplied by the travel fraction and the type of driving i.e. a particular fleet, it is broken into different fractions of different technologies and the driving habits. So, this travel fraction comes from the fleet file and the running emissions are measured based on this travel fraction, that is

the percentage of time spent in each VSP condition i.e. a time spent at different speeds. The base emission rate for running emissions has to be converted from grams per kilometer to grams per time, since it has to be multiplied with average velocity or the speed in that particular driving condition. For the vehicle starts i.e. for the start emissions, it is in gram per start. In this way, the total amount of emissions coming out from different vehicle types can be determined.

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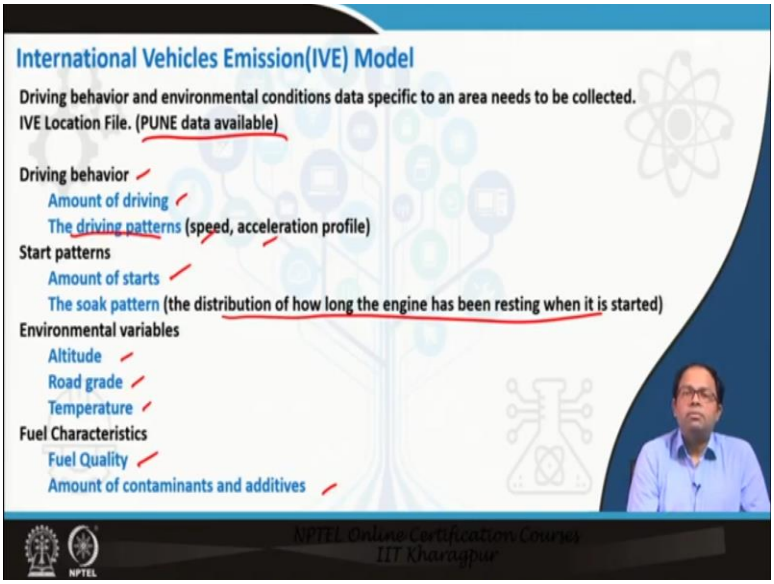

So, driving behavior and environmental condition data specific to an area needs to be collected. Data for running IVE model is available for many cities including Pune. Thus, if detail data collected for a specific city is not available, these available datasets for the driving cycles can be used. However, one must be careful since the driving cycle of Pune and Kolkata will vary or Pune or Delhi will vary.

Hence, different kinds of data needs to be collected like data on driving behavior(kilometers driven), the driving pattern(average speed, acceleration, other profile), the start pattern like the total number of starts, the soak pattern, the distribution of how long the engine has been resting, when it is started, then environmental variables like altitude, road grade, temperature, fuel characteristics, the actual quality and amount of contaminants and additives, etc. These data needs to be collected for different kinds of vehicles for different technologies and so on. Thus, a huge amount of data is required to run this kind of model.

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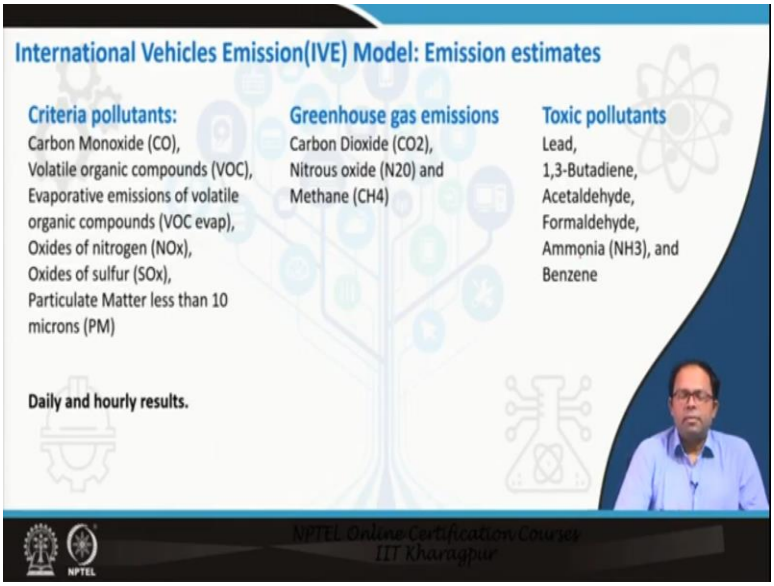

Finally, daily and hourly emission results for different criteria pollutants such as carbon monoxide, VOCs, evaporative emissions of volatile organic compounds, oxides of nitrogen, oxides of sulfur, greenhouse gases like CO_2, nitrous oxide, methane, toxic pollutants like butadiene, acetaldehyde, formaldehyde, lead, benzene, ammonia, etc. are found. After getting the total emissions for each of these particular gases or pollutants how they will spread in the atmosphere is modeled.

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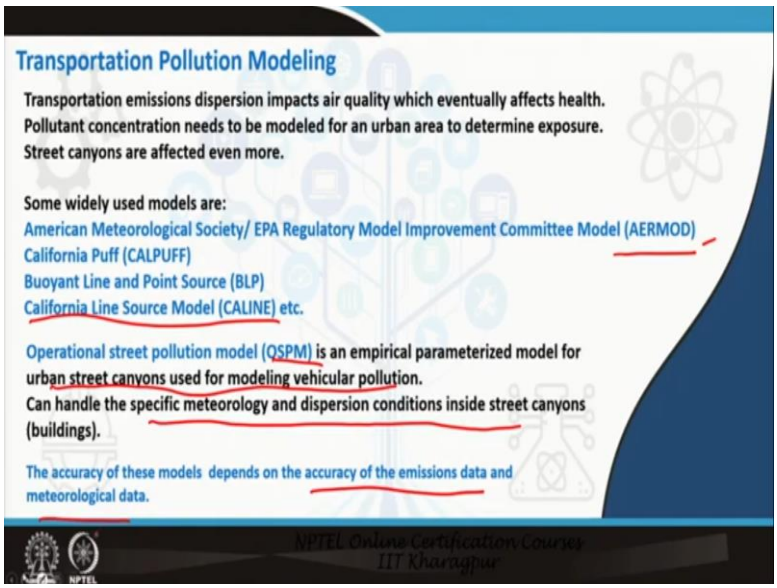

Transportation pollution modeling

Transportation pollution modeling is even more challenging as specialists are required. As a transportation modeler, one can end at the total amount of emission estimation, while

environmental enginners may model the resulting pollutant concentration as well. Pollutant concentration is not only related to the total emission, it also depends on meteorology, background concentration, other emitters, etc.

Transportation emission impacts air quality and eventually affects health as well. Pollutant concentration is modeled for an urban area to determine exposure. Street canyons are the most affected i.e., people living along major streets with high vehicular flow are exposed to high amount of pollution. There are different models for determing pollutant concentration. Some widely used models are the AERMOD (American metrological society and EPA regulatory model improvement committee) model, California puff model, Buoyant Line and Point source (BLP) and the California Line Source (CALINE) model. As these models are usually used for predicting line source emission, these are called line source models not point source models.

Whenever emissions are coming out from an industry or a stack it is called point-source emission. Since there are a lot of vehicles on a particular road, it is called line source emission. In addition, there is another model which is the Operational Street Pollution Model (OSPM). This is an empirical parameterized model that is specially designed for urban street canyons and for modeling vehicular pollution. This kind of model can be used to estimate the amount of concentration of pollutants in urban canyons. This model can handle specific meteorology and dispersion conditions inside street canyons.

The accuracy of emission dispersion/pollutant concentration models depend on the accuracy of the emission data and metrological data. A huge amount of metrological data is required to support this kind of models. There are usually some preprocesses where this metrological data can be generated based on some inputs and then those data can be also used as basic input for this kind of model.

These are the different kinds of transportation pollution modeling software that are used in conjunction.

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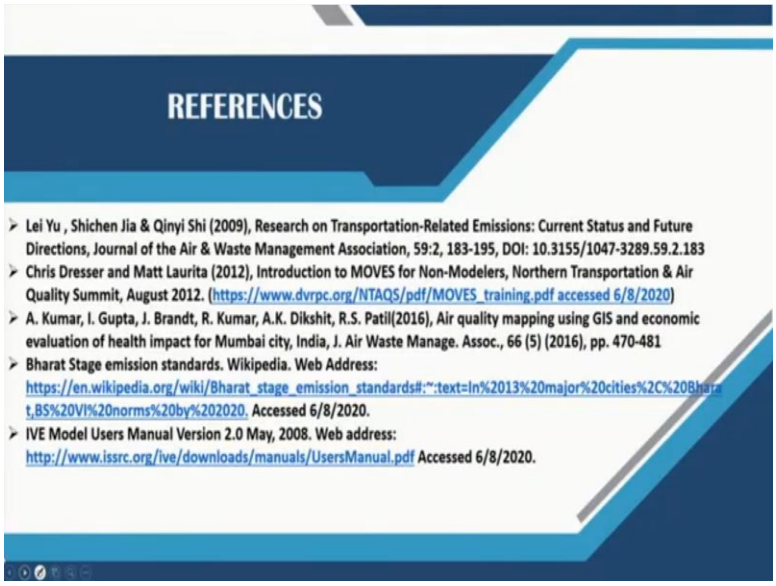

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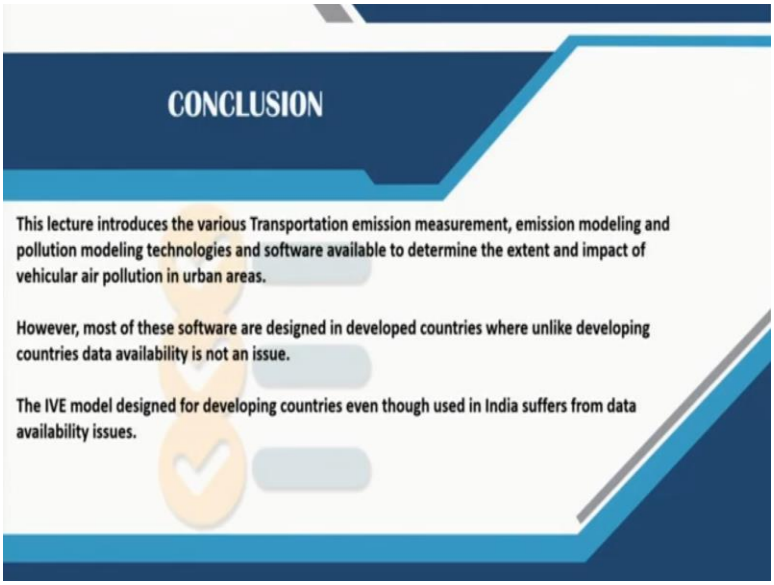

Conclusion

this lecture introduces the various transportation emission measurement, emission modeling, pollution modeling technologies and software available to determine the extent and impact of regular air pollution in urban areas. However, most of the software is designed in developed countries where unlike developing countries, data availability is not an issue and the IVE model designed for developing countries even though used in India suffers from data availability issues, and so there is a requirement for developing a more robust model for the Indian context.

Thank you.