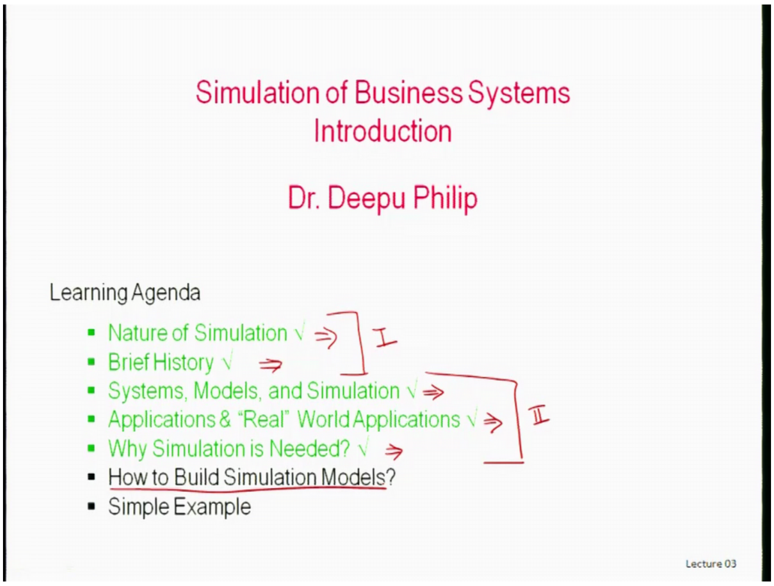
Simulation of Business Systems
Prof. Deepu Philip
Department of Industrial & Management Engineering
Indian Institute of Technology, Kanpur

Lecture - 03
How to Build Simulation Models?

Good afternoon everyone. Today we are in the new topic actually the continuation of what we were having yesterday's lecture about the Simulation of Business Systems and how can we use simulation to study business systems. You might have already seen that we have worked on multiple topics, about the simulation and introducing to you the language of simulation various concepts of it. And, today we will further go deeper into the topic and so, that you can understand the individual module of simulation systems. And, how can you use such modules to build a simulation model of a business system?

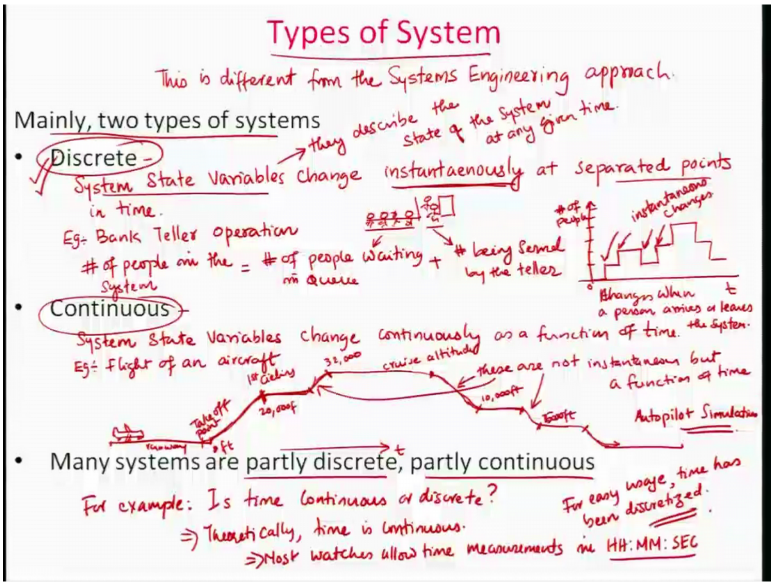
(Refer Slide Time: 00:57)



So, if you look at the learning agenda we already seen that we have studied the nature of simulation, in the previous lecture in the brief history. These things were covered in the first lecture ok. Then systems models in simulation the applications of it real world applications and why simulation is needed the advantages disadvantages this all we covered in the second lecture ok.

Now, today we will focus more towards how to build simulation models? That kind of a question we will try to indentify. And, the examples we will work on the next class to actually demonstrate, how an actual simulation works by hand? And, why it is intractable to do large simulations using hand you require a computer to do that.

(Refer Slide Time: 01:41)



So, first we will get into the concept of type of systems or types of system ok. And, there is in for the people classify again this is different please remember this; this is different from the systems engineering approach; systems engineering approach. So, we are talking about business systems here and business systems generally we are trying to create into what we call as a using simulation to study the system.

So, for us there are mainly 2 types of systems. The first one is the discrete system and the second one is the continuous system ok. So, what is a discrete system? Discrete system is a system where system state variables; system state variables change instantaneously, instantaneously; please check my spelling I am not very sure about my spelling instantaneously at separated points in time points in time.

So, remember we studied what is a system state variable? These variables what are they? They describe the state of the system, state of the system at any given time given time, that is a system state variable.

So, these state variables they change instantaneously at an instant they change like this quickly. At separated points in time ok. We will give an example is a Bank Teller Operation ok. And, remember we looked into some of the system state variables and, if we use one of the system state variables is number of people in the system ok. This is equal to number of people waiting in queue plus number being served by the teller. If you imagine a bank teller here is a bank teller and people are waiting in a queue in front of the bank teller, these are all individuals waiting in a queue and there is one person being served or maybe 2 people being served it does not matters.

So, then the total number of people in the system is the people who are waiting in the queue this one and the people who are being served sum of the. So, if you plot that in a graph on a time scale t. At initially when the time t equal to 0 and if you say here as the number of people, as the y axis. Initially the value will continue to 0 for some time and at a particular point, when one person arrives this number will go to 1 1 2 3 4 5 6 like this. And, then it will continue and then one person more arrives it goes to 2 continuous and at some point of time this first person's service gets done. So, it is goes down to 1 and then it continuous like this for some time and then maybe an another arrival happens then it goes to 2 then it goes to 2.

And, then it remains for some time then another arrival happens it goes to 3, then it comes down to 2, then comes down to 1, then it continues like this ok. So, this depends upon this changes, when a person arrives or leaves the system. So, these are all these things that you see, they are instantaneous changes. Only at a particular instance the system state changes and then it continues in the state for sometime then it changes again ok. So, such type of systems are called as discrete systems for the purpose of simulation. So, then and what would be a continuous system, continuous system will be something where systems state variables change continuously as a function of time ok.

One of the examples of this would be flight of an aircraft; flight of an aircraft. So, if you think about it; if you think this is being the runway and then here is an aircraft standing here it is wing ready to fly. And, this is a runway and then it flies then from here it takes off and it flies to some level, then it again flies to some level, and continues then it descends to some level, continuous and then descends and then here is another airport where it finally, comes and lands ok.

So, if you think about it in (Refer Time: 08:05) and here is time ok continue. So, at every instance of time the aircraft is doing something things are changing it is not instantaneous. Even, if it is gaining altitude once it takes off let say this is the take off point ok. From here let say this is let say first ceiling or something like that ok. Let say 20000 feet or something the aircraft does not go from 0 feet to 20000 feet in like instantaneously, it takes time to climb ok. So, this is the continuous variation.

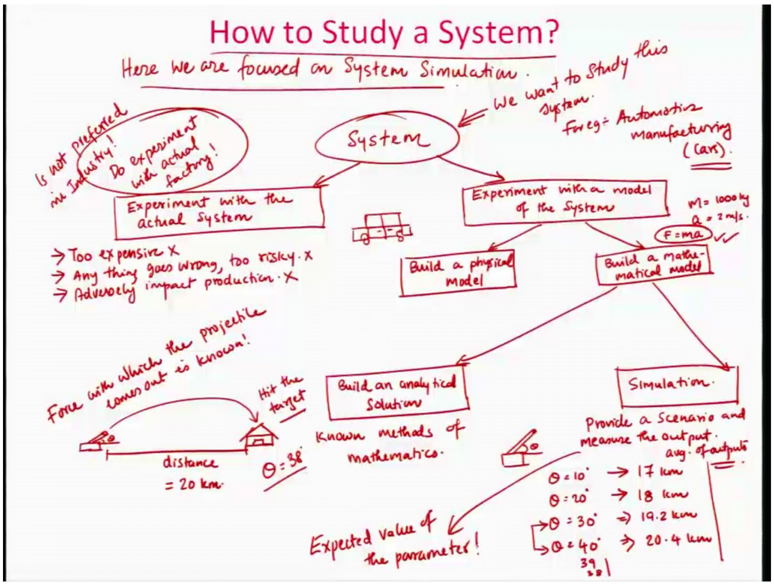
Similarly, then it might continue in 20000 feet for some time then it will go to maybe 32000 feet ok. So, this will be the second set of climb then this would be probably it will stay in it is cruise altitude ok. And, then from here it may come down to the 1 altitude let say 1000 feet ok. And, then stays in this then maybe it come down to 5000 feet ok. And, then it comes and lands something like this.

So, all these changes ok. You can see that these are not instantaneous, but a function of time all these changes ok, these changes these changes they are all functions of time. So, such kind of a system where the system state variables change continuously as a function of time and this is important, because this kind of systems are also simulated. For example, autopilot simulations they include studying such kind of continuous systems.

The only difference is that mostly in this course we will be focusing more towards discrete like systems as, we are more interested in discrete systems, rather than continuous systems will only look at few examples of continuous systems in the class. And, in realistically many systems are partially discrete and partially continuous. So, for example, is time continuous or discrete ok. So, this is a interesting question because time by rule is continuous ok. We can say theoretically time is continuous, but the watch that you wear you can only measure the time in seconds.

So, most watches allow time measurements in hour, minute and seconds not the other values. Why because for easy usage time has been discretized; first discretization allows us to study the systems quickly ok. So, that is why we actually discretize time. So, if you look at your watch you will see that the second’s clock tick tick tick and that tick is by the seconds that is what happens. So, I hope you will now understand the concept of what is called as a discrete system and what is a continuous system. And, as I said earlier we are going to focus more towards the discrete systems.

(Refer Slide Time: 12:05)



Ok. So, now, the second question is the next biggest question is how do we study a system, what are the ways in front of us to study a system? Again, as I want to remind you guys here we are focused on system simulation not systems engineering ok. So, we are going to study how were we are trying to find out how we are going to study a system. So, let us assume that this is a system that we want to study a system. So, we want to study this system. Let us assume that you want to study this particular system denoted by there are 2 ways we can do it ideally ok.

So, the 2 ways; the first option is to we make a big rectangle experiment with the actual system. Second option is experiment with a model of the system ok. So, assume that you have a car manufacturing facility ok. Let us say for example, automotive manufacturing, let say we are interested in manufacturing of cars 4 wheeler ok. So, one way to do it is actually do the experiment with actual factory this is means do experiment with actual factory.

This sounds good and this is probably the best way to do the experiment, but this has it is own inherent disadvantages. What are those inherent disadvantages? Number one too expensive, nobody will give you a factory to play around with ok. Second one is anything goes wrong, too risky. And, the third one is adversely impact productivity impact production. The job of a factory is to produce cars; this car manufacturing factory the aim is to produce cars, not to allow you to conduct experiments with the system. So, because of this expense and the riskiness and the adverse impact on the production this approach is not preferred in industry.

While, if you want to try a weapon, then as you do how to make a weapon and then drop the weapon and find out how the weapon is, but if you want to study about a factory it is almost impossible for you to expect that the factory will come to you somebody will give you the factory to do the experiments. So, the second option is experiment with a model of the system. So, here also we have 2 options ideally speaking the way to do this is first used to build a physical model ok.

Physical model is like a model of the system, which has how do you put it the like for example, if you are building a car. So, some people will say I will take play like if I draw something like this. It does not look like a car much, but if you see something like this and then put 4 wheels on it then you will say oh this looks like a car. So, I can actually make a physical system of this also I can make it in using the actual materials and build a physical model of it, other option is I can build a mathematical model of it build a mathematical model.

So, I want to I can say that the mass of the car is equal to 1000 kilograms and I want to accelerate it at 2 meter per second or something like this. Then I can find out the how much of force is required using the mass into acceleration and something like that. So, then this mathematical model will be applicable to car, jeep, motorcycle, bus, whatever it is. So, these kind of systems is called as a mathematical model. So, you mathematically represent the system ok. Then in the mathematical model again you have 2 options ok. So, I am kind of drawing it little far away the first option is to build an analytical solution.

And, other option is using the simulation ok. So, using an analytical solution is by you know non methods of mathematics ok. So, an example of this would be one way to think about it is what would be the best example to do here. So, let me give a simple example you want to let us say here is a gun with a (Refer Time: 18:43) and here is a target ok. And, you want to find the angle theta at which you need to fire, so, that it will come and hit the target ok.

So, if you know the force with which the projectile comes out then you need to find out is known, if you know that then you know what is this distance ok, and then using this you can find out that at what angle you need to fire so, that the a projectile will reach this particular distance so, that you can hit the target ok. So, you can solve for the theta you know and then you are able to identify it is you fire at 38 degrees then you will be able to hit this targets on like this ok.

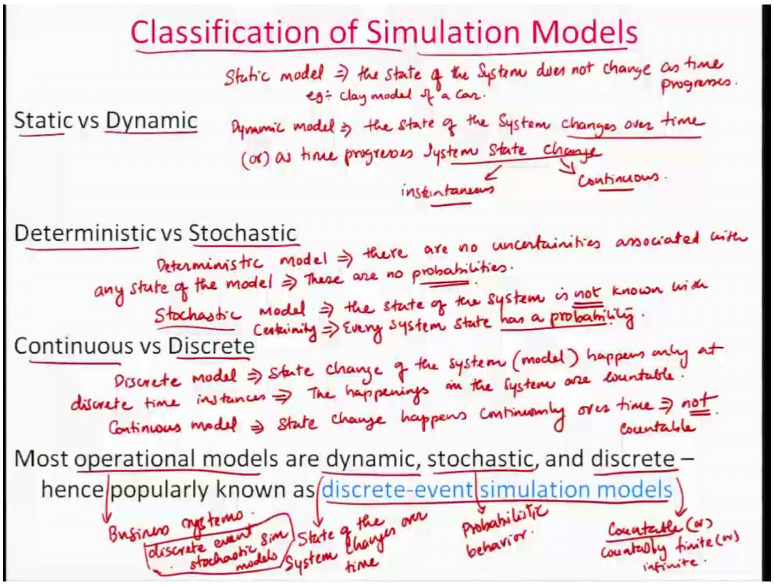
So, this is the analytical approach. In the simulation it would be a numerical approach. So, what you could do think about it is you can say that here is the gun and here is the barrel ok, then you can say here is the theta and then you will say I will start with theta equal to 10 degrees and then find what is the distance? So, let us say let us assume that this distance equal to 20 kilometers ok. And, then you find out that it reaches 17 kilometers ok, then theta equals to 20 degrees you find out that it reached 19, 18 kilometers. And, there is a theta equal to I am just giving you an example 30 degrees it reached 19.2 kilometers and theta equals to 40 degrees then it reached 20.4 kilometers.

So, now you know that the desired angle is somewhere between 30 and 40 ok. And, then you can basically figure out it is 40, 20 is close to this. So, I might start reducing from 40. So, I might do now 39 then I do 38 like this ok. So, this is one way of numerically studying the system you are trying to simulate the behaviour of a system for different range, different thetas, and then find out which one would actually work for it.

It is kind of same way what you actually do is simulation is you provide scenario and measure the output, then once you how many such outputs then you find the average of outputs ok. And, then use this averages I am just giving you a broad example, but what you are looking at is you are looking at the you know, what the something called as the expected value of the parameter is what you are looking at some point of time, you will see what is an expected value and all those aspects let it later (Refer Time: 22:02).

But, for the time being let us I hope this will give you an rough idea of how the simulation and analytical model actually works ok.

(Refer Slide Time: 22:14)



Now, from here let us look into what we call as the classifications of the simulation model ok. Most of the simulation models that are built for studies are classified into multiple option. The first classification is static versus dynamic ok. So, static model means model implies the state of the system does not change as time progresses ok. So, for all practical purposes the system remains constant there is not no change it. So, an example of this will be a clay model of the car ok. You built it and then once you present the design it just stays there nothing is going to change.

Dynamic model on the other hand what happens is the state of the system changes over time or as time progresses system state changes. This change can be either instantaneous or it can be continuous ok. It does not matters the important thing is as time progresses the state of the system changes ok, that is a most important.

Second type of a classification is what we call as deterministic versus stochastic ok. So, deterministic model means deterministic model implies there are no uncertainties associated with any state of the model ok. How do I put these that there are no probabilities, you know that is what is going to happen and that what it is there is absolutely no probabilities that are associated with this. So, the system is deterministic ok.

On the other hands stochastic model implies, the state of the model state of the system is not known with this is the most important thing not known with certainity or it implies that every system state has a probability ok. So, there is a probabilistic occurrence associate with every system state ok. Such kind of a system such kind of a system that a model that makes such a system is called stochastic model ok. So, there is one option is deterministic and stochastic.

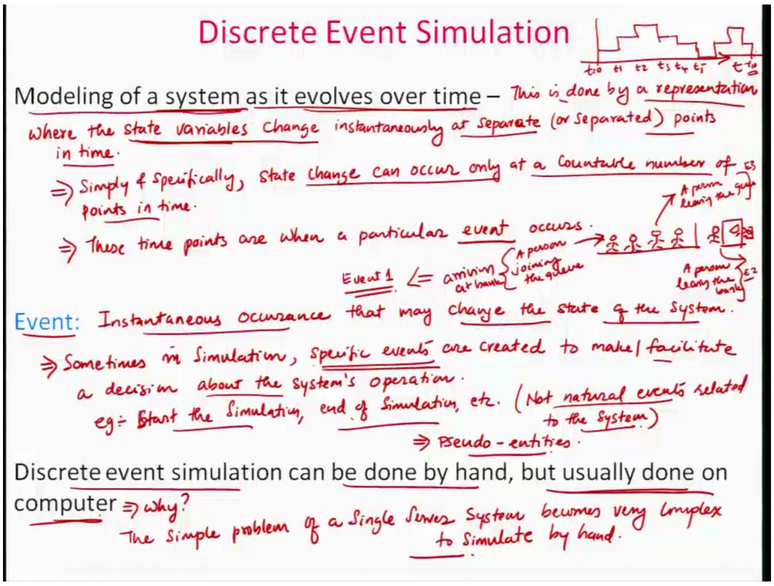
Then the third one is continuous versus discrete, we have already discussed with this. So, discrete model implies state changes state change of the system, if the system changes are which also means that is also applicable to the model. The state change of the system or the model happens only at discrete time instances or in a way that or we can think about that is the happenings in the systems in the system are countable, since it happens in discrete instances you can start counting it now ok.

Whereas continuous is the, the opposite of the same state change happens continuously overtime which implies not countable ok, you are not able to count what is happening over time in the system. So, hence for our course mostly most of the operational models most of the models that we are going to study. This operation models in this case we are talking about is the business systems ok. Most of the business systems for which we build operational models are dynamic, dynamic means the state of the system changes as over time.

So, the system will change the so, we will say it as state of the system changes over time then this is also stochastic which means probabilistic, there is a probability component probabilistic behavior. So, the system occurrences different aspects of the system or different states of the system are not known for certainty, but the occurrences is associated with a particular probability.

Discrete means the system is countable ok, countable or countably finite or infinite. So, it happens at the specific instances of time and those instances or occurrences are countable as far as here concerned ok. So, what? So, now, in our case hence we actually study more on discrete event simulation model. The right phrase for this is actually, what we are going to study is what we call as I was just going to write it here a discrete event stochastic simulation model ok. That is what we will be focusing more in the class ok, discrete event stochastic simulation models.

(Refer Slide Time: 29:51)



So, as we said earlier the discrete event simulation. So, in our case we are modelling a system ok. The system is studied as it evolves over time. So, the system evolves over time. So, how do we do that? This is done by a representation, this is done by a representation where the state variables change instantaneously, at separate or separated points in time.

So, what we are talking here is that, we are modeling the system ok; we are modeling the system as it evolves over time. And how do we are doing is, we are doing this by representing the state variables or the state variable changes are represented in instantaneously at separate points of time ok. So, the things happen as I drew the graph earlier ok. As, time progresses the system state is drawn something like this ok. As, time progress will come down then it goes up again, then it comes down stuff like this ok.

So, such kind of instantaneous changes at separate time intervals so, if you say this is t equal to 0 this is t 1, t 2, t 3, t 4, t 5 etcetera. These are individual separate time instances ok. Or in a better way the simply (Refer Time: 31:51) we can say that simply and specifically ok. We can always say that state change can occur only at a countable number of points in time.

So, we are modelling the system where the state change can occur only at a countable number of points in time. So, we can say how many events happened 1 2 3 4 5 6 7 8 9 10 you can actually count, you can say that here t 10 so, 10 events happened. So, because of this countable number of points in time you can do this. And, these time points these time points are when a particular event is a new word for you event occur.

So, what is an event an event is something like if you talk about this is a particular happening that. So, what is an event we are going to talk about it, but remember if we talked about the bank teller example people are waiting in a queue here 3 people are waiting. And, here is the bank teller sitting in a chair and there is a computer right next to it. And, here is one person getting served. So, as of now the number of people in the system is at a value of 4.

And, let say one more person came and joined the queue, then that that instance that particular time instance the system state changes. Because, now the number of people in the system because 1 2 3 4 plus 1 5 and from that time period onwards until the next person comes or the person leaves, the state of the system continues to be in the same place.

So, this kind of when the person joined the queue or a when a person leaves this is what we call as a particular event. So, let us just define what is an event ok. An event is instantaneous occurrence; instantaneous occurrence that may change that may change the state of the system ok. So, what we are talking about here is an event is an instantaneous occurrence that changes the state of the system. So, when I said a person arriving ok. A person joining the queue ok, which in another way we can think about it as arriving at bank this is one particular instance that is an event this translates to a event; Event1.

Another example of this is a person leaving the bank this is another event ok. Event 2 and the person can leave then another person leaving from the queue ok. A, person leaving the queue this is E 3, Event 3 like this. So, there can multiple events can happen and any of those events happening will change the state of a system ok. So, that is exactly what is called as a event.

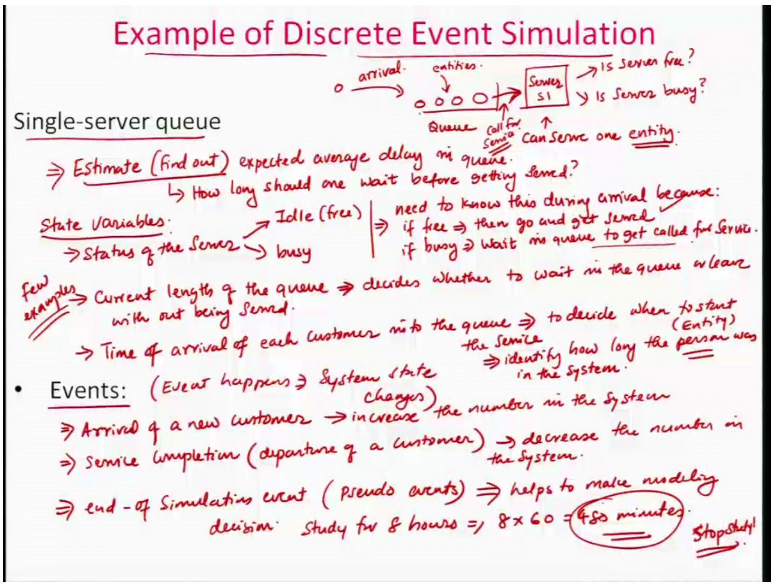
So, in another ways sometimes in simulation ok, specific events are created to make or to facilitate to make a decision or facilitate a decision about the systems operation the systems apostrophe s operation.

So, sometimes other than the natural events that are happening you might have to create specific events very specialized events. So, what are that kind of a specialized events an example of this will be start the simulation ok, end of simulation etcetera. So, these kind of specialized events that are created for you to learn or facilitate the simulation model or operation of the system is what they also events. They are not really that these are it can also be not natural events related to the system ok.

So, hence some people also called this as pseudo entities ok. When somebody says pseudo entities; that means, we are referring to these kind of entities, which are not really natural events related to the system, but is created to facilitate a decision about the systems operation whether the simulation need to be started or simulation need to be ended that that kind of a thing. Also, the discrete event simulation can be done by hand there is not no rule that you have to use a computer do it, but it is usually done by a computer why, why do we usually do it with the computer?

The simple problem of a single server system ok becomes very complex to simulate by hand ok. If you are going to do the simulation by hand be prepared to be there for a long time period because, these are not very easy to do ok. So, hence we usually use a computer to do it, but we will do a very small simulation the class for you to make you understand the various aspects of simulation ok.

(Refer Slide Time: 38:54)



Now, with that we will move into what we call as a the example of a discrete event simulation, which is important for us let see what are the major examples that we are going to take. So, as I mentioned earlier that the single server queue or a single server system is a very simplesting system, but it is quite hard to simulated with hand. So, a single server system is something that you can imagine this way, here is a server S 1 single server only one person is there at service and the single server can you can think about it as can serve one entity ok.

Now, the questions is what is an entity? We already studied what is an entity, they are the items things that flow through the system you already study that. And, there is a queue and the entities wait in the queue these are entities. So, what happens in a single server system is that, you know an entity arrives it is an entity arrival when it arrives if it sees that the server is free ok. So, the 2 questions is server free or is server busy?

If the server is free then immediately go get served ok, if the server is not free then join the queue and wait in the queue and when your turn comes in you will be pulled from the queue. So, this is the call for service. So, this is one of the most excuse me simple systems that you can see ok. So, what is the one of the most important aspects of this, why people study such systems. The main thing is to estimate or you want to find out want to estimate or find out expected average delay in queue ok. Or you want to find out how long should one wait before getting served. This is the big question that is to be answered as part of this, how long you should wait before getting served. Ok. That is why you study a system like this.

And, what are some of the state variables of this the major state variables include one is the status of the server ok. There are 2 options in front of this one is idle or what you call as free, the other one is busy servicing someone ok. So, you need to know this during arrival, because if free then go and get served, if busy wait in queue to get called for service ok.

So, the server is free then you go and get served, if the server is busy then wait in the queue to get service. So, this (Refer Time: 42:55) is important for you to know when a entity arise into the system. So, this is one of the state variables.

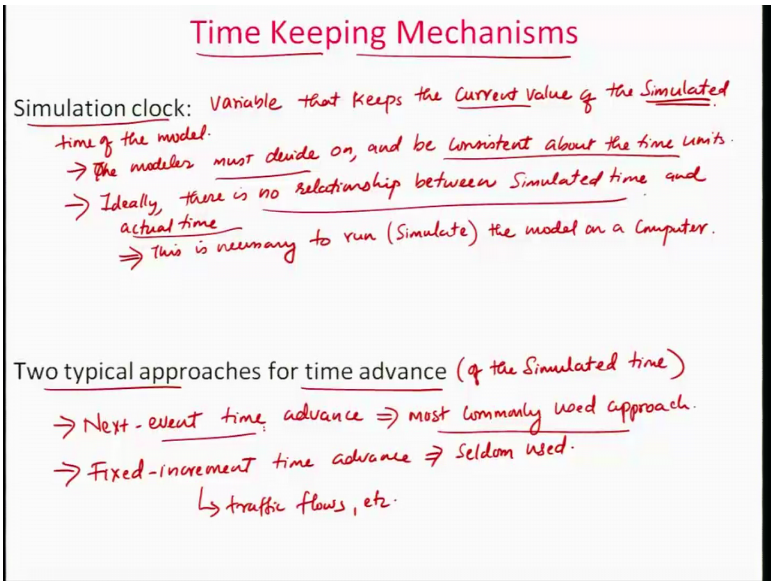
Then, other aspect is current length of the queue ok, you need to know this because decides whether to wait in the queue or leave without being served. Sometimes when you actually go to a place and see very long queue there then what people do is that people sometimes say I am not going to be here I will leave and I will come back later ok. So, such kind of a decision happens for that you need to know what is the length of the queue. Then another state variable these are not all the state variable these are few examples what we are talking about ok.

Now, the third one is the time of arrival of each customer into the queue ok. This is required to decide when to start the service also helps you to decide identify how long the person was in the system? If you want to find out how long the person or how long the entity, when you think about the person as a entity ok. How long the person or the entity was in the system is another aspect that is related. So, these are few examples of the state variables of the system that tells you how the state of the system or how the system state behave? Ok.

Similarly, about events some of the major events are arrival of a new customer. So, when an event happens event happens implies system state changes ok. So, when an when a new customer arrives then the number of the people number of the queue everything goes up by 1 then service completion or departure of a customer. So, when the service is completed and a customer departure from the system then that is also it will reduce the number in this system. So, here it will increase the number in the system in this case it will decrease the number in the system ok.

Then we can also have end of simulation events or we can think about the pseudo-events this is helps to make modeling decision. So, if you say that I want the bank to simulate for 8 hours, if you say study for 8 hours which is equal to 8 into 60, 480 minutes. So, you say that the clock keep on ticking and as soon as you click reach the 480 minutes stop the study stop study. When this happens then you see the reports and other things. So, this is not a actual event it is a pseudo-event which allows you to do the what we call as the modeling decision off the system.

(Refer Slide Time: 47:38)



Now, as the other major thing that we also need to do is how is this time being kept in the system ok. This is a important aspect of the system, because the time keeping mechanism is quite significant for our work ok. So, the first thing is what we called as a simulation clock ok. So, what is a simulation clock it is say simply a variable. Say variable that keeps the current value of the simulator time of the model. It is not the real time that we talk about we are talking about the simulated time the time is simulator time we are not going, if you are going to study the system for 8 hours; that means, that does not mean that you stand in front of the computer for 8 hours and observe it. The simulator time is way faster than the actual 8 hours that is the reason why you use simulation ok.

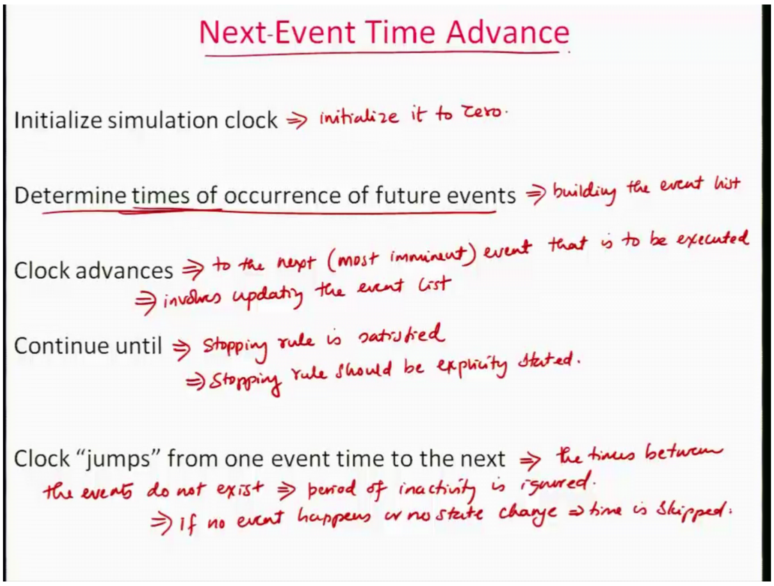
So, this actually variable that keeps the current value of the simulated time of the model. It, what it does is the moduler must decide on and be consistent decide on and be consistent about the time units. So, if you say that I am going to study this time in minutes then stick with minutes do not keep on changing things here and there ok. Ideally there is no relationship between simulated time and actual time so; that means this is necessary to run or simulate, when you use the word run it is also equivalent to simulate the model on a computer ok.

So, you are having what we call as the you know simulation clock a variable that keeps the current value of the time. And, the modeler must decide on initially and be consistent about the time units. And, there is no relationship between the simulated time and the actual time. And, you require this because you want to literally run the model on a computer. And, there are 2 approaches 2 typical approaches are used for the advancing the time or to do the time advance of the simulated time we are talking about the simulated time how are we doing this? Ok.

The first one is the next event time advance ok. You identify what is the next event that is going to happen and then the do the time advance. This is the most commonly used approach this is one example. Next one is the fixed increment time advance ok; that means, the clock will advance by every 5 minutes and then the system states are measured at every 5th minute ok. This is Seldom used not very common, but this is typically used in sometimes in studying traffic systems like traffic flows etcetera, but not very commonly used the most commonly used one is the next event time advance approach ok.

So, with this what we will do today is that we will stop today's actually we will continue with one more slide and then we will stop after this.

(Refer Slide Time: 52:07)



This is the we will talk about how the next event time advance work and then we will stop today and then we will come back in the next class. So, what happens is how does a next event time advance work? So, first what you do is you initialize the simulation clock. You initialize it to 0 that is the first thing you need to do. Then so, you start with the time t equal to 0, then determine times of occurrence of future events ok, this is called building the event list.

So, you are here to build the event list. So, you build the event list and from there you determine the times of occurrence of the future events. Then, what happens is clock advances, where does the clock advances to the next or the most eminent event ok. That is to be executed. So, you advance a time to the next or the most eminent event to be executed and this involves updating the event list. So, what happens is you remove it from the event list and then you, once it is executed you removed from the event list and then next one comes up in the higher in the order. And, then continue until when how long will you continue, continue until stopping rule is satisfied rule is satisfied ok. And, stopping rule should be explicitly stated should be explicitly stated ok.

So, that is the continue until then clock jumps from one time one event time to another next event that which means the times between the event, between the events do not exist which means we are only in the period of inactivity is ignored ok. So, implies if no event happens or no state change time is skipped ok. So, this is how the time gets managed in the simulation. So, hopefully this was now make you understand that how the and when you do an example a complete example then you will get a clean idea how to do it and go from there. So, hopefully you guys understood the more advanced or internal modules of the simulation and how the inner workings of it. And, in the next class we will do an example. So, that it the concepts becomes crystal clear to you. Thank you for your patience listening and please read the text book so, that you can be updated on to be a concepts.

Thank you very much.