Sustainability Through Green Manufacturing System: An Applied Approach

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Lecture - 05
Introduction to Simulation Continued

Good morning, welcome to the course on Sustainable Manufacturing; Greener Sustainable Manufacturing. We have been going through various aspects, tools and techniques required to realize or convert existing manufacturing system to a sustainable or a green manufacturing system. And we have covered quite a lot of aspects of it; we talked about the hierarchy of the manufacturing system, what are the factors that drive sustainability in manufacturing.

And then we got into the main tool that is used in this analysis is called the simulation, and we studied quite a lot of aspects about it; I mean quite introductory aspects of it. We studied about what is the system and we also studied about; what is the state of a system and we studied about how is the simulation process, the inputs and that the black box we studied into. And we looked at the output and the importance of the feedback in the system and how feedback is important for making decisions.

We studied about the concept called system state and how this change of the system changes over time. And we also studied about the environment; why the system environment, the boundaries, the interactions with the boundaries and the environment; all these aspects were covered as part of the previous lecture.

Now, we are getting into the continuation of that and where we will start with today's topic on system classification.

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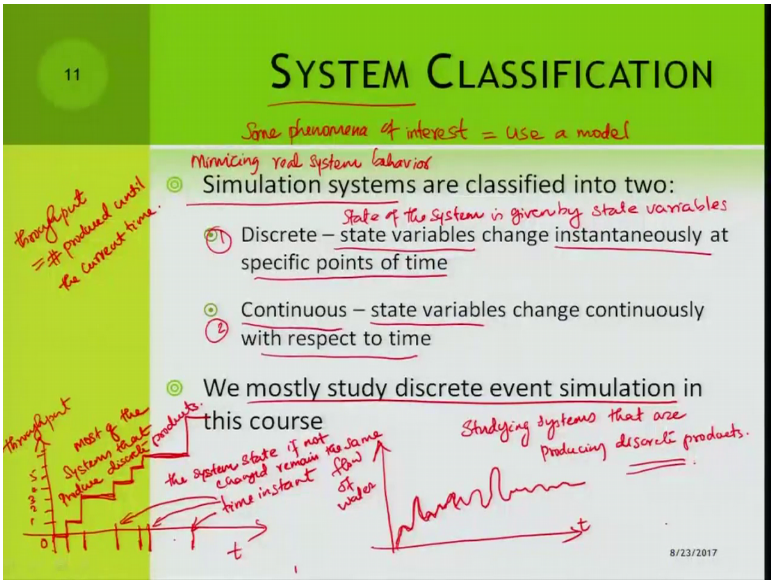

So, as we studied earlier; the concept system; system is an important concept which we know that we are trying to study like some phenomena of interest. Let us keep it simple for today's discussion, we just looking at some phenomena of interest and where we are not just phenomena, but it has different variables and other things and we are using; how do we study a system? We use a model to study the system. So, we have seen how the entire simulation is classified, we seen the analytical model; why not analytical model all those aspects earlier. But today what we are going to see is that the simulation systems. So, as I said earlier simulation is trying to mimic.

So, simulation is mimicking real system behavior, so we are studying the phenomena really; actually what is going on. So, for the course purpose; the course on sustainable manufacturing, we are more interested in two simulation systems; those are number one is the discrete system. So, the discrete simulation systems means the system state, the state of the system is given by state variables.

So, these variables tell; what condition the system is; so the state variables change instantaneously at specific point of time. So, if you are trying to study in a manufacturing system; if you look at here, this is the time axis; the X axis is the time and let us say Y axis we call it as the throughput; throughput is a concept where it is the total number of quantities that are; total number of products are produced or in a given time. So, let us for the time being; let us consider this way, for simplicity because there are many audience who are not used to this.

So, we will just say throughput equal to number produced until the current time. Let us think about throughput for the time being, we will define this later. So, here is 0; so, ask the day begins here, in this process; no production has happened after some point of time you will actually get to see the first unit. Then it will stay like that, then somewhere you will probably get 2 units together then it will stay like this; for some time then it will get 1 unit; then it will get like this, then will go for some time; then will get a large spike something like this.

So, if you look at it; the system, the state of the system changes at discrete time intervals; whatever I am marking this horizontal lines, these are the time points; instantaneous time points in which the state of the system changes. So, this is the time instant; the instant at which the; these are all specific discrete time instance in which the system state changes. Here the state is the number that is produced; so, if you start this will be like a 1, 2, 3, 4, 5 like this.

So, this type of a system is quite common in all the cases of a manufacturing systems, where you are actually; so this is where most of the systems that produce discrete products or discrete means they are countable unique products. Whereas there is another system which is called as a continuous system, the second system; the important thing about this continuous system is state change; variable change continuously with respect to time.

So, if you look at it in a diagrammatic fashion; so, it is like here you have time and here is if you think about it as flow of water in a river or something like that; then obviously, it will have some graph like this; where if you look at the instantaneous flow, it will kind of. So, at each and every time point it will actually have a very different value; whereas, if you look at in the discrete system, at specific time intervals the state of the system does not change. The unique thing is the system state if not changed, remains the same.

So, you can see that these horizontal lines; all these horizontal lines means the state of the system does not change during the time period. The state with respect to throughput whereas, in this case the continuous system, you can see that it continuously changes as time progresses. For this course, we are more interested in studying or utilizing the discrete event simulation. The reason we are using the discrete event simulation is purely because; we are studying systems that are producing discrete products. You are focusing mostly in discrete manufacturing systems. So, hence we will be mostly using discrete systems and we are also only interested in instantaneous changes of the particular systems state variable.

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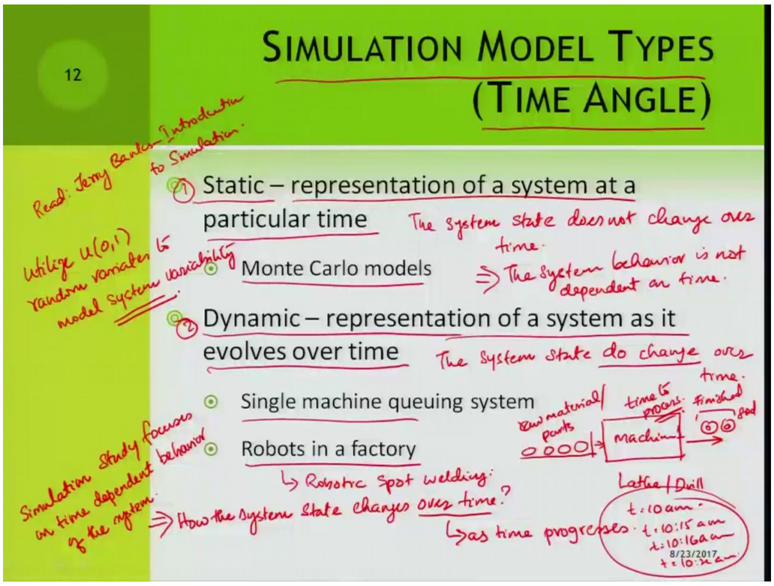

So, again one aspect that we talked about is the previous slides you might have seen is that; there is one important aspects of simulation which is called as a time angle. The entire simulation one aspect you are trying to study. So, simulation study focuses on time dependent behavior of the system. So, when you are interested in studying which implies how the system state changes over time? That is the fundamental question, how does a system state changes over time? Or how does a system behaves as time progresses? So, when you say changes over time means as time progresses.

So, this simulation models whatever we are going to study; we talked about the discrete and the continuous models. From a time angle; we are going to look at two things, number one is a static, number two is a dynamic. Static models is a system that is a representational system at a particular time or in another way to look at it is; the system state does not change over time. The system is kind of in a study state is or you can think about in a state where the system does not change; however, the time progresses how much ever time was a elapsed, the system continuous to remain in the same.

Or in another way, we can look at it is the system behavior is not dependent on time. Since a system is not dependent on time, the behavior of the system is not dependent on time. So, the system state does not change over time and such systems are typically studied as static simulation systems. And the most important or most useful model to studies a system is called as Monte Carlo models or Monte Carlo simulations. So, these simulations use utilize uniform 0, 1 random variables, random variates to model system variability.

So, these studies are of not much important to us; it is just and you can read about more on Monte Carlo simulations, on Monte Carlo models. I will recommend you guys to read Jerry banks book on Jerry Banks Introduction To Simulation; simulation to learn more about Monte Carlo simulation or there are many other resources available in the internet also on Monte Carlo simulations on Monte Carlo models. That is of not much importance to us, I just gave you an introduction and so, that you have an idea what it is.

We are more interested in the dynamic simulation, we are studying the systems that evolves over time or the system state; state do change; please remember this, this is the most important part it do change over time. As time progresses, the state of the system changes; it evolves. Classic example of it is a single machine system, a single machine system or is a think about it this way that you have a one machine.

So, here is a machine one; it could be a lathe or it could be a drill or something like this, one single machines sitting there. And then you have a queue and parts arrive and join this queue and then they get out after finishing into a; some new product or something like that; some new product it comes out.

So, this is the finished good, this is the raw material or parts whatever you want to call it and it gets processed here. And the machine takes some time to process which we call as the processing times. So, that happens; so, this kind of a system where; so if you look at it at time t equal to; if you study the system t equal to 10 am; what is the condition system? And there are t equal to 10:15 when one part is finished, then the stage of the system changes. So, then a t equal to 10:16, a new part is loaded.

So, t equal to 10:22 another part is over something like this. So, we study the system at discrete time points; so, the discrete time points and as well as dynamic because as a time progresses, the system state changes; new products get produced, new parts join the queue parts waiting in the queue, the length of the queue or the service time, the average service time all these aspects get taken care of us part of this.

Second part is also think about a; robots in a factory; this is also a time dependent system. So, if you go to manufacturing like automotive manufacturing, you will actually see robots doing welding. So, an example of this is robotic spot welding; as time progresses, you can see how they move and how they weld, how they assemble a parts and as the time progresses, as the day progresses more and more car gets assembled and the number of cars; number of spot welds that are completed by the robot, the number keeps on increasing as day progresses. At some point of time; one of the robot breaks down and then the system has to be stopped for repair. So, that is also a particular state of the system that we might be interested in.

So, the reason we is use simulation is because we want to study the time dependent behavior of the system. And time dependent behavior of the system is mostly studied as dynamic systems whereas, in static systems; we are not much worried about the time dependent behavior of the system, but we are more; because we assume that the system state does not changes over time, but there is variability in the behavior of the system, so that is what we are more interested in the static models.

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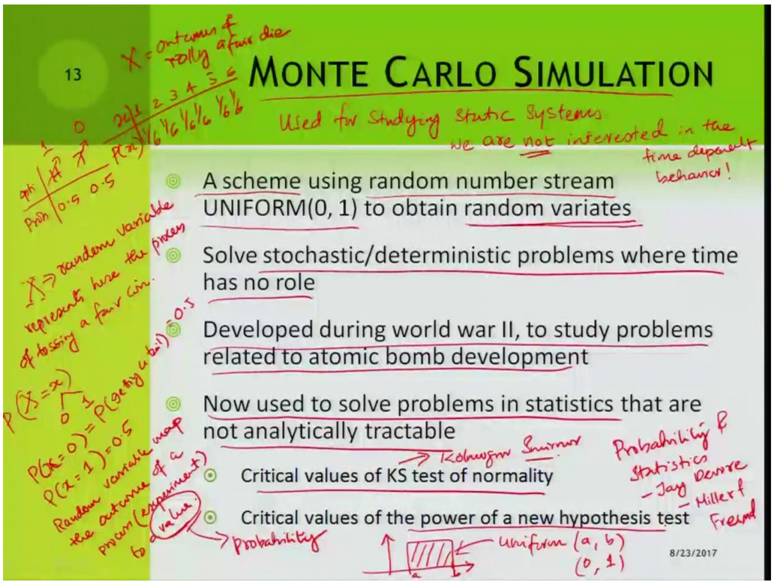

So, Monte Carlo simulation as I said earlier; this is just one slide to keep you guys updated on what it is. So, the Monte Carlo simulation this is used for studying static systems or we are not interested in the time dependent behavior.

In other way, you have to think about it as a system where the state of the system does not changes over time. So, it is just scheme or it is a method; using random number stream of uniform 0, 1. So, for the people who do not; who are not taken probability in statistics; random variable is one of the most important fundamental concepts of simulation.

I hope that all of you can look into probability in statistics textbook, but as a quick primer; I can give you an example. Let us say you have a fair coin that you are tossing and you have two options. So, let us think about it as the options here one is a head, another is a tail and the probability is 0.5 and 0.5. And we can say that getting a head is a success and we represented it by number 1 and getting a tail is a failure and represented by 0.

So, then we can always say that there is some variable X; capital X; that can map the outcome of this experiment, of this tossing the coin process into a success or a failure. So, we can say X is a random variable; what it represents is, it represents here the process of tossing a fair coin.

So, the random variable capital X; upper case X; big X can have two values, so which is typically represented by little x. So, if you say that the probability of X equal to little x and the little x can take values of 0 or 1. So, then we say probability of x equal to 0 and probability of x equal to 1; when we say this little x equal to 0 little x equal to 1. This means probability of getting; getting a tail which is equal 0.5; this is also equal to 0.5; getting a head when you toss the coin.

So, the random variables; map the outcome of a process or experiment to a value; in very simplistic terms; this is the way I look at random variables. It maps the outcomes of a process to a value and the outcome in this case is getting the tail or head after tossing a fair coin and what are the probabilities of it you know. So, this value is basically the probability associated with it.

This is the fundamental aspects of random variables and when you say the random variables have a particular random variate. So that means a random variable take a different set of values. So, like for example, let us take an example of rolling a fair die. So, then we can say X random variable denotes the outcomes of rolling a fair die. So, the values little x; it can take is 1, 2, 3, 4, 5 and 6.

So, these are the faces that it can get and the probability of little x; the probability that each face each of these faces coming in a fair die is 1 by 6, 1 by 6, 1 by 6, 1 by 6, 1 by 6 and 1 by 6. So, what we are saying is that and; so, this is like you know.

So, this kind of a process we can say or in a better way to think about it is; if you think about a process, where all values are equally likely kind of things. So, if you represent it in a graphical scheme it will look something like this it will look between two limits a and b; you have the same set of probability; so, all values within this are equally likely.

So, this is kind of a typical uniform distribution uniform a and b is what we call it, but when the limit change to 0 and 1; then that becomes the uniform 0, 1 and so, when you get a value between this and you can basically use it to scale to represent any value. But the most important thing is; it is used to solve stochastic or determinacy problems where time has no role.

So, we are trying to study the system where the time is not importance to you; then you use this methodology to study that. Some history on this; it was developed during world war II; to study problems related to atomic bomb development. So, that you are not really worried much about the; how the time, we are more interested in the strength of the blass and those kind of thing; so, this was a good model to study at that point of time period.

But before getting into this; I would really recommend everybody to read a little bit on probability in statistics, this is important and there are many books available on this. There is a book by Jay L Devore; that is one, otherwise is Miller and Freund; something like this.

So, these are the 2 books I recommend you guys to basically look into the concept of probability random variables etcetera; because we will be using those concepts in this class. So, once you develop; in a Monte Carlo simulation, it is now used currently it used to solve problems in statistics that are not analytically tractable. Or it is very hard to solve the problem analytically to use Monte Carlo test to; Monte Carlo simulation to study that.

An example of it is a critical values of KS test of normality; KS stands for Kolmogorov Smirnov test. So, critical values of the power of the new hypothesis test etcetera. So, analytically intractable problems in statistics are quite a lot studied using Monte Carlo simulation because of behavior of the system does not changes over time.

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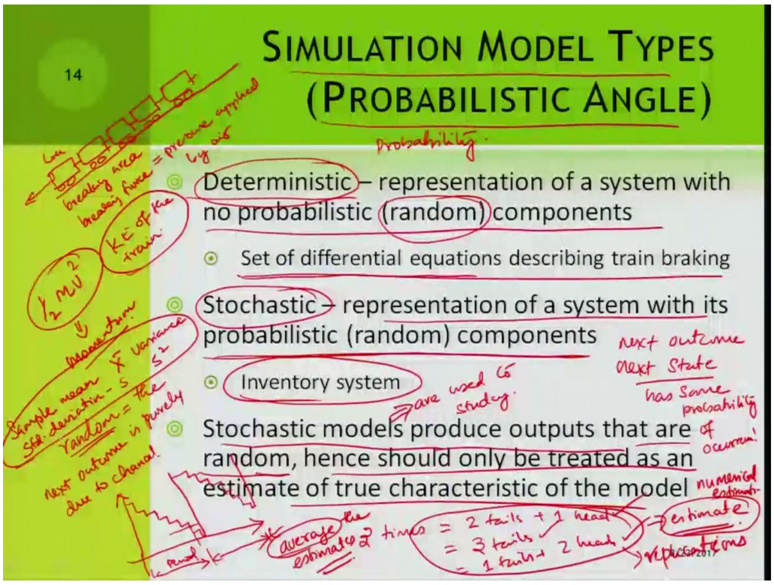

The second part of the system is also we are looking at the type of simulation models; we are also looking at something called as a probabilistic angle of simulation model types. So, the simulation model can again be divided into the probabilistic angle or the concept of probability. So, the deterministic is the first one and deterministic means representation of the system with no probabilistic random component; that is the deterministic studies. So, for example, if you want to study the train braking; braking of a train, locomotive; then that is important that can be studied as a deterministic system.

So, like for example, if you are looking at a locomotive or a train braking; you have a locomotive this is the one and then you have rights behind it, they are all interconnected and they have wheels underneath them and my train looks ugly, but that is alright and it runs on a track. And the loco goes forward, it is going this way and when you have to apply the braking; when you brake the train each wheel has a brake associated with it.

So, you know the braking area is known to you its fixed and then if you want to study the and the braking force is known based on the; it is obtained from the pressure applied by air. That can be studied; that value can also be obtained, based on those value you can calculate the braking force and with the braking force; then you know the currently the train has a total mass of M is running at a velocity V. So, we know the kinetic energy half MV square; this is the kinetic energy of the train. And to stop this train, you have to apply how much force? So, that force can be calculated because from this you can calculate the momentum and then how much of force is applied to stop this moment or retard and bring the train to a complete halt.

So, if you are trying to study the distance within which the train brakes; it can be very well solved or modeled with the set of differential equations. And with minimal variability on probability that kind of a things or when we say probabilistic, we also talk about is random. Random in a sense is the; random concept, random implies the next outcome is purely due to chance.

So, when you are tossing a coin fair coin; whether it is going to be head or a tail; the next toss, you do not know; it can be head, it can be tail; there is a 50-50 chance to that, but at the end of the toss; you will get either a head or a tail, you will not get both ever. So, the random is the occurrence of the outcome of that experiment is left chance; you have no control over the outcome.

So, when there is nothing left chance then you would really that system is no longer considered as probabilistic systems. So, such systems are called as deterministic systems, there is no random component as part of that. Whereas, there as set of systems where the there is a probabilistic or the next outcome; the next state of the system next outcome or next state is probabilistic; it has some probability of occurrence. So, this is the such kind of systems are called as stochastic systems. So, the system is represented in which there are random or probabilistic components are part of that.

A classic example of is the inventory system. So, like if you look at the inventory model in operations management, you have time that progresses here and as time progresses; the inventory get consumed and when you reach a particular point; you make an order and when it reaches 0; you receive a order and then you keep on doing this. At some point of time you get another order when you reach here and something like this.

So, as time progresses; this is the period in which the inventory was consumed to the different periods and something like this. So, we have periodic review, continuous review; quite a lot of models associate with inventory. But you really do not know how much is going to be consumed in the next given time period because it is purely dependent on the chance and the variability in the demand and those kind of stuff.

So, the important thing about the stochastic systems is; stochastic systems or models because remember models are used to study systems or you use models to model system. So, these stochastic models produce output that are random; that are random means, there are probabilistic. There is a probability associate with the outcome and hence should only be treated as an estimate of the true characteristics of the model.

So, if you toss a coin 3 times and you got 2 tails plus 1 head in the toss; that does not mean that in every 3 tosses; it will be a 2 times head and 1 times tail, the next time when you do it; you could actually get all three as tails. The next time you do it; you can get 1 tail and 2 heads; something like this. So, what we are saying here is that; whatever you are getting here is an estimate of how the system will behave.

So, if you want to study the long time behavior of the system; then you need to take lot of estimates and you take these estimates and average this estimates. So, that is why we are actually trying to say is that; we typically take estimates and that is why sometimes simulation is also called as a numerical estimation. Because, you are estimating the true behavior of the system; so, these one study in which you got 2 tails and 1 head; this is another study, this is another study.

These kind of studies are also can be called as replications or replicates; is called as replications. So, you replicate the system many times using different random numbers, random variates and study the behavior of the system; you get an estimate of the behavior of the system and you collect all those estimates and use that estimates to average the behavior of the system. That is when; the two characteristics of the system is studied as an average of the estimates. So, you think about it as estimates and average the estimates.

So, I would request all of you to look into the concepts of averages; which is a sample mean, a large extent; which is X bar; standard deviation represented by S, variance S square; these kind of concepts, again in the probability in statistics books these the concepts are available. I would request all of you to take a look into it; we will go through this in a very simple one slide each primer, but we I do expect you guys to do little extra reading to understand these concepts clearly. Then one more ways you can look at the simulation models; there is a granularity angle to the simulation model.

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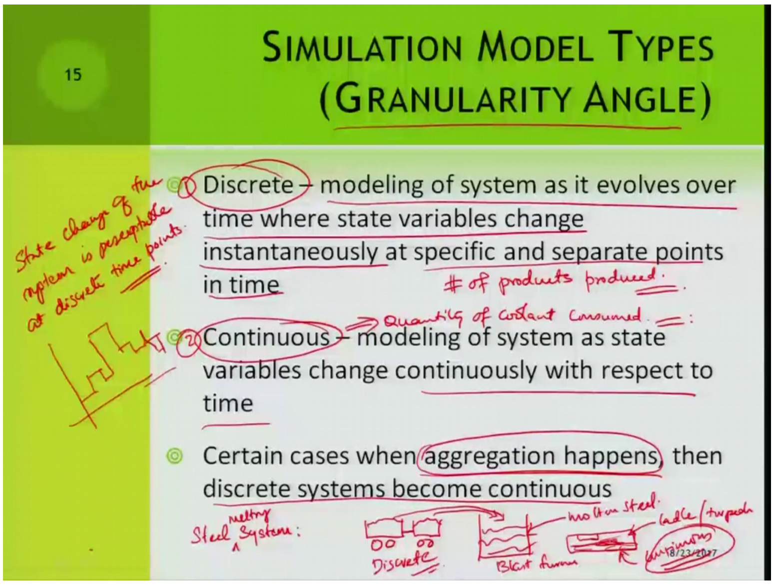

So, the granularity angle we can talk about it as discrete and as well as continuous; as I said earlier; discrete models the system it evolves over a time where state variable change, at it instantaneously. So, you are looking at specific and separate points on time; the state change of the system is perceptible at discrete time points, alright.

So, this is the most important aspect of this granularity angle of discrete time. So, when you look at that such a system as I said earlier; you have different time points when the behavioral system depends like this, you can measure discreetly. Where continuously is; as we said earlier it change continuously with respect to time. The trick in this is and certain cases when the aggregation happens; then the discrete systems become continuous.

A classical example of this is you can think about it as a place; where you are melting iron ore. So, think about steel system; steel melting system think about it this way. So, you get the input to this is you have railway wagons coming in with iron ore; so, this has heaps of iron ore in it.

So, and you have a blast furnace; so, you can count how many wagon load of iron ore went into the blast furnace. And once it goes there; it gets molten steel and this molten steel is poured into something called as a ladle or a torpedo. Here this when you pour into this; it becomes aggregated and this is a continuous system at this point. It started as a discrete system of wagon loads of iron ore, but later became you know molten steel of continuous system where the aggregation has happened.

Certain cases when aggregation happens; the system do at discrete system will change to a continuous system. So, in this case when we are studying this concept; at some point of time mostly we will model everything as discrete, but at certain point of time; we will actually be looking into things as continuous as well.

So, like for example, is if you were looking at the number of products produced; then you think about it as a discrete system. Whereas the quantity of coolant consumed; that will be a continuous system that it all; so, keep this examples in your mind.

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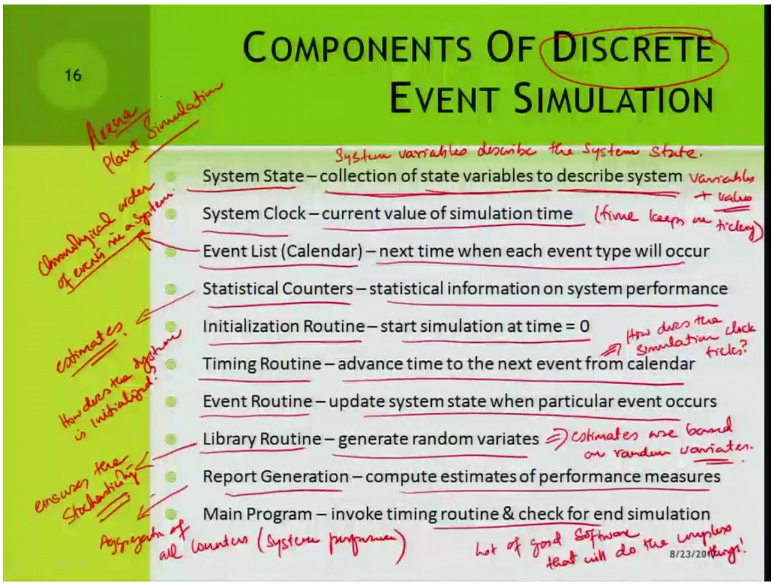

As we said earlier; we are mostly going to focus on the discrete system, the discrete simulation system, discrete event simulation system. So, there are some concepts that we need to be clear about and the first concept is call the system state and system state is defined by a set of state variables and it is a collection of state variables that describe the system.

So, system variables describe the system state; what is a state of the system is described by the system variables? So, when you use a system state; it is a collection of system variables; collection means the variables plus its values; it is called variable because it can take any value. System clock is another concept that you need to know and what does sees is the current value of the simulation time. So, time keeps on ticking; so, the time continues and keep on varying as the value of time changes; as the system goes through different processes and different state changes and that is maintained the time of the system is maintained by a system clock.

Then there is something called as an event list or popularly called as a calendar and what it does is; it is a next time when each event type will occur or it is a chronological order of events in a system. So, what it does is; it basically create a chronological order of events or chronological means time dependent order of events in a system. So, the calendar kind of tells you what to do next. Then statistical counters where means the different performance of the system is measured, as I remember we are studying things as estimates. So, this keeps the estimates of various performance of the system.

Then initialization routine, which means starting the system starting the simulation at time t equal to 0; so, how does the system is initialized. So, think about when you come to a factory you switch on the mains, then switch on the machines, switch on the lights, switch on the air conditioners all those kind of things. And then go to a store; bring parts, bring to the machine and then start assembling it; those all aspects are part of the initialization routine.

Then comes the timing routine which means; how does the clock ticks? So, this determines how does the simulation clock ticks? So, this is what is estimated here the timing routine. Then we have the event routine; the system state is updated when a particular event happens. And then we have; what we call as the library routine, what this option is generate random variates; as I said earlier estimates are based on random variates.

So, the random variates decides how the system will change, the time dependent behavior of the system. And this random variates are used to change the system state because remember it is a discrete stochastic simulation. So, this is where this ensures the stochasticity of the system.

Then report generation; which is the estimates one aspect is; once you use a statistical counter at the end of the day this is a aggregation of all counters or system performance. And then the main program which actually does this; there are the advantage of this is there are lot of good software that will do the complex things. In this course, we will be looking at two such software; one is called as Arena by Rockwell Automation and another is by Plan Simulation by Siemens; these two software we will be using to do the simulation, we will not been using our own; we will not be writing our own programs.

Instead we will be using the software to build models and study the system, but there are people who actually write computer programs like C C plus plus based programs and using that programs, you study the behavior of the system. So, what is advantages of the simulation? So, we studied we have an overview of the major aspects of the simulation.

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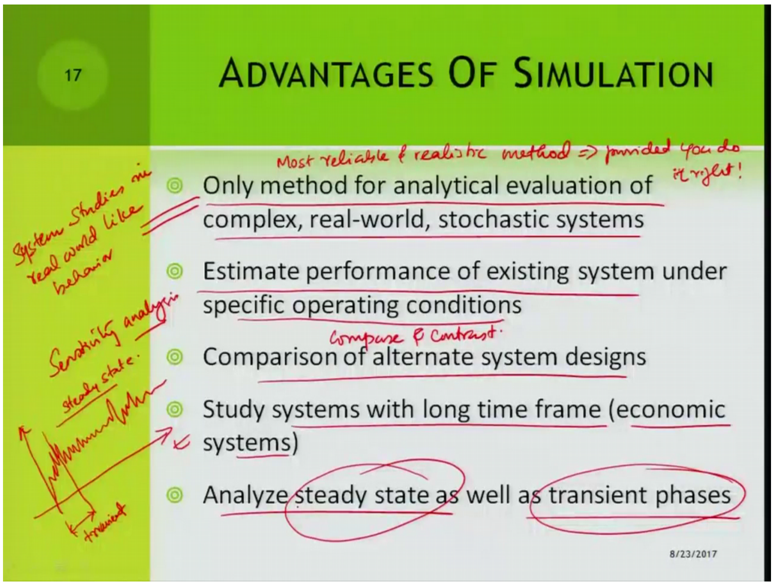

Now, let us kind of conclude the discussion by looking at the advantages and the main advantage is; it is kind of the only method for analytical evaluation of complex real world stochastic systems; it is a big million dollars sentence. But if you want to really study complex systems; there is multiple subsystems; they are interacting with each other and they are of real world.

And you want to really study the real world behavioral system and the system has lot of variability in and stochasticity which means there are lot of randomness in the system. And you want to study that system then or you want to estimate the behavior of the system, you want to study the performance of the system, you want to find out where the problems are in the system; then this is pretty much the only method available to study the system in its reality.

So, if you are interested in system studies; in reality in real world like behavior; then this is kind of the only method or the most reliable method in my opinion in this regard or what we say most reliable and realistic method provided you do it right; this is the most important part. And you can always study; the best part of simulation is that you can estimate the performance of the system under specific operation conditions.

So, if you want to change; so, what we can actually call it as sensitivity analysis is this concept. If you want to study; if you vary certain parameters, certain operating conditions of the system; then how does the performance of the system changes, how does it varies all that aspects can be studied as part of this. And we can also think about comparing the alternate designs of the system. We want to how a one particular design or you want to see another particular design; I going to compare on contrast.

So, if you want to do compare and contrast and decide which design of the system is better and; obviously, simulation is a very good tool to do that. And if you want to study the long time behavior of the system not the beginning; it like long time like 5 years, 10 years, 15 years behavioral system. Classic example is the economic systems; how does the economy of a country behaves; will it grow? Will it go down? Will it be steady; all those kind of things.

For a long time frame you can use simulation to study that; it can also be used to steady the steady state as well as transient phases. So, if you look at the system to begin with; any system if you look at the time dependent behavior of the system; you can see that initially it will do something like this and then it starts kind of doing this. So, this kind of a behavior this is called as the initial or the transient phase and here is the study state phase.

So, you can use simulation to study the transient phase; the beginning where the system changes from one phase to another or were transition from one phase to another or you can study the steady state as well. That is the main advantages of the simulation, but same we as it has advantages; it has disadvantages also.

The main disadvantage is that people have because such a complex and realistic behavior; how the system is presented, people just tend to behave believe simulation very quickly.

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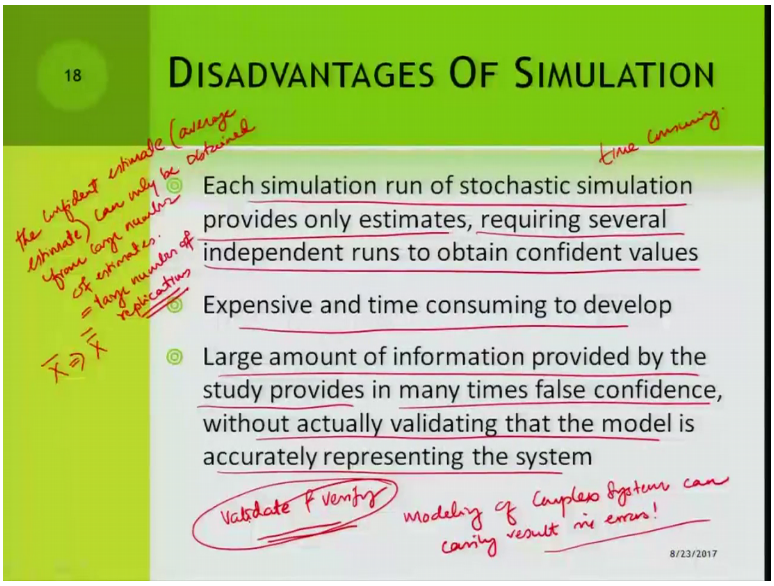

But you have to keep in mind that each simulation run of is a estimate; it provides you only estimate; any stochastic system that you study, it will each simulation run will always gives you only estimates; which means you require several independent runs to obtain confident values. So, the confident estimate which is an average value; average estimate can only be obtained from large number of estimates.

So, if you require large number of estimates; it require large number of replications. So, which means it is time consuming and expensive as well; which is a second point, time consuming and expensive to develop. So, you require; you cannot just take one run and say fine I know what the system is going to behave; that do not just happen. You have to run the system multiple times, with multiple variates, to get multiple estimates and use all these estimates to average the values out and then predict the average behavior of the system using that.

So, that is one of the reasons why we usually say; we collect lot of X bars or the average behavior of the system and use it to calculate X bar bar; the average of the averages and then use that average of the averages to estimate the behavior of the system. So, hence most of the major pit falling all the simulation studies I have seen is; people have just started believing the one simulation run. You require multiple simulation run to get multiple estimates; these multiple estimates will then provide you the average system behavior.

The another major pitfall is there is large amount of information provided by the simulation study. Many a time it induces false confidence in the people or the person who is doing the study. And what they start doing is because you are getting a lot of information; you think that this should be right, this that no way it cannot be wrong and without actually validating whether the model is accurately representing our system; people start believing the outputs that is coming out of it.

So, another thing is validate and verify because this is modelling of complex systems; can easily result in errors. So, and when you are modelling a complex system; it is quite hard to find where the error is. So, many a times my suggestion in this regard would be that you have to keep on specifying or checking that you are model is actually doing what the system is supposed to do; not anything unexpected.

So, the validation and verification is also an important part of the simulation which many people does not pay that much of an attention to or they usually tend to pay lesser attention to it; due to which many errors do creep in the system model. So, I hope that all of you had an idea of what a simulation is all about. And we should also be little bit more interested; I am just going through this slight quickly because we should all be aware about the pitfall of simulation.

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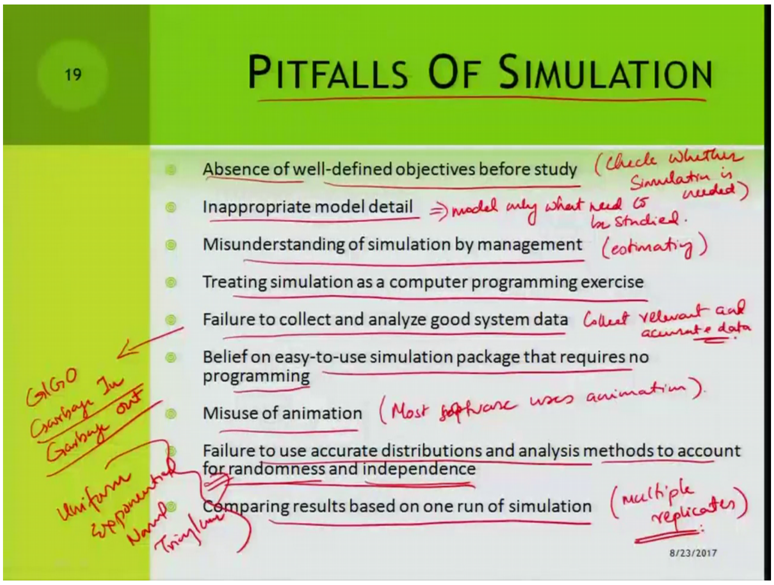

What are the major mistakes that you can do; you can commit and what are these ones will result in you know; you spending a lot of time in money and energy and not coming up with a tractable results. So, the first one is the absence of a well defined objectives before study; the check whether simulation is needed; it is an expensive tool, it is a complicated tool and your objectives should justify; whether you need it or not; that is a first most important treat.

Second one is inappropriate model detail. So, you basically say model only what need to be studied; is modelling is an expensive process? And you are only interested in studying a particular thing then just model that. You do not need to model all unwanted things that are that are absolutely no relation with that. So, please do understand that and there some concept called a simulation by management.

So, lot of the time what happens is you show a simulation most of the simulation software which are their expensive, they come with very realistically looking 3-D models and everything. So, the (Refer Time: 49:31) present any of those videos, the people in the management starts believing the simulation; more than anything else. And they start pretty soon focusing on a number.

So, that is the reason why you how to keep on reminding people that it is a method to estimate. You are just estimating the behavior of the system, it is not the true behavior of the system; it is an estimate of the behavior of the system do that. Treating simulation as a computer programming exercise; it is really not a programming exercise, it is a modelling exercise you are modelling and you are statistically studying; numerically studying the behavior of the system.

So, hence if you treat it as a programming exercise; it will never work because the modelling is not a programming exercise and also to a large extent; collect relevant and accurate data; that is the most important aspect of it. So, if you fail to collect that then your analysis is wrong. So, here the concept of GIGO is very true; garbage in; garbage out. So, if you have garbage data coming in; you will only get garbage output; so, remember that.

So, people tend to believe that there are be easy to use simulation programming and there requires no programming, then you start believing that you cannot do anything wrong here is; so, easy is actually not easy and the modelling is a involved exercise and requires training. So, hence people start believing the behavior of the system. Then misuse of animation; most of the models or most software uses animation and such animation has a big issue of like you start looking at the animation and start believing this is what is going to happen. And people misuse animation to gloss over the; or hide the important aspects of the behavior of the system.

And another aspect is also failure to use accurate distributions to account for the randomness and independence. These two concepts; what is a randomness and what is independence; we will discuss little bit later in the course on additional topics. But you have to use appropriate distribution, whether you are using uniform or exponential or normal triangular all those kind of things, which distribution to use to model what; these kind of things is very important when you are studying a model.

I am comparing the results based on one run of simulation; I told you multiple replicates is a must, you have to do multiple replications; there is no excuse to it. And then use this replication to come up with estimates and then use that estimate to predict the average behavior of the system. That is the only one way you can actually make a sound conclusion from the simulation model.

So, with that we conclude today’s presentation on simulation. I hope you guys had a basic idea of what simulation is all about. In the next class, we will start looking into;

how do we do basics of probability statistics and as well as experimental design so, that you have a clear idea how to analyze the models of the system.

Thank you.