Simulation of Business Systems
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Lecture -16
Simulation of Tandem Queues using ARENA

Good morning students. Welcome to yet another lecture of Simulation of Business Systems course. And we have been in this course we are more than half the way through and we have been studying the importance of simulation, why simulation is necessary and how is simulation helps in solving complex an open ended problems. And why this is kind of like the last resort to study things that are extremely complex and cannot be model using physical or mathematical models. And still also how does it allows to model the uncertainty and variability of the system and it also allows us to model the time dependent behavior of the system for a long time.

And we also seen the important aspects of simulation, the important nuts and bolts of simulation. And we have see worked on a simulation by hand also we looked into another form of simulation called Monte Carlo simulation where the time is not there, but the random behavior the variability of the system is being studied the uncertainty and variability. Then we looked at started looking into what is probability in statistics and why probability in statistics is important for simulation and the other aspects with.

And I also gave you a brief idea of what arena is and arena as a software that can be used to do system like simulation. And we have been looking into the manufacturing system or a production system mostly and one of the ways we were looking into was a what happened when a factory where there is only one machine available, but you know in real life there is very rarely there are factories with one machine. there are, but they are very small and very, very small machines like somebody having one lathe or one drilling machine or something like that.

usually they will have 2 or more machines doing a small part or doing a small job and that job will go to somebody else who has a much larger facility. And that person will be producing more similar part like that he will join together to make a more complex parts and then finally, it will become a bigger complex part. A classic example of this is like looking at how the gearbox is getting manufactured so many of the people with single

hobbing machine which actually cuts the gear. They cuts they make different type of gear wheels below that there are foundries.

Small scale foundries which actually forgers that blanks from which the gear is gear wheels are cut; then these blanks are bought by these people they cut the gear wheels or the teeth according to the hobbing machine use on using the hobbing machine as per the size. And then these teeths are procured in bulk by a guy who is assembling a gearbox and where he will have another bigger person who is making a gearbox casing which is casted out of bigger foundry maybe then all are these things somebody will be making the shaft and other things and then there gears will be mated with the shaft assembly is done and there finally, the gearbox is made.

And his gearbox are procured by automotive manufacturers and this gearboxes gets assembled onto the automotives that they are producing. So, these are the production system the top down chain of the production system works. On the top where is the vehicle assembler is there that below that there is subcomponent manufacturer from the manufacture. It goes down all the way down to the person who makes the first nut and bolt from there this kind of aggregates all the way up.

So, today what we are going to do is we are going to see a arena again. And we are going to see in a system where there is more than one machine is present. So, we will try to do scenario where there is multiple machines are present and how the presence of one machine influences the presence of other and these are the kind of systems where we call about it as standum queues because where the queue from one machine the output of one machine becomes input of the another machine.

So, we are thinking about making a scenario or creating a scenario the simple scenario where there is multiple machines queue machines arranged in sequence where 2 or we can think about 2 services also let us think about 2 services today because you are looking at machines or we will we can change it in anyway machine or services it does not matters. So, first we will see how the system is a without any variability, then we will slowly introduce the variability and then we will get into the concept of replications today.

What is replication and why replication is important and possibly I will try to show you the half width today and the theory behind half width why is how is half it calculated that

aspect I will get back to you in the later class. So, with that if I if you pay attention to the computer screen that we have where we are presenting about the how the arena is opened I think all of you know how it is opened, once you download and install arena.

It comes under the all programs and you scroll down this you will get to see Rockwell software. Here it is and then there Rockwell software here it based and then there is a link under Rockwell software called as arena. You click arena and then the links comes up and if there is input analyzer output analysis or process analyzer which I promise to you guys that I will teach you later which I will do depending upon the time, but let us first look into arena now. And here is you click arena it opens up.

And it comes up with the Rockwell automation it takes little time because it needs to verify the license analyze, but all the examples that I will be demonstrating in the class can also be run on the unlicensed version or the free edition the evaluation version of arena that is away made available by the software the company. So, once you come in then you get different of these 2 project bars.

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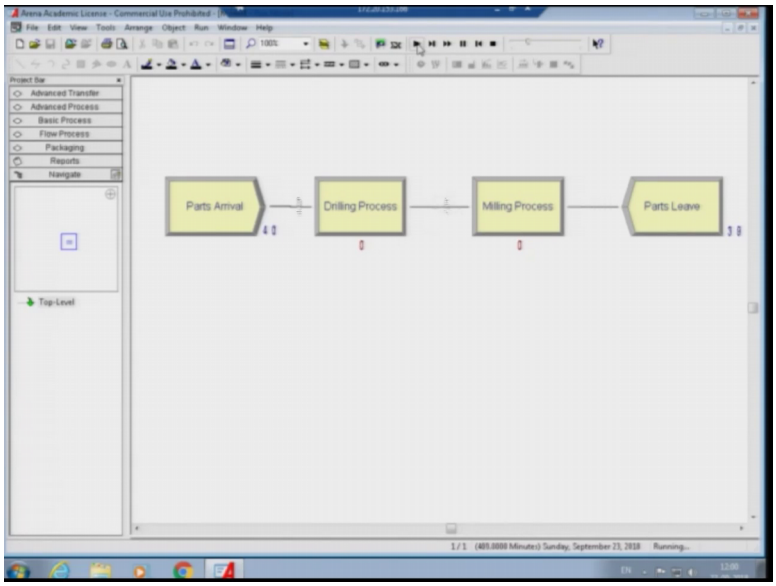

As I said earlier the toolbar the file edit all those options are right here. And then the , you know saving running of the model and all those aspects are right here. And here is the major modules of arena some or the major process modules of arena. So, there is we are now looking at the packaging, but we want to start with the basic process is, where we had a create dispose process and stuff like that. And. So now, let me show you a

model. So, we go to the basic process and then we were trying to make a system in this regard. So, the model that we are trying to build here today is a the 2 machine model. So, as I said earlier we start with the create.

And when you click on this you can see in the bottom bar the details of the module that you are clicking shows up here. Now what you need to do and those kinds of things all of them shows here. So, we click the create and drag and drop it into this place. And let me zoom it up slightly bigger. So, that you guys can see this better; I hope it is visible hopefully we make it 100 percent; so, that you can see. So, it says the create one is basically put right here and we are going to change the name of it.

So, one way is to change it right here or other option is double click on this and you get a dialogue box opens up. So, I am going to say that parts arrival v. So, the create module says the parts arrival and the entity type I am going to change it as part and I am going to say time between arrival is going to make it as constant ok. And I am going to say in every 10 minutes a part arrives there is no variability in the system absolutely no variability just constant time between arrival is 10 minutes.

And one entity will arrive at this time and arrivals are infinite and first entity will arrive at 0.0. So, the parts arrival whatever I changed I made the changes, you can see that there immediately shown right here. Then I know that I know how to make a single machine model. So, I am will start with a single machine model to begin with then I click the process I drag it here ok. So, this process one. So, let me say it as the name of the processes drilling process and this is a standard process as is not a sub model and remember we are not going we are going to make it as a seize delay released instead of the anything else.

Because you have a resource associated with it the minute you click the seize delay release the resources shows up and I have to add a resource. So, I am going to add a resource called as drilling machine drilling machine is a resource and there is one unit of the drilling machine available right here and I hit ok. So, the resource name is shown up in the list there is a resource called drilling machine with one unit of it is associated with this and I am going to make it as a constant and the time as minutes and I am going to say that the time is 8 minutes.

It takes 8 minutes to drill a hole ok. And I have to click the report that is ticks to ensure that statistics of the thing is collected hit ok. So, have a drilling process and I a queue here and I click this and I click the queue it will show you the drilling process view. It is first in first out and you are collecting the statistics of the queue. And then I will take the dispose drag and drop it right here alright and I say parts leave and I am recording the statistics of the entity. So, parts arrival it goes to drilling process parts leave.

So, this is our single simple single machine system that we talked about the earlier class because people had doubts on this. So, I am showing this to you. And you know that the parts arrive one every 10 minutes and I am able to drill a hole once in every 8 minutes. I it takes me 8 minutes to drill the hole it is parts arrives in 10 minutes and the parts leave and there is no variability in the system and I connect them to simulate the flow of that ok. And then if I run this ideally I should not be seeing any queue there should be no queue.

Because it will take me lesser time to drill the hole compare to the arrival. So, I go to run and I go to the setup and I go to replication parameters today's date is correct number of replication is one. And replication warm up period I change the time to minutes time units are also change it to minute replication length is infinite I am going to change it into let us say a one shift is a 480 minutes. So, we running it for 8 hour time period 24 hours per day and basic time units as minutes and we apply a hit ok.

And what we do is we run the simulation ok. So, we run this we can see that there is the simulation is completed like to see the results.

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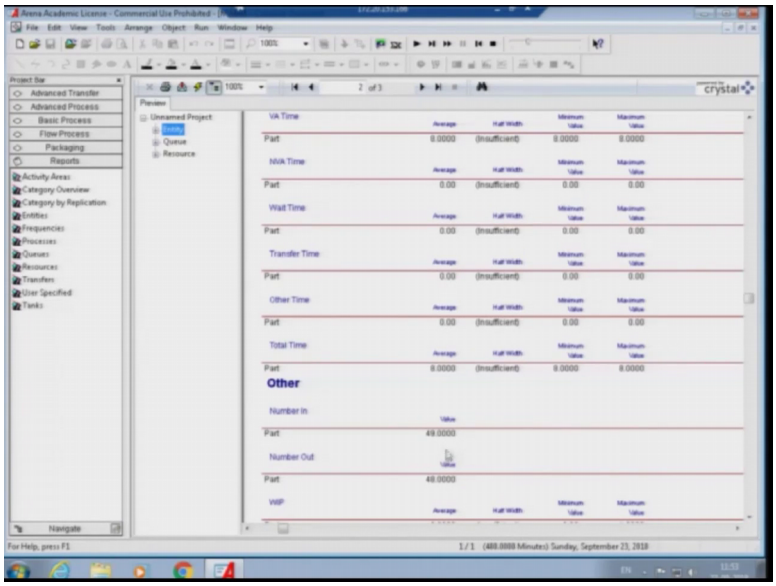

And yes, it is showing the results please hold. So, until the report is generated it takes little bit time. So, there are 48 entities that you are process. So, if you click the entity it will show that the average time is 8 minutes minimum value maximum value is 8 minutes there is absolutely no variability and the total time the number of the parts that came in 49 came in 48 was out one was still left on the machine when the simulation was stopped.

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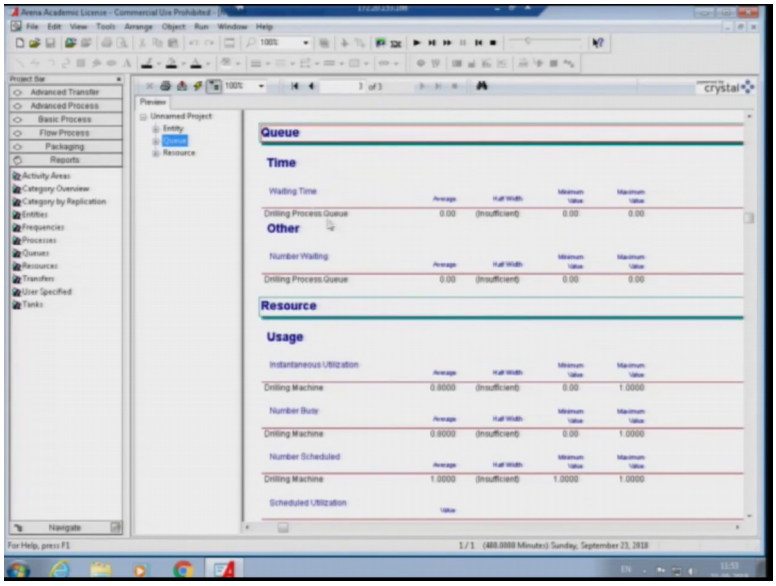

And if you look at the queue the queue length is 0 ok. So, average nobody was in the queue there is the minimum time is 0 maximum time is 0. So, there is no one ever waited in the queue ok. So, this kind of tells me that yes my system logic is working. So, this is calculation.

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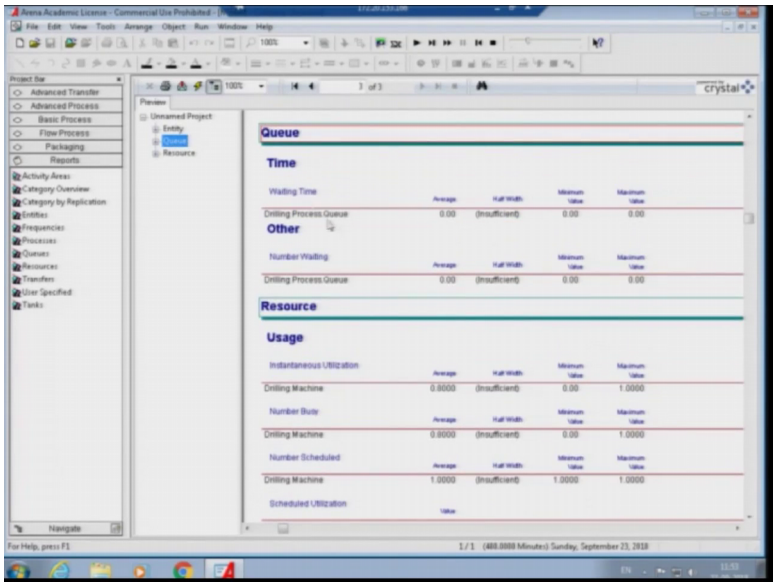

And if you look at the resource it should be utilized 80 percent of the time. So, the average instantaneous utilization or scheduled utilization of drilling machine is point 8 which is 80 percent if you multiply by 100 you will see that the machine was used 80 percent of the time.

Because the service the time taken to drill a hole is 8 minutes. And time taken for the arrival is 10 minutes. So, if you look at the ratio of which is 80 percent. So, you get exactly this planned utilization. So, you can check again as a theoretical system. This process that I just did now to ensure that the model is doing what it is supposed to do is called as verification. And also checking that the output of the model were matches with the expected output is called as the validation. So, verification validation is being done. So, then I think fine, I am with that.

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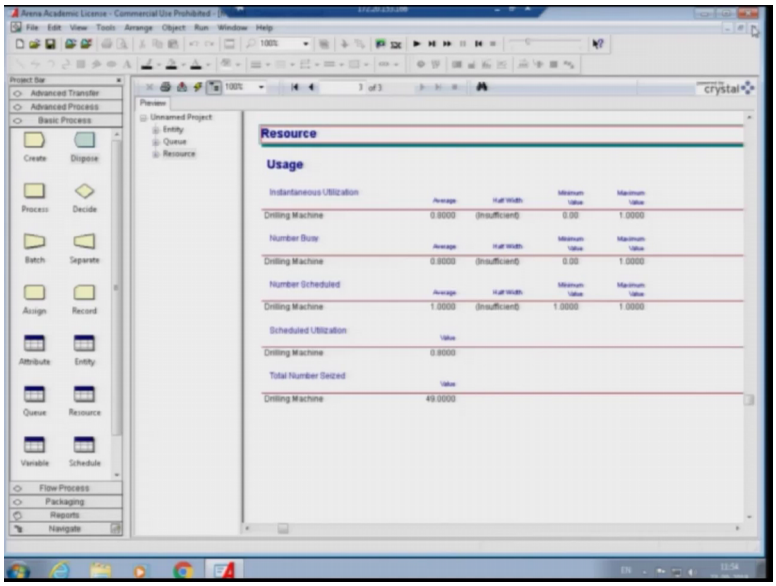

If that is a case, then I will go back to the model and I can modify this model to ensure that I can add one more part into this. So, what I will do is I will slightly move this here and there. So, that I can make little bit a space. So, you kind now what I am doing parts arrive and the parts leave is move slightly here backwards and I am going to add one more process. So, I click this and I hit the delete button ok. So, the minute I delete this what happens is that connection is gone away. And I am going to do add one more process in addition to this. So, I click this and I drag it right here.

There is this auto connect nonsense are comes up I delete this ok, and see whether this works without the auto connect drag and drop. So, I delete which will do something like this. I move it right in between this and I change it into milling process. And this is a standard again the logic is seize delay release which means it immediately and remember we have not playing around with the priority of the system at this point. The reason we are not playing with the priority of the system is because all the queues are first in first out.

Whoever is coming in will come leave at the first chance. So, what we do if we click the add resource and we are going to put in a resource here which we are call it as the milling machine. So, there is a drilling and then resembling and there is one unit of a milling machine. And again we make it as a constant time units as minutes is value added process and I making the value of this as let us say 5 I. So, 5 time units and the drilling I

double clicked and I changed this time to 5 ok. So, that my arrival is one in every 10 minutes and both of these guys are 5 minutes and 5 minutes to process.

So, ideally I should not see any queue and I should see 2 machines you utilize the 50 percent of the time. Once I do that the parts leave they remain exactly the same and I added a new process in between and then all I need to do is I need to connect them to show the flow of the logic. So, I click here from drilling it goes to milling. So, the arena understands that now after the drilling process is over the part will go from the drilling process to the milling process. Once a milling process is over then I click it and click it this way it tells that after the milling the parts will leave the system.

So, I have done this now. And so, if you look into this now you can see that in the basic process you see there is 2 process the drilling process and the milling process. And if you click the queue here you can see that the there is a drilling process queue and a milling process queue both are first in first out and we are reporting statistics on both of them. So, the good thing about arena in this regard is the more keep on adding resources they will show up here is a list in this particular part of the software ok. Once again repeating when you have more than one process then the process is the.

Now, this black arrow mark shows which process you are clicked you click this then the yo,u can see the highlight moves to the appropriate process. So, if you have 10 process is there will be 10 rows of things right here which each process detail shown here. So, that you can actually compare what type of process is you are doing and it can also look you click into this because once you start building complex models, you will be using these this spreadsheet like view more common than looking at the model. Because sometimes this area this window may not be sufficient enough to look at the model.

It might be. So, you might be doing something like this you know scrolling here there to see the model completely in the trigger. So, with that what I will do now I will just now simulate the system for the time being. So, what I repeat to you once again is the parts arrival they arrive at once in every 10 minutes. If the drilling process is value added process and the uses one unit of a drilling machine and it is a constant and it takes 5 minutes to drill a hole the value added. Then is a milling process it uses a standard resource call milling machine.

One unit of the resource it is constant it takes 5 minutes to do this do the drilling of the hole and is a value added process and then the parts leave their system. So, say it is a quiet of a simple of a model. So, that we can see how the 2 machine system works at (Refer Time: 17:56) ideally speaking. Then we go to the run and we go to set up and we want to it is only one replication. We want to run it for 8 hour shift which is 480 minutes and we shift after 480 minutes stop the simulation which will it will stop at the replication length and hit.

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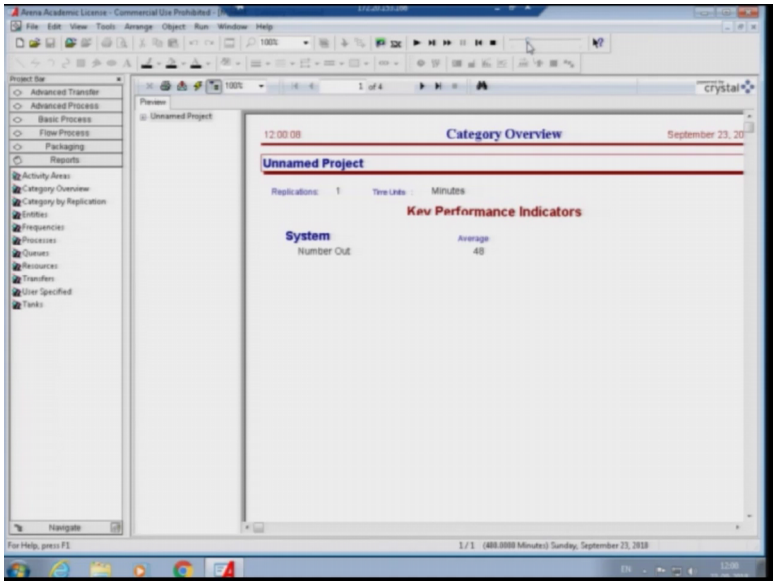

Alright and now what we do is we press the play button we can see the parts run between the simulation is over hit yes and what we see now the report is coming up and it shows 48 minutes 48 things came in.

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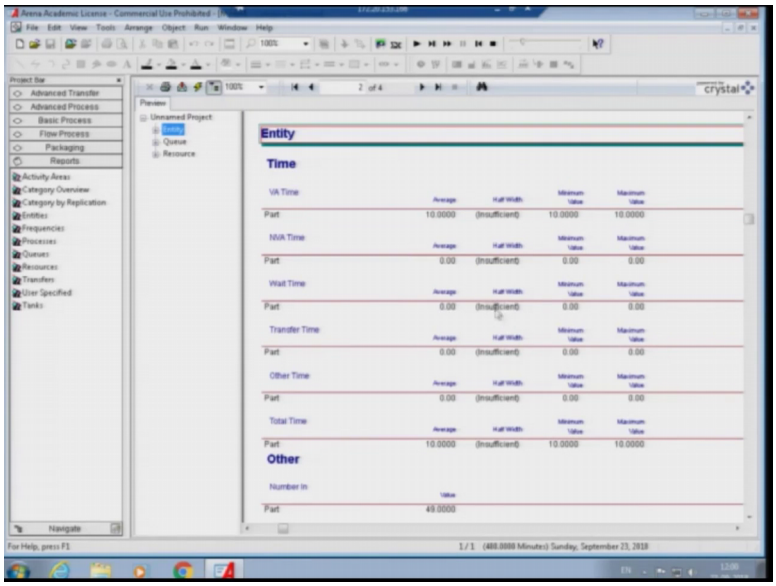

So, will look at the entity the value added time is 10 minutes exactly 10 minutes 5 plus 5 minimum value is 10 maximum value is 10 because these all constant there is no variability. So, we will see that minimum maximum values are exactly the same and if you look into it the number n is 49 parts arrived 48 left ok.

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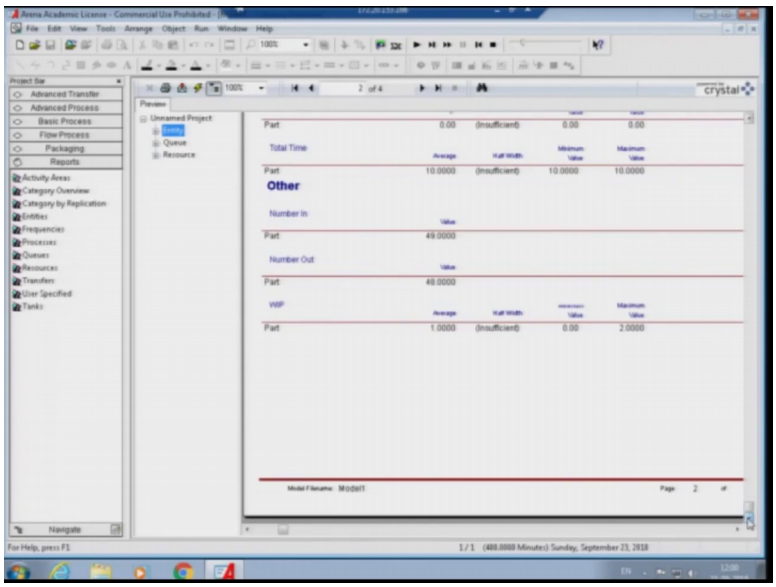

So, one is on one of those machines you can see that even though we added one more of those resource it nothing has changed ideally.

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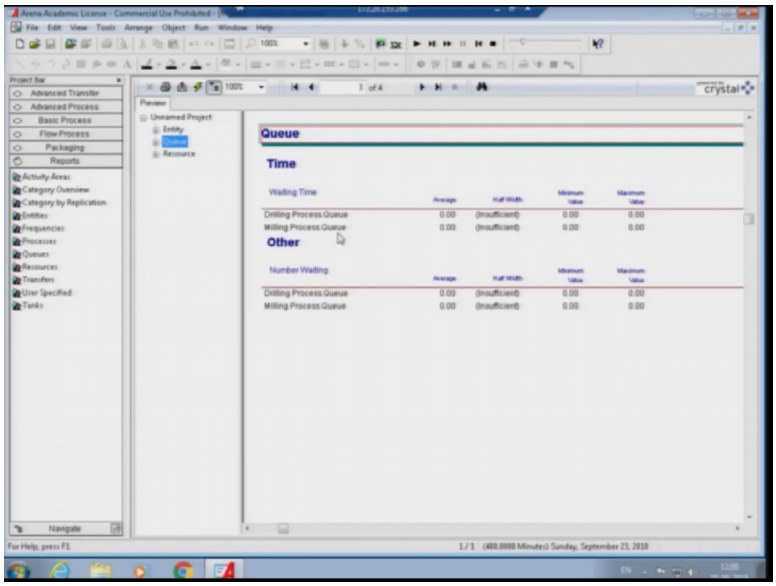

Waiting time, in both there is absolutely nobody is the queue. There are 2 queues drilling process queue and milling process queue absolutely the average queue length is 0 minimum time in the queue is 0 maximum time in the queue is also 0.

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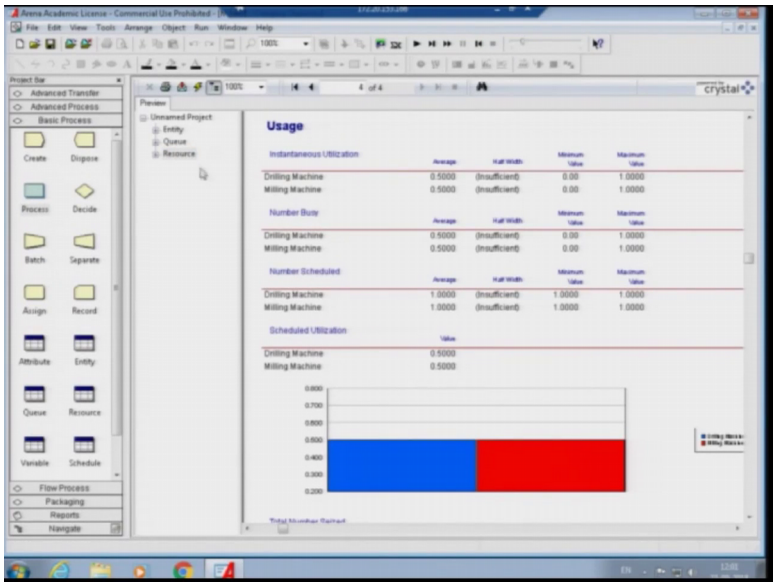

We look at resource both the resource and now you can see a graph showing up in the report because there are 2 resources and both of them are utilized 50 percent of the time.

And this is not surprising because we know that the blue is the billing, milling drilling machine red is the milling machine and it is not surprising because the arrival time is 10

minutes and it takes 5 minutes to drill a hole and 5 minutes to mill a mill the hole that was built. So, if that is the case then it is 50 or 50 percent of the time both the machines are utilized ok. Now with this you might have. So, know I know that the system is performing in the expected ranges when there is no variability now with that if that is a case then our.

Let us try to introduce a little bit of variability in the system slight amount of variability. So, the time taken to do the milling the average as of now you seen there is absolutely no queue, in there will there is nobody in the queue no not a single of the end part waited in the queue. So now, the average time taken to mill is let us say 5 minutes. That is what we have using here let us now make it as a slightly of a varying process slight amount of variation. So, I am going to say that the milling process queue for the milling process time I am going to double click this.

And I am going to change this to uniform ok. I am going to say that the milling process time varies following uniform distribution between 4 and 6 ok. So; that means, minimum it will sometimes it will drill a hole 4 minutes, sometimes it will drill a hole in 6 minutes sometimes it will drill the hole in 5 minutes also. So, in the average the when the uniform, distribution the average is calculated by minimum plus maximum divided by 2; so, you take the minimum value and sum it with the maximum value and that divided by 2 will give you the average.

So, it is 4 4 plus 6 6 divided by 2 sorry 4 plus 6 is 10 ten divided by 2 is 5. So, the average comes exactly as that of the previous average which is 5 only that there is some variability. So, you have used a probability distribution or a some distribution to model a variability, where the time is varying between 4 minutes to 6 minutes with an average of 5 minutes. We did that and we hit ok. So now, you can see is that the drilling process is a medium the delay type is constant. So, means the time taken to drill is constant it is value added is minimum is 5 sorry there is no minimum and maximum value is 5.

Because it is constant and in the milling process it is the other way round it is a uniform the slight amount of variable it is value added again the minimum is 4 the maximum is 6 the average will be 5 then. And we are reporting statistics of that and we go to run setup and we look at the replication length are same exact all things nothing changes everything is ok. And the let us find the simulation model. And we do that and we see the

results ok. So, the system the total number of people out of the system is 48. So, looks like exactly the same.

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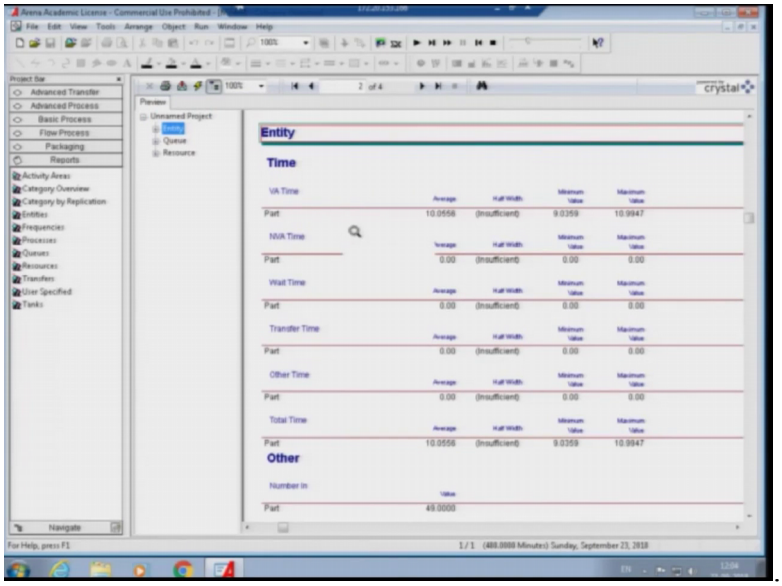

But here you will start seeing some slight amount of changes. Now, the value added time is no longer exactly the 10.000. It is 10.0556. And you see that the minimum value of 9.03 and which used to be 10 and 10 in previous case you can now see that the minimum time varies between the time average time varies between or individual times varies between the value added time varies between 9.03 in minutes to 10.99 minutes. This is what we call as a physical observation of what a variability is all about.

Where the we already introduced a variability into the milling machine time and you can see that the process time survey you know a variation in the system. So now, if you look into this the average the total time is the 10.556 again what we saw that and then 49 parts arrived into the system 48 left.

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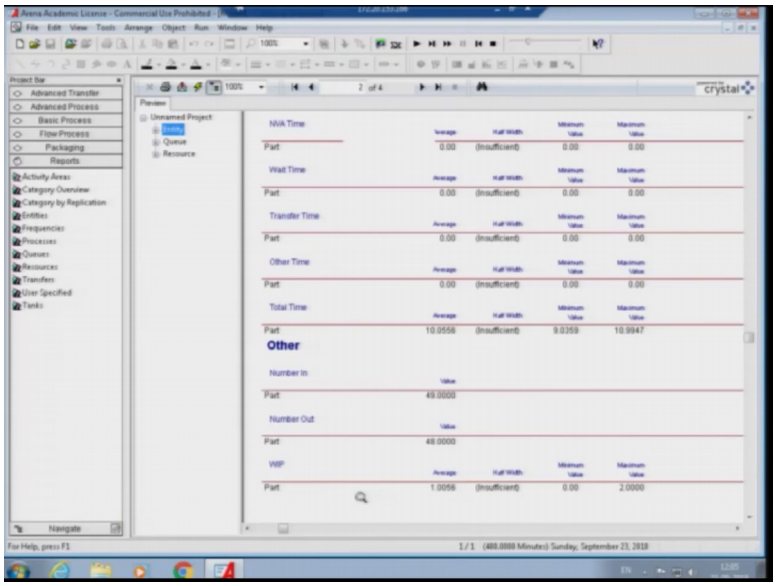

And work in process in process inventory is one point is there some slight amount of inventory that you see minimum is 0 maximum is 2. So, we look at queue there is a still nobody is waiting in the queue then only nobody waiting right.

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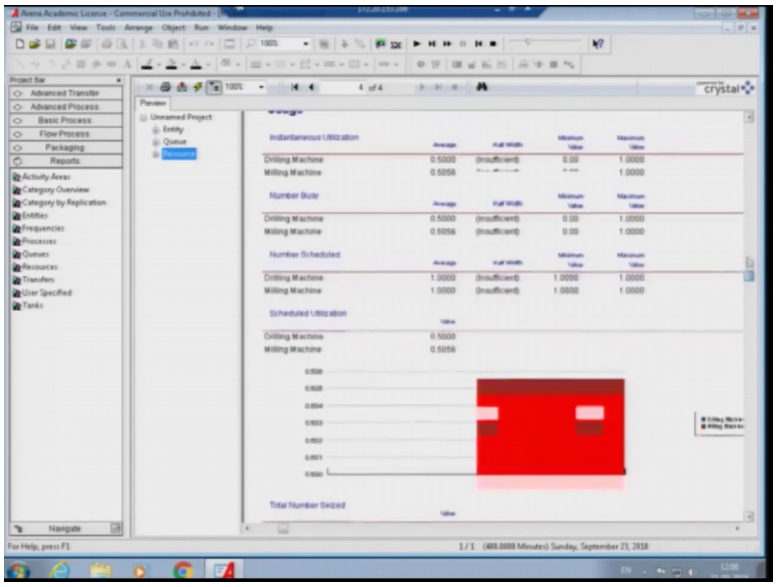

If you look at the resource utilization, we can see that the drilling machine is still utilized the 50 percent. The milling machine is slightly more than 50 percent slightly more than 50 percent and why because if you look at this queue this graph if you see it starts at 50. So, milling machine is slightly more than the drilling machine purely because of the fact

that the 2 reasons for this. One is that there is some amount of variability. So, it has been busy for slightly some more amount of time, but we had not done this simulation long enough to see anybody waiting in the queue it is only 480 minutes.

So, will anybody wait in the queue for if you run the simulation for a long time period well let us see we can try that let us do that let us go to run and setup and instead of an 8 hour shift for 480 minutes, let us run it for 4 thousand 8 100 minutes this may not be possible with your software the student version the software the free version, but let me show this to you because I at least you should be able to see this and see whether there is several queue that happens in the system ok.

Now, you can see; obviously, it is going to take a longer time the simulation is happening, 48 simulation is over.

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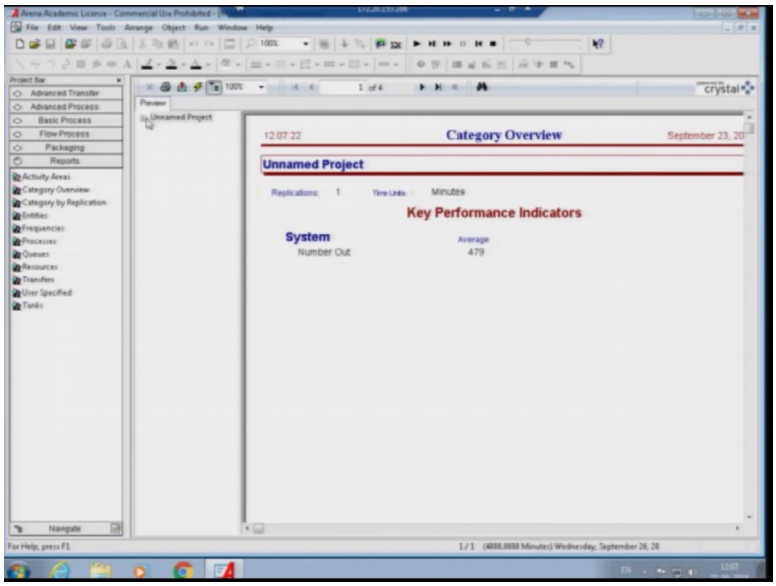

So, 400 and 70 9 parts more than 10 times of what we had seen earlier that is out. Now suddenly you see the half width value showing out. Previously it was saying insufficient.

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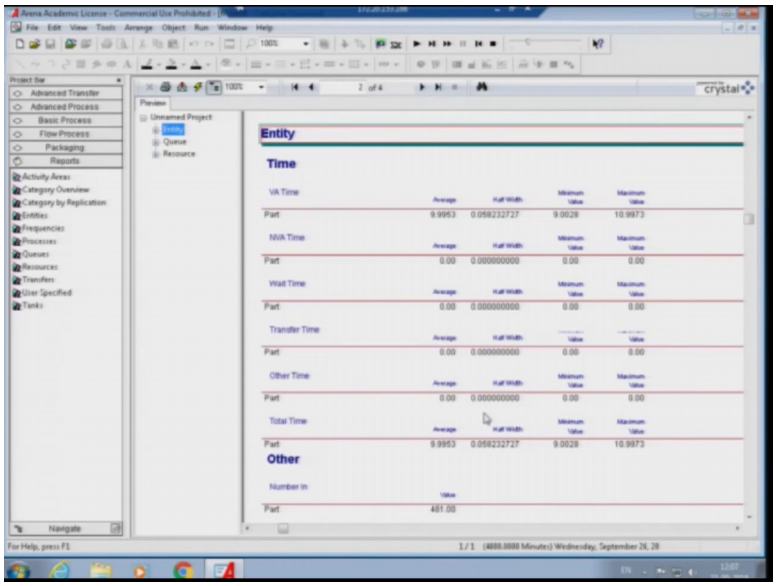

Now you see half width values are 000.05 whatever it is.

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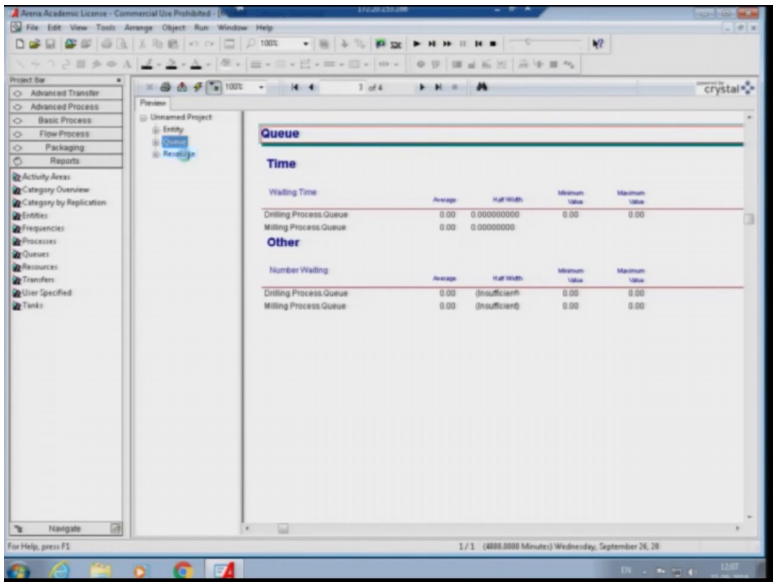

So, then if you look at the queue, there is absolutely no and then the half width somehow the half widths are insufficient.

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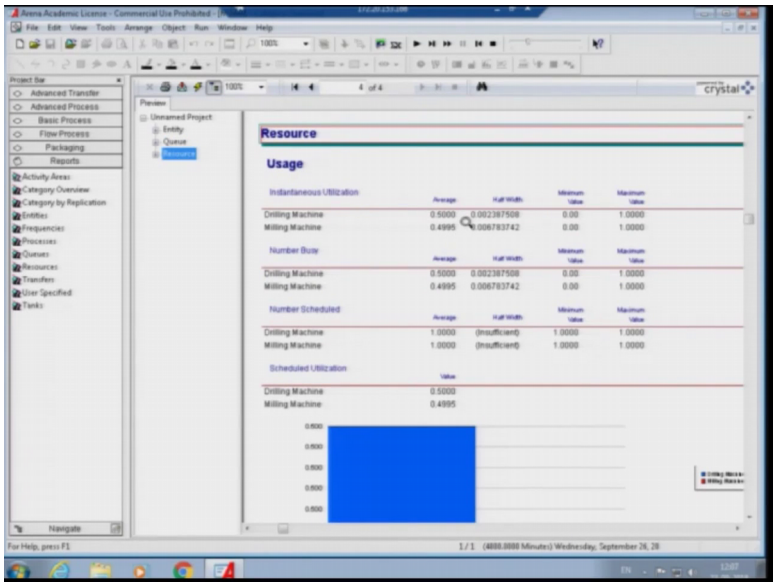

And resource you will see that the drilling machine is utilized exactly 50 percent of the time. And the milling machine is actually utilized 0.4995. It is not utilized fully is slightly less than 50 percent utilization that is because of the variability of the system as I said earlier. Now you look at the graph there is this one is a misleading graph, but yes you can see that it is slightly small ok. That is all what it is 4.995 that is the idea here.

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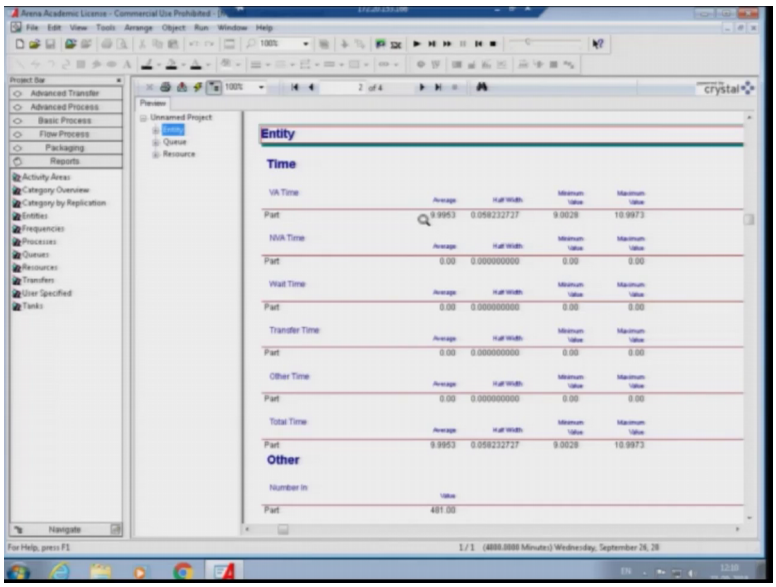

So, what we are trying to do here is the half width now shorter. So now, what is this half width? So, half width is to an extent is in a way it calculates what is the this average ok.

V some for a given 95 percent of the time what will be the limits what will be the value is within which this average will be found that is what the half with to a large extent is being told in there is some there is a concept called confidence interval and the half width is one the half of the width of the confidence interval is what we are talking about how much very, very similar to that. So, here it is at arena uses 95 percent I believe. So now, you can see that with the longer run when the system has a much longer time to perform then you how half width or in a way the system ran for a long time period.

Or the sample size was large enough for the simulation to have enough confidence or a enough data enough sufficient data to give you that 95 percent of the time from the data. I am confident that the mean the average will be between 9.9953 plus or minus 0.058232 whatever that value that is given. So, you are saying then in that regard is the mean will vary between 19 9.9953 the mean value at a time will vary between 9.9953 minus 0.0582 that will be the lower value.

And the higher value will be 9.9953 plus 0.0582 whatever it is how you round it off to whatever value. So, that 195 percent of the time that is where you will find out is find the average lying around this what the what the half width helps you to tell. Or it is in a weight will tell you with 95 percent of confidence what is the expected value of the meantime, mean is the average we have talking average is called as the mean in this regard.

So now what happens is let me show to you guys as little bit of a difference since we already added little bit amount of variability in the system, what happen if I make it 3 and 7. I increase the variability slightly it is till the average is 5 it is 3 plus 7 which is 10 divided by 2 it is 5. The average comes to 5, but the time can vary between 3 and 7. I was only changing I am doing and in one of the things that you need to do in simulation study is always ensure that your study follows a step by step process.

You do not randomly keep on changing things all over the place. this kind of thing where you slightly change things at one step at a time. And then study the behavior of the system what I am now doing his I am actually doing experiment with the simulation model. This is called experimentation. So, you set up a model you see ensure that the model behaves as expected without any variability. And slowly introduce variability one after another to see how the system behaves how the system works. And then study the,

understand the process of the system and then go from there. So now, you can see that I change the milling process mean time from 4 and 6 to 3 and 7. So, I have.

Introduced more variability into the system I have not changed with the means, but I have introduced more variability into the system. So now, with this now I go to run setup, I do not want to run it to 4800 minutes I just run only to 480 minutes. So, that you can you can also replicate this with your system. I press this, the fronts and say simulation has come to completion we are like to see the results. The number out is 48 and let us see, what happens.

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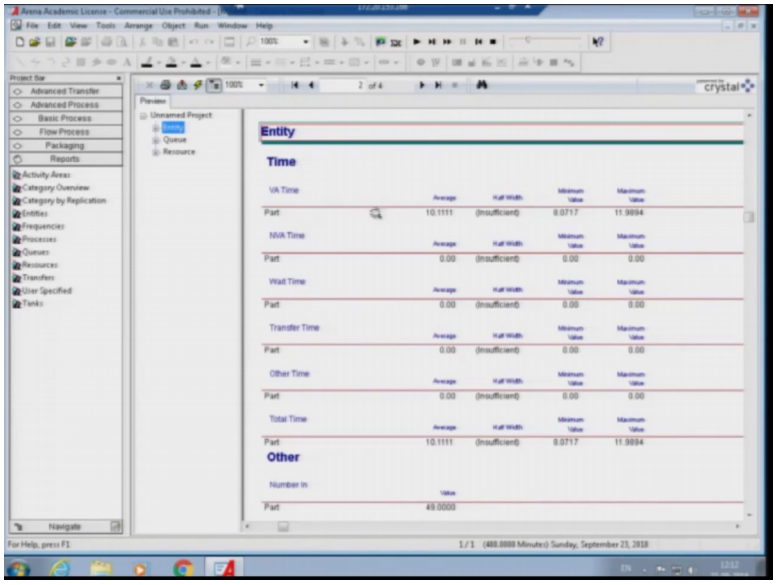

Now the value added time the average time you can see hours be increased 10.111. The minimum value is 8.01 and the maximum value is 11.98. So, the time variability varies now between 8 to 12. And you can see the half width is now insufficient. And the minute I changes this to you know before that it is look at the queue.

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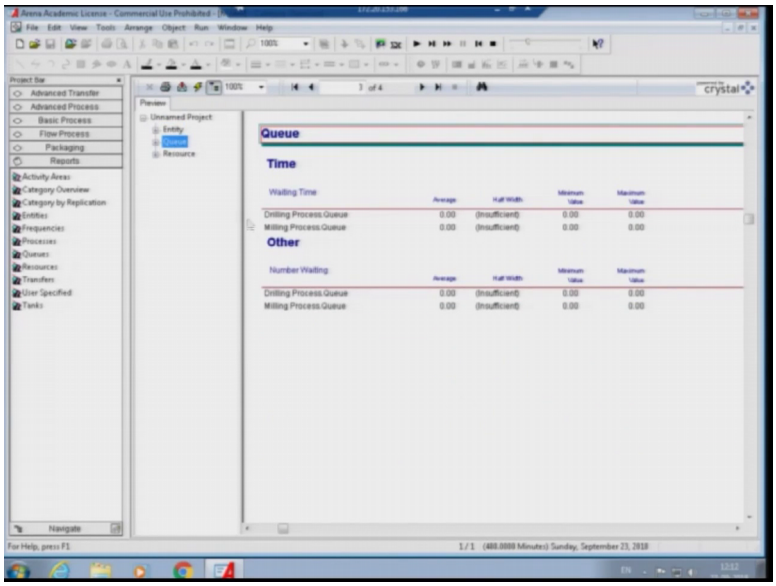

Nobody was still waiting in the queue, everybody there is no queuing happening at this point at all.

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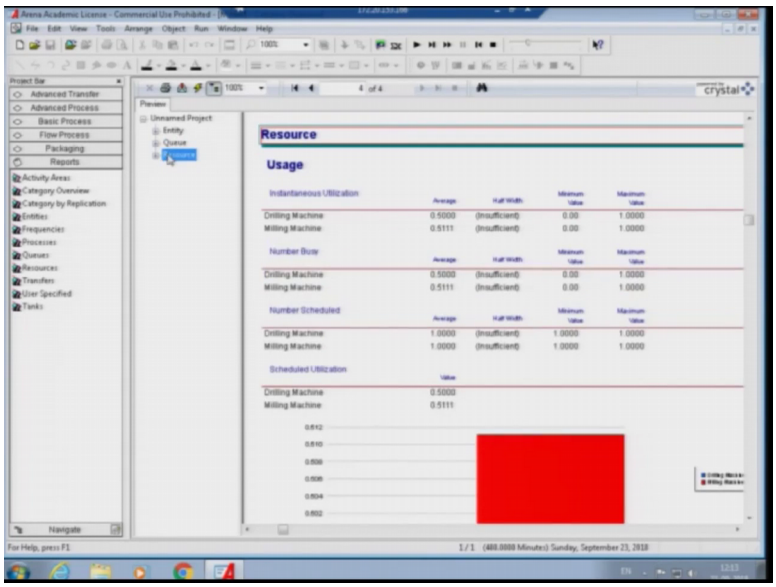

And the resource utilization if you look into it milling machine was slightly more utilized compared to the drilling machine.

So, I just wanted to show you the half width now showing up the minute I change the runtime to 4 thousand 8 100 minutes. So, apply and we run the simulation model let us

see whether there is other any queue showing up probably not. It is take little bit of time to finish the simulation because it is a simulation has finished and 479 as expected ok.

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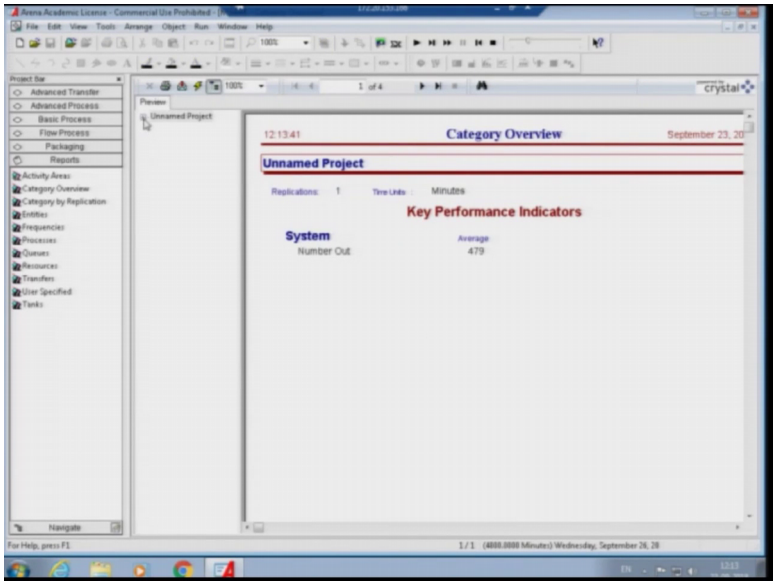

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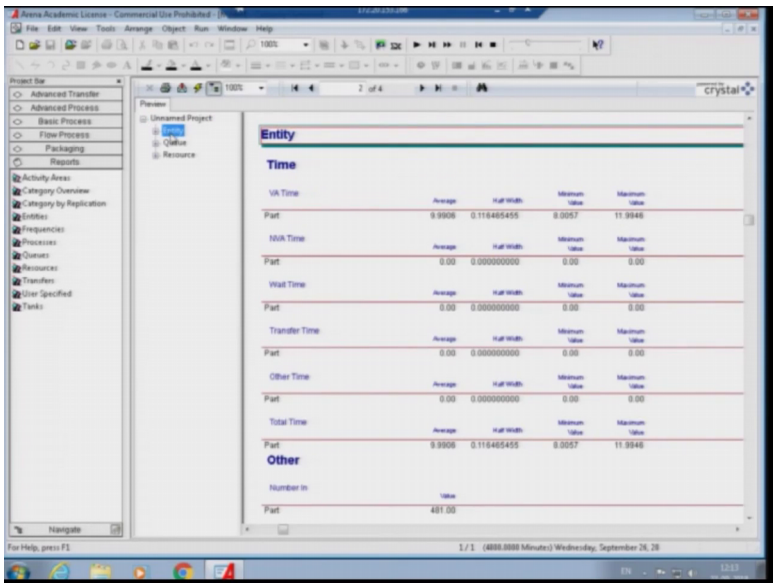

And if you look into it the average value added time is now 0.9906 very close to 10 and half width you can see half width value has shown up.

This half width was larger than the previous half width which was point 0 0 5 was a previous half width, when I did the variation was between 4 and 6 like made between 3 and 7. And you can see that the half width has increased, but you can also see that since I

run the model for a longer time period then what did I what happened I had more entities instead of the 48 entities there are 480 one entities are came in the system. So, when you have larger number of entities or larger the sample size ok. Then you have sufficient enough confidence to create the confidence interval, where you are basically saying that your now I can tell you with 95 percent confidence that the value added time the average of the value added time which is 929.991.

Or 90 9 0.9906 after bit after 90 9 point 9 991will vary between 90 9.9906 plus or minus 0.116 5 95 percent of the time the values will lie between that limits that is what the half width is trying to tell you and you look at the queue.

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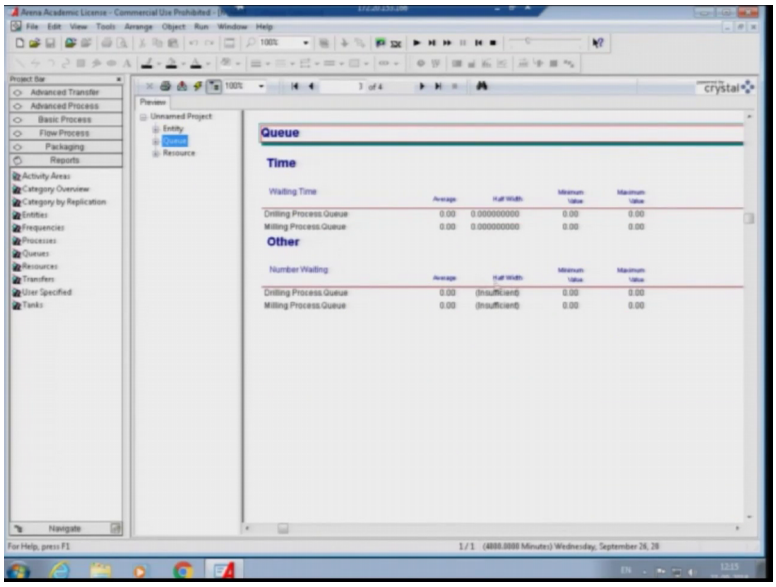

Still there is no queue look at the resources.

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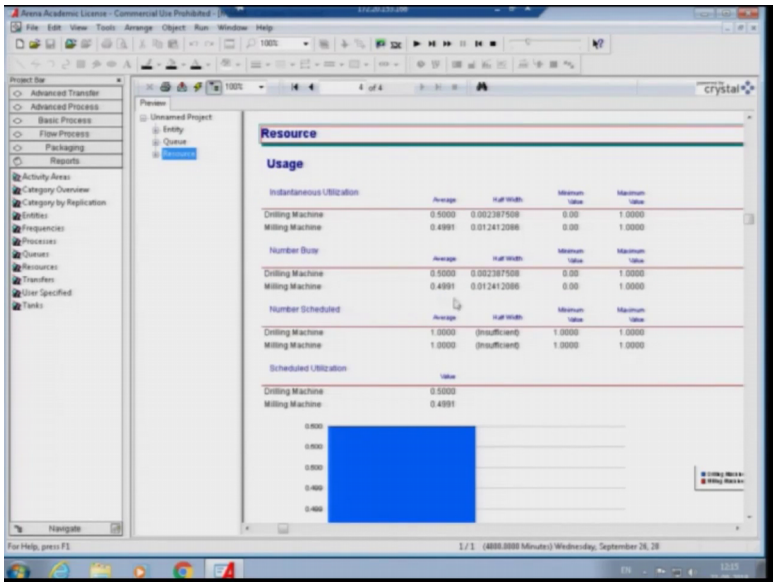

You can see that drilling machine is utilized 50 percent of the time. And milling machine is only utilized 40 percent 49 9 percent of the time slightly because of the fact that the drilling machine the milling machine has more variability in the system.

Now, that we are played with only one machine where there is variability in the other guy is basically being a constant. So now, let us see whether if you change the drilling process let us introduce variability in the drilling process. Instead of a constant let us put uniform here again. And in uniform I am going to make it as the 4 and 6 seen as that of previously 4 and 6 there is some variability in system hit ok. So now, immediately you see that the pillar type is uniform 4 and 6 this case also is uniform 7 and 3 ok, but the only thing is that both of them have the same average, but except the minimum and value maximum values are different.

And let me go back to the setup and make it into 480 minutes not 4 thousand 8 100. So, that you can also run and see these results for yourself and I hit the play button ok. Simulation has finished number out 48 ok. So now, you see that the value added time ha is changed.

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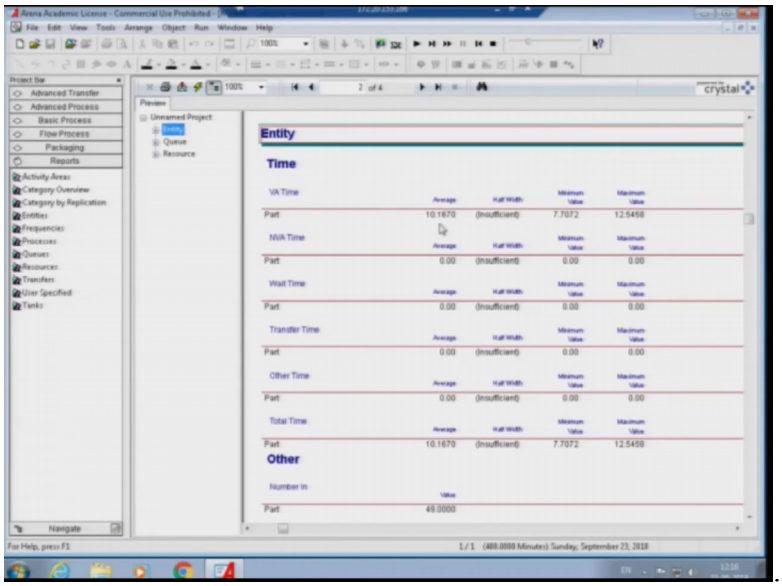

10.16 and the minimum and maximum values has now become 7.7 0.54 the half width is insufficient ok, but 49 100 is came in and 48 went out of the system.

And that is look at the queue.

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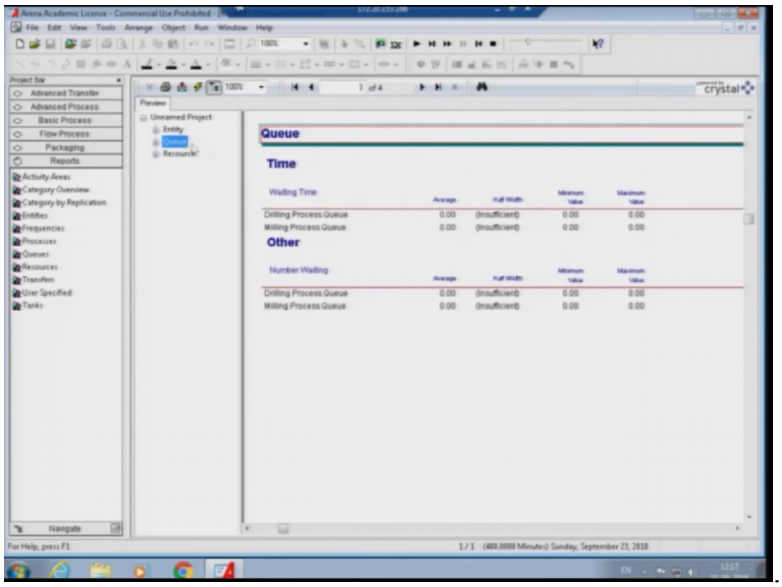

Absolutely there is nobody still in the queue, as because there is still every 10 minutes parts are arriving.

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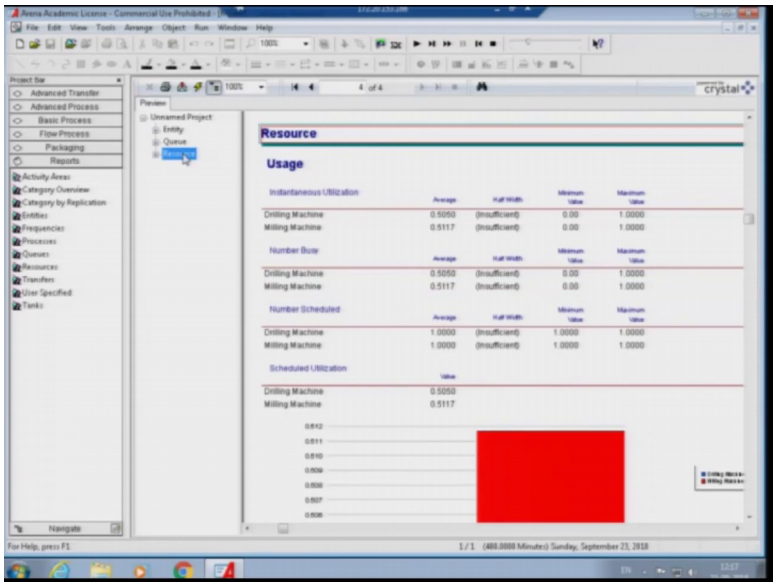

There is no variability to the arrival yet and you can see that the utilization of this, but this is for only for an 8 hour shift and this is a cardinal sent to make any conclusion from the simulation model or simulation by running a small study. So, what we do is we go back and we run it to 4800 minutes.

Which you guys may not be able to run because of the analyzes the version that you guess off. You might be able to run up to thousand minutes. And we are looking into this and let us see how it actually works simulation is running ok. And 0s at the bottom which say shows you what it is the status of the machine ok. So, I will get back to that later the numbers come to be exactly the same.

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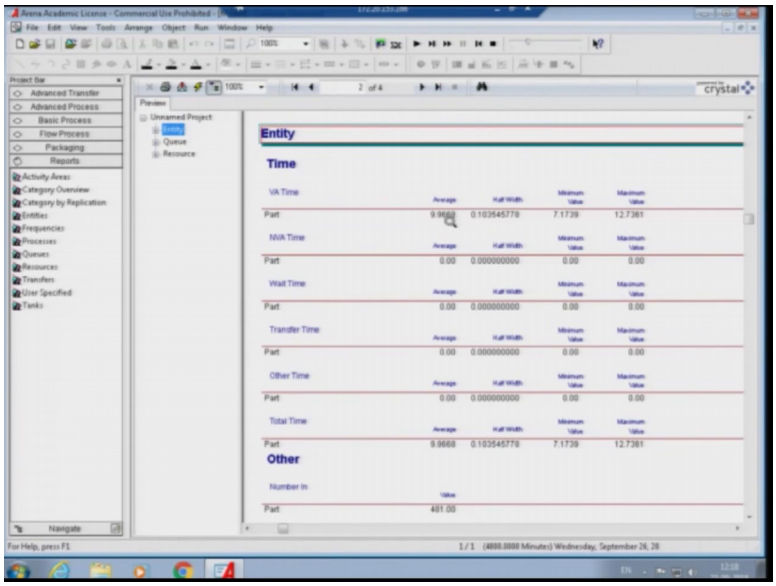

But now you can see that it is 9.9968 and half width values are slightly changed.But you can see the minimum and maximum values you have seen now the half width values whichever earlier not there. So now, when you run it for a larger time period when you have 491 observations or end it entities that has went into the system you can basically say you can tell that fine.

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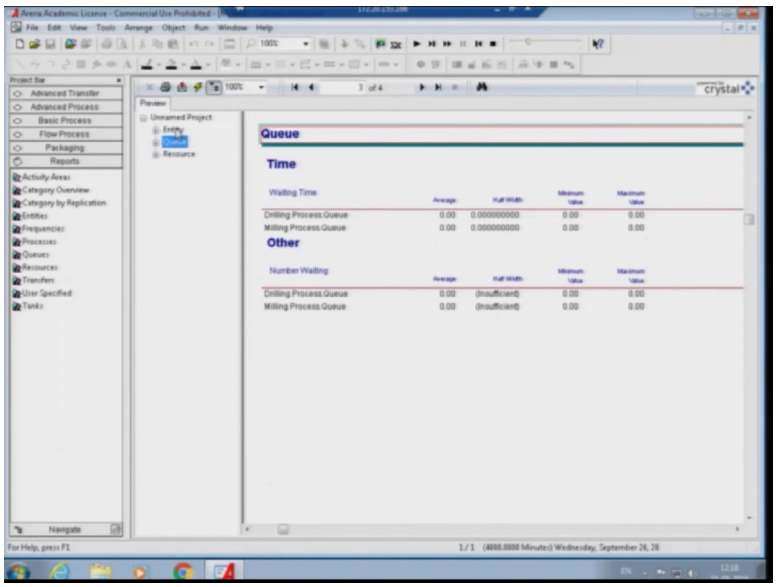

I have sufficient confidence to tell you what is going to happen with the entities or with the I can tell you how much of with 95 percent confidence.

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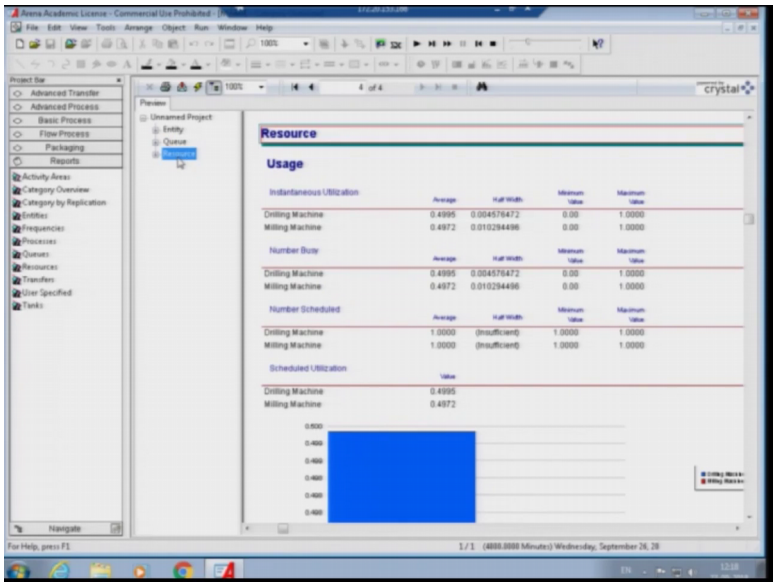

What will be the average value added time this is exactly what the value be a time value added time of the entity if you look at the resource you can see that both of the resource utilization has come down to below point 5 that is because of the variability the system. And because of that you can actually say that still if you look at the entity the time busy there because of the variability you can see that some point of time there will be you know some reduced utilization.

Because sometimes you are not really operating at 5 you are actually operating and 4. So, some might sometime you might be slightly free depending upon a time that you have calculated ok. With that now let us get back into. So now, we introduced some variability. So, let us see whether the drilling process also behaves exactly the same how does that happen. So, go to drilling process and I change this to 3 and 7. Exactly that of sort of the other case ok. So, this process is exactly the same now same variability except that there one after the other.

And we go to the setup and we run it for only 480 minutes apply. So, that you can also simulate the system we run at and we look at the results.

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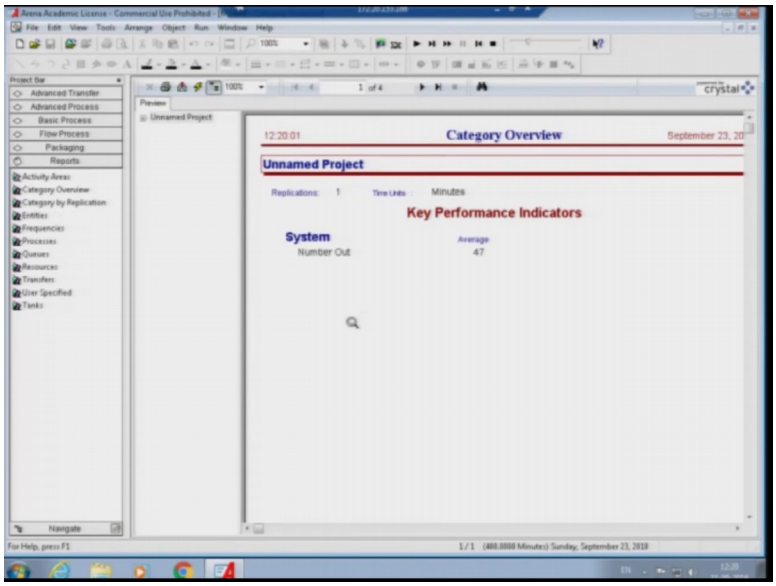

Now surprisingly the number out is no longer 48 is 47.

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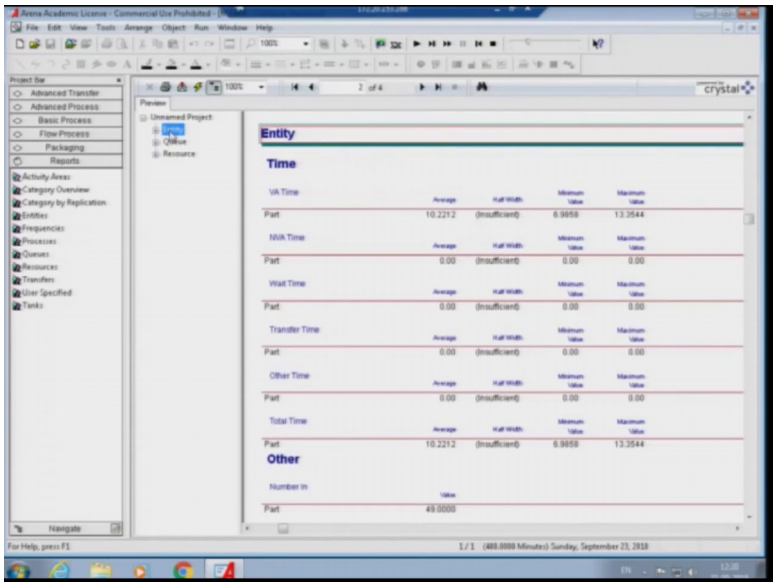

one entity less the value added time we can see that now this is the variability the system has picked up drastically and the you still there is no queuing.

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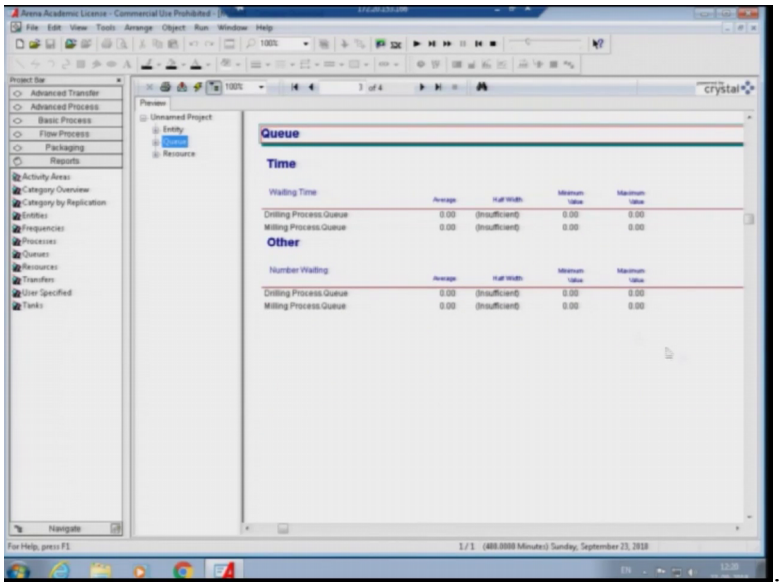

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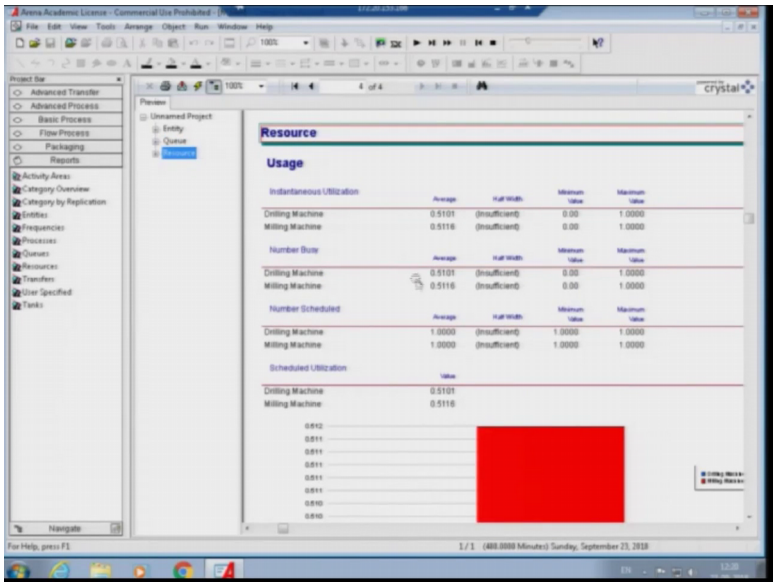

But the resource both of them are showing more than 50 percent utilization that is because the weird ways these time values are picked up that is because of the variability.

So, if you run it for 4800 minutes the half width will show up as I said earlier and you might be able to come up with a long time behavior this kind of longer simulation studies are called as the long term behavior of the system alright ok. So, as still the arrivals are

very constant there is no variability in the arrival of the system. So, it is getting very close to 4800 minutes, but it soon it will be over simulation is over alright and 479 is the average entity.

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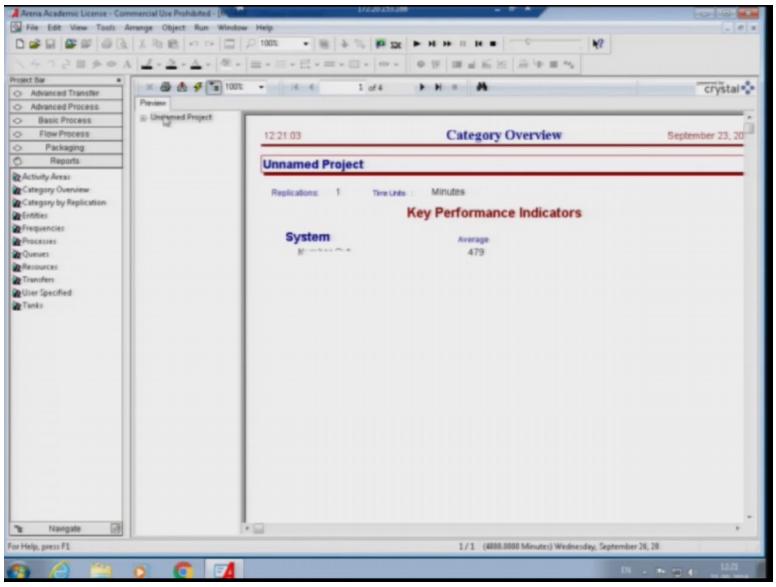

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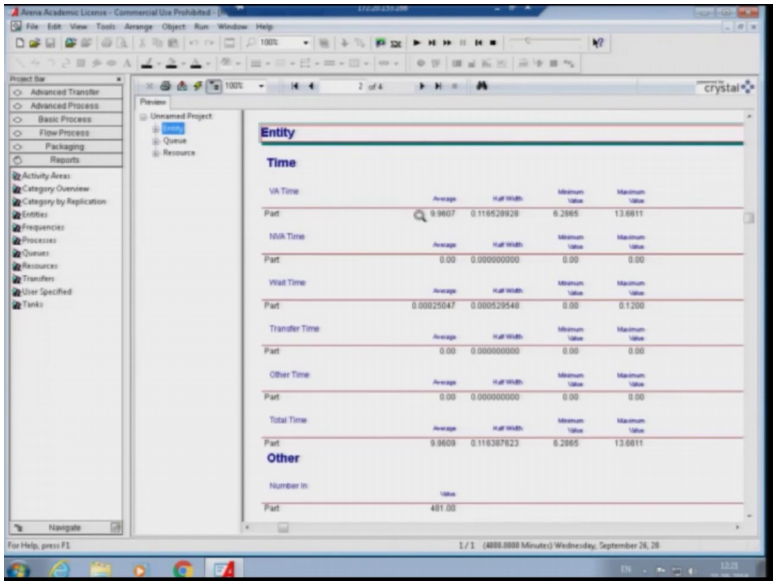

You can see that it is now 6 6.28 and 13.66 is the minimum and maximum value of value added times.

And the average is this much earlier given a half width which is slightly more than the values that you have seen.

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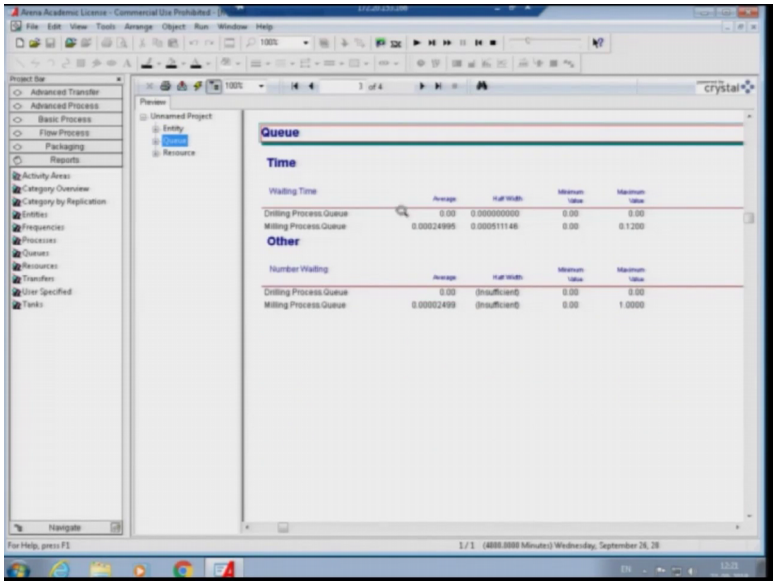

And you see now you see that there is a very, very small average in the milling process queue; that means, 0.0002 the waiting time about a very small fraction of a time somebody waited in the queue. This actually means that a some point of time in the part arrived if it. So, the milling machine busy and it ended up waiting in the queue.

So, we can now see that now that when there is large amount of variability in the system queuing can happen. So, the first evidence of a queue, the minute you see a queue in the system one of the first reasons that you should be worried about you should be thinking about is to quantify the variability of the system ok. Because one of the factors major factors that will result in queuing is the extreme amount of variability. With that now let us go back to the simulation process again. As close this report and now we have made both of these guys models are 3 and 7 varying and stuff like that. Now I want to go back I am going to change them to constant again value add the 5 mean.

This also is goes back to constant mean value of 5 absolutely no changes 5 5 and other things and go to the arrival and here what I am going to do is I am going to change the arrival to a different process ok. So, instead of the constant I am going to make the arrival variable arrival extremely random arrival I have no control over this. So, I am going to take the random arrival make it as random and the value remains it as 10, I am

not going to change value at all just remains as 10. So, from the constant turn I am making it as a random or will say random process means an exponential time between arrivals.

The time between arrivals follow exponential distribution or the arrivals themselves will follow a process called poison process is some people called as Poisson Poisson process. We will see what Poisson processes is in the next class for the probability statistics aspects of it this is why probability statistics is important for simulation because you use quite a lot in modeling the behavior of the system. So, with that we now go back and we see and heat and everything else only the arrival is exponential with 10 minutes the mean did not change from constant it has become a random process.

Drilling is a constant process with 5 milling is a constant process with 5. Everything else remains the same I go to run control I setup and this you know the 4800 minutes I heat 480 minutes apply. So, the also do this and run the simulation and you can see that some queuing definitely has happened.

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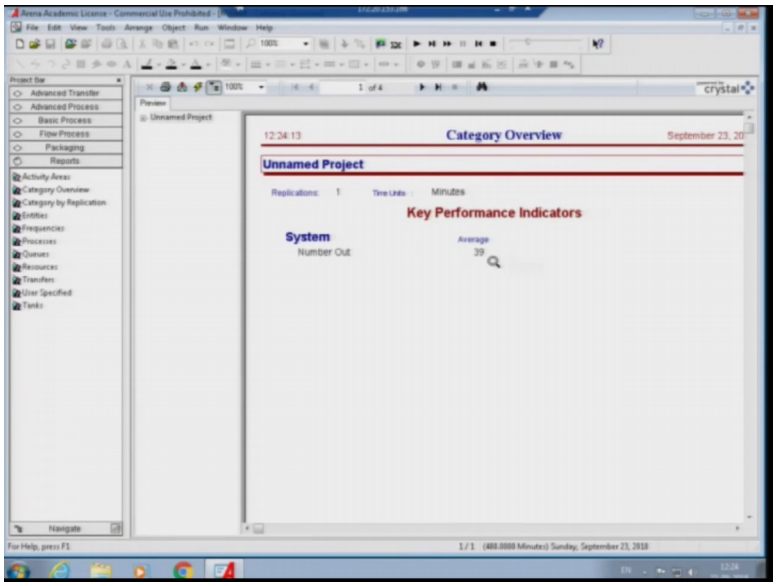

Now, the number out which we were playing around in 49 47 and those kind of numbers there is only 39 of them.

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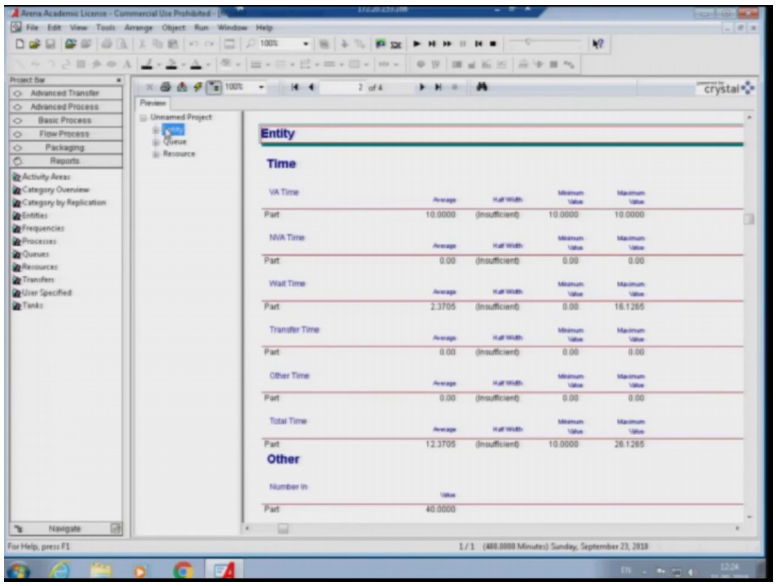

That actually has come out. So, the throughput the productivity of the system which used to be when a constant arrival happened which was at 40 7 this time previously it is now come down to 39.

So, will look into it the value added time is 10 minimum and maximum is 10 if you look into it you will see some values where that used be earlier 0 0 0 you will see wait time now showing the value wait time shows us 2.37 minutes and at one point of time we can see that the maximum value of wait time is 16 minutes what is going on. So, the total time in the system the average is 12 minutes 10 minutes of value added time and 2 minutes of wait time these 2 put together.

The v a time and the wait time summed together will gives you the average total time in the system and we can see that the minimum value of the time in system is 10 where as the maximum value is 26.1265 which is this maximum value summed by this particular maximum value. So, the total time in the system in the entity this is the time I am trying to you we calculate the total time earlier which is the sum of the value added time and the wait time. So, average value at a time plus average wait time gives you the average total time in system.

Maximum value of value added time and maximum value of wait time sum together will give you the maximum value of the value added time in this particular system. And you

can see that 40 part only 40 parts arrived instead of the 48 parts only 40 arrived and 39 were finished ok.

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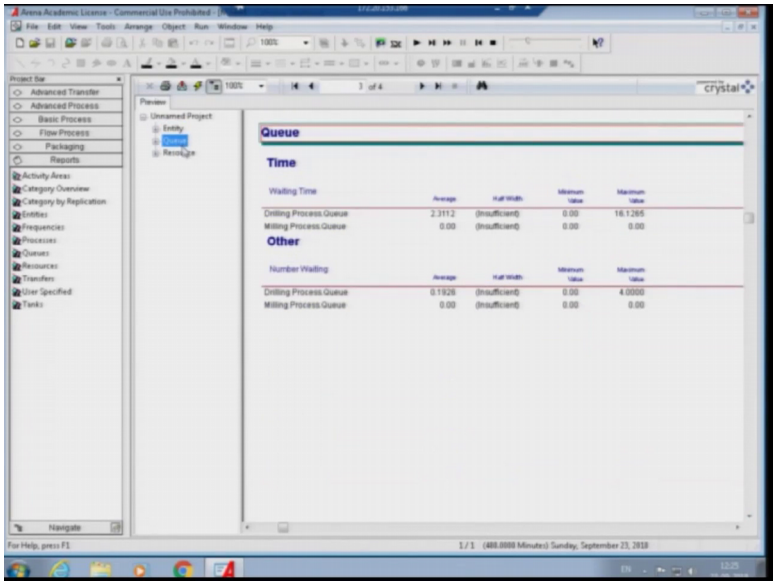

And if you look at the queue, you can see that the drilling process queue surprisingly average waiting time is 2.31 minutes. And minimum value is 0 maximum value is 16 how is this even possible whereas, the milling process there is no queue absolutely no queue and number waiting is 0.19 as like sometimes there is 4 people waiting in the queue.

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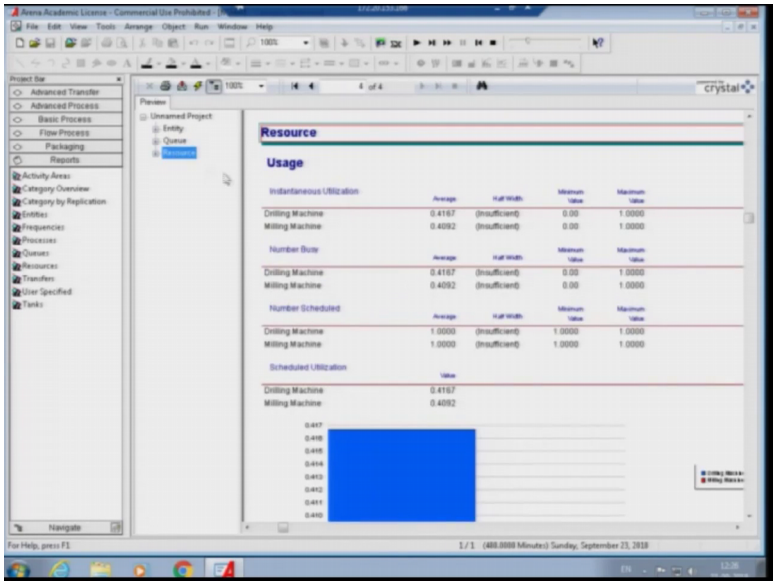

If you look at the utilization of the resource billing machine is utilized 41 percent of the time milling machine is utilized 40 percent of the time the utilization has come down. Drastically which used to be 50 percent 50 percent utilization that is about 10 percent 9 to 10 percent reduction in the utilization. How is this possible? What does going on?

So, maybe we might made some mistake in the model. So, let us try running it for 480 minutes sorry 4800 minutes long time simulation. And see whether it is a small phenomena or is it actually a serious phenomena. So, we will run the simulation and you can see that in this simulation itself you will see queuing happening here. This particular place you can see parts queuing up whereas, there is still no queue in the milling process ok. And we are running it for 4800 years.

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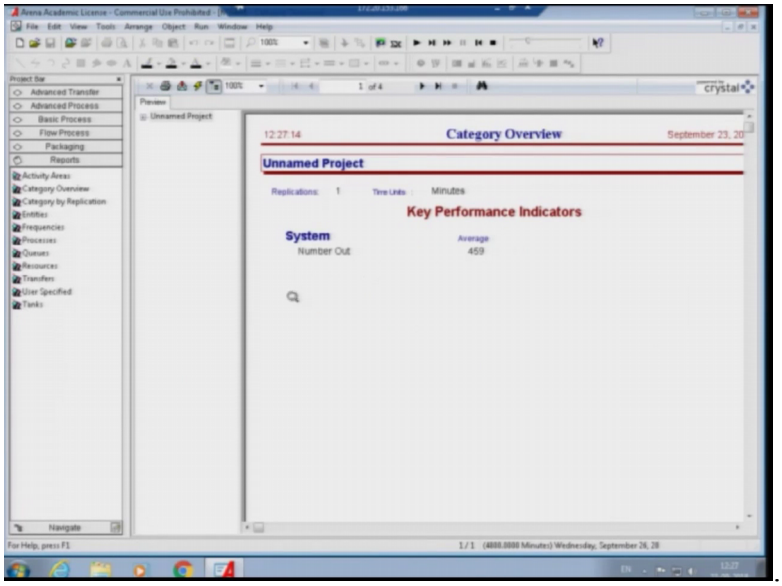

Yes, and if you look into it the one that use before 100 and 79 parts that used be out in the earlier system we are only getting 459 and about a reduction of 20 parts are going on here.

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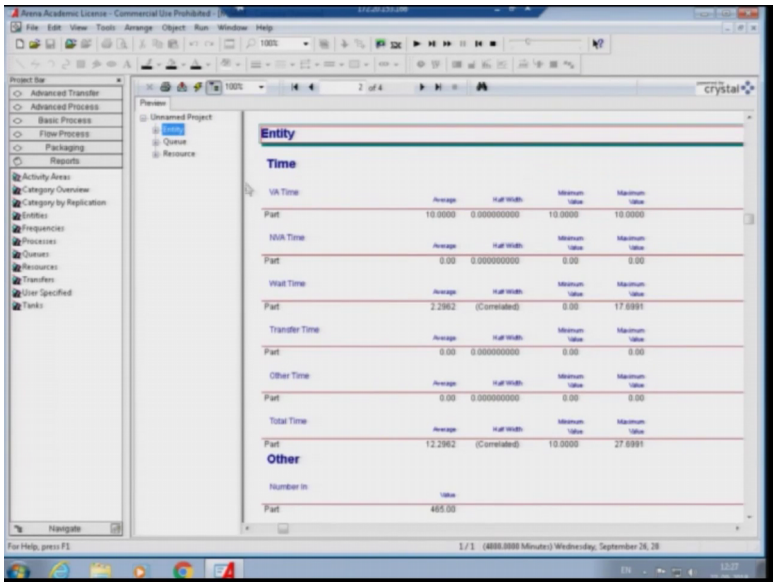

So, you look at the entity you can see that the value added time average is 10 minimum value is 10 maximum value is 10 the wait time is 2.29 minutes minimum is 0 maximum is 17 you can see that this simulations results kind of you know somehow and here you will see the total time ok, it says 12.2 9 6 2 that is average which is the sum of this 10 plus 2.

Then the maximum minimum value is this the minimum value of the value added time minimum value of wait time and maximum value of wait value added time and maximum value of wait time sum together will give you this. And you see the time correlated written here half width correlated. Correlation is a situation where the effect of 2 variables or 2 aspects cannot be separated out ok. They are related to one another. So, when we say that half width is correlated, which means because of what is going on in the drilling machine the things are happening in the milling machine is also correlated with that ok.

Or in another way to say it is because there is a crazy randomness in the arrival process that randomness results in the behavior of the waiting time and all those aspects of it. So, this correlated mean there is an impact or a some evidence of correlation going on due to something. So, let us see what this correlation is all about. What happens here is if you look into this what I have done is I have not done anything else I kept all the variability

to be the same and what I did id I introduced uncertainty into the system the randomness into the system.

And you can see that, how I introduced uncertainty into the system I introduced uncertainty by changing the arrival time arrival processes into a Poisson process ok. That is all I ended up doing the minute I did that what happened to us the system behaved drastically. When I introduced variability I can see that the behavior of the system was nasty, but still I could get things to work ok. Now that this now that when you look into this you can see that it is not exactly the same because the randomness the uncertainty that is put in with the unpredictability that I put in those system is very much more craze here than the uncertainty or the variability that I put it into the by into the 2 process by varying that processing time using a uniform distribution.

So, this is the reason why we use probability in statistics to study the system. Purely because of the fact that when you have a system like this where an arrival happens it goes through a drilling then a milling and a parts leave, this is what we call as a you know it can be an simple example this kind of a systems are called as floor shops systems. Because all parts flow follow the same loop or same path. So, as a flow floor shop ideally parts arrive then go to the drilling milling and then leaves the system.

So, here you can see that when I change these 2 2 uniform distribution. Both of them I even varied the processing time largely and I was able to see some slight amount of queuing why what where the parts arrival was made as the, it was constant. Then I made these guys as constant and I made this as the arrival as a random process. I introduced uncertainty in the system and the system became crazy. Now before I stop what I will do now is I will introduce the same instead of the constant I introduced the uniform 3 and 7 into both cases.

I am doing is I am doing the uniform 3 and 7. So now, what I have is I have both uncertainty and variability in the system now. I have introduced uncertainty the arrival we you see the random process. And variability is introduced into the processes by interchanging the process time from constant to a probability distribution. I go to the run setup I run it only for 480 minutes so, that you can also run it on your run it on your student evaluation version. We run it and we see the we see what the result is.

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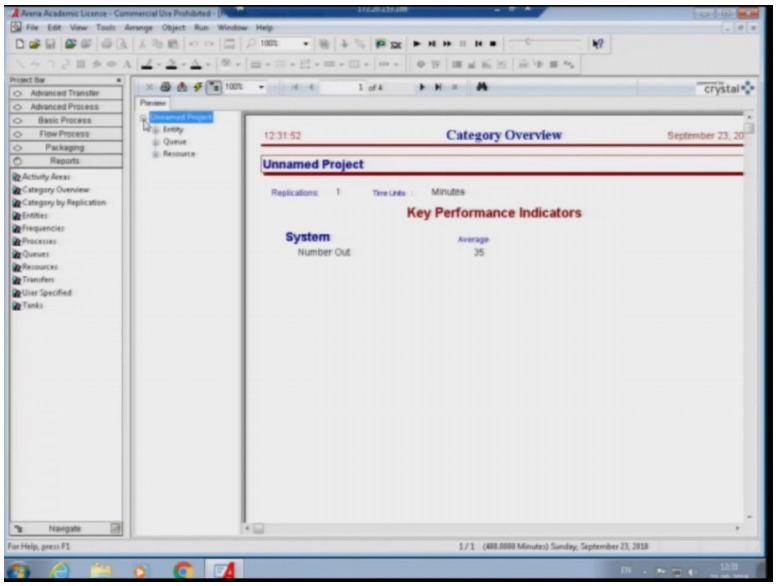

And now all of a sudden you can see that it is now come down further to 35 it used to be 30 9 earlier now it is come down to 35, we can see that the minimum and maximum values the value added time is now changed.

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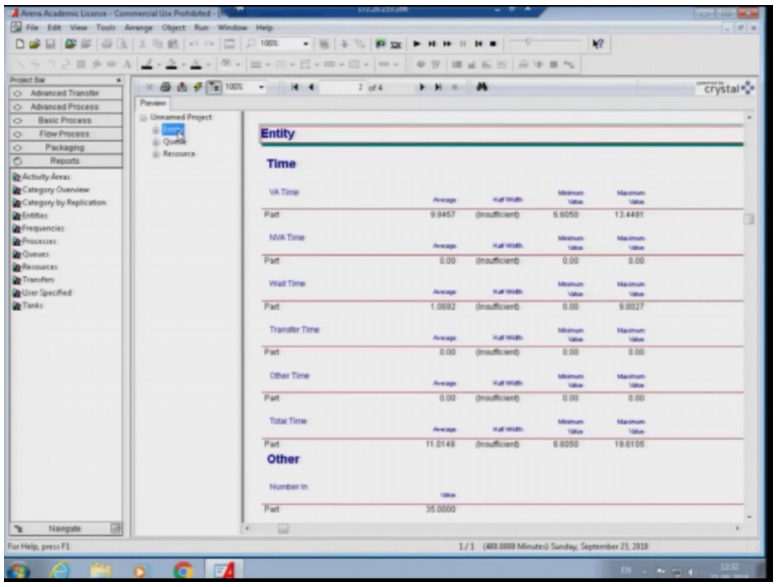

Minimum is 6.6 5 maximum is 13 now earlier it is to be 10 and 10 now it is drastically changed. The wait time has slightly reduced, but you can see that the total time in the system has actually increased in this case 3500 is arrived and 35 are processed

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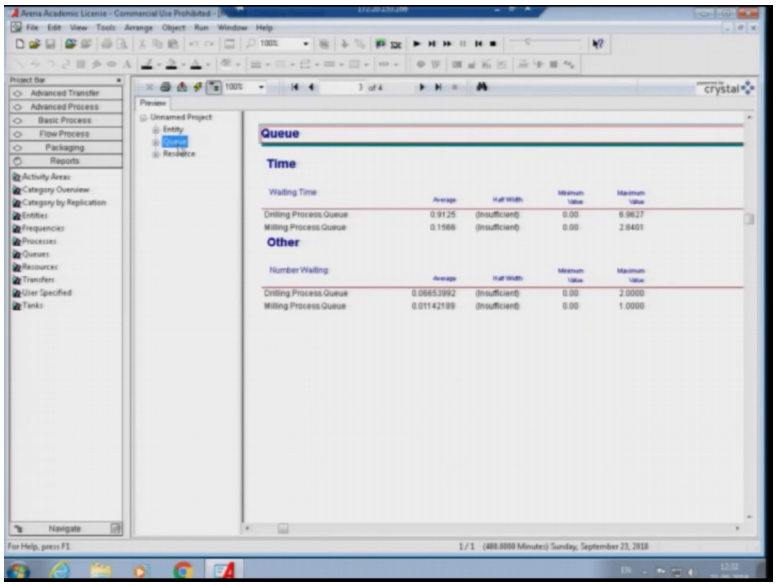

The queue you can see that both of them there was some slight amount of queuing actually is going on in this regard.

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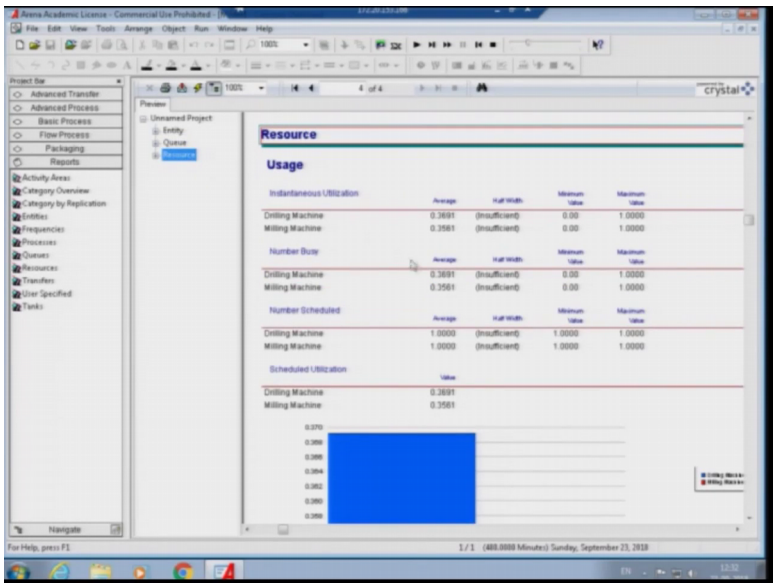

And the resource utilization you can see they have now come down drastically. So now, before making any conclusion; let us run the system for 4800 minutes for a longer time period ok. So, that we have much more larger sample size and the system is more confident of giving as the behavior of the system and let us see how the queuing and you can see that some amount of queuing is happening on both the systems at this time

period and let us wait for the system or simulation to complete and you can see that the values are further come down 454.

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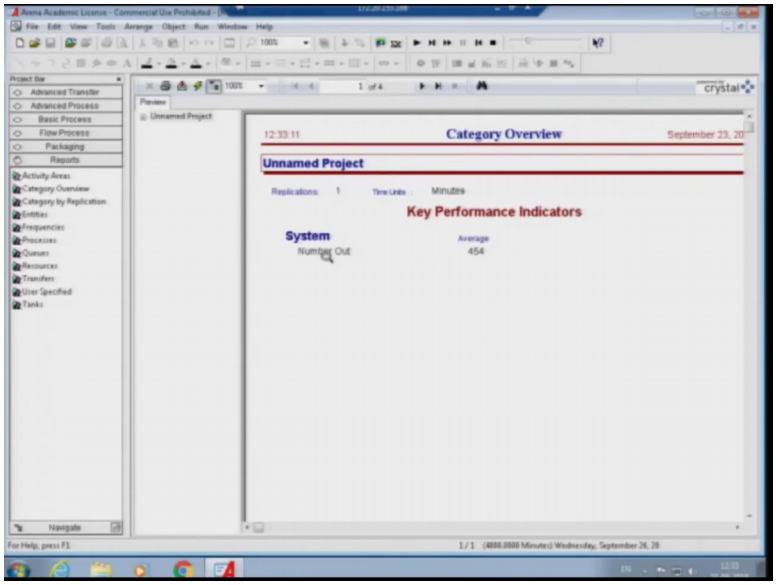

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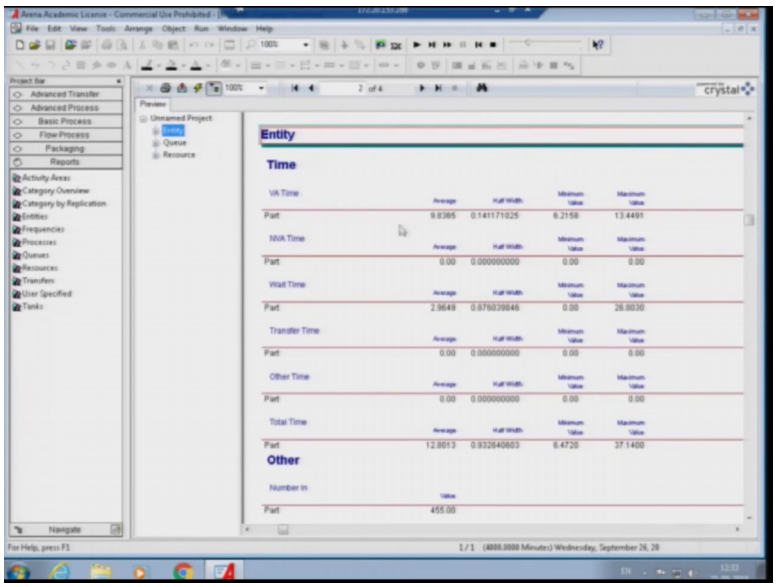

So, if you look into the entity the value added time it is 9.8 minutes and the half width is now shown up. And minimum and maximum values, there is no correlated return at this point. It is one of the reason is that the half width are calculated properly because there is variability. So, what happens is one of the queuing will actually break the impact of the arrival process into the system. So, there is there is not much evidence of the correlation

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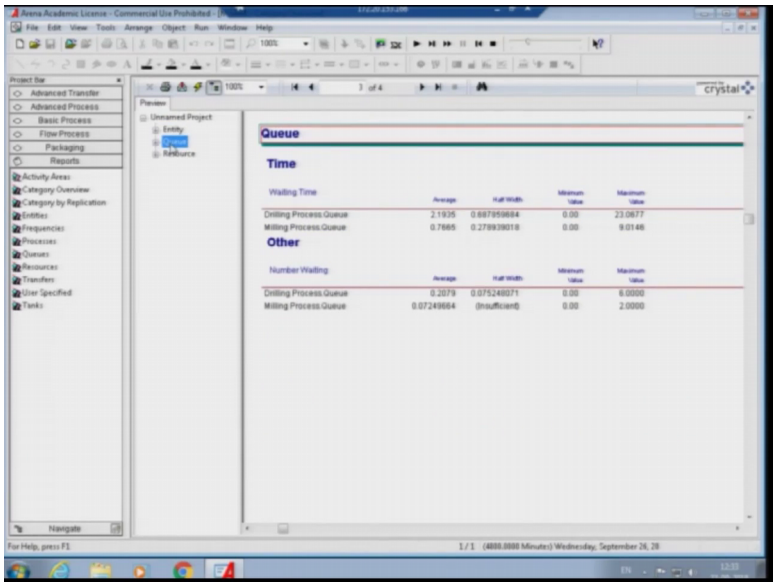

And you can see that the total time in the system is now 12 minutes a larger time value with a minimum between 6 and this one. And you can also see that the there is queuing going on in both cases in the drilling process the queue the there is unscenario you will see that there were 23 parts that were on an average sorry not 23 parts 23 minutes this is the one part waited in the system and you can see that the number waiting the minimum value is 0. And maximum values is 6 at some point of time there are 6 entities that were waiting in the drilling queue whereas, in the milling queue only 2 entities were waiting on an average.

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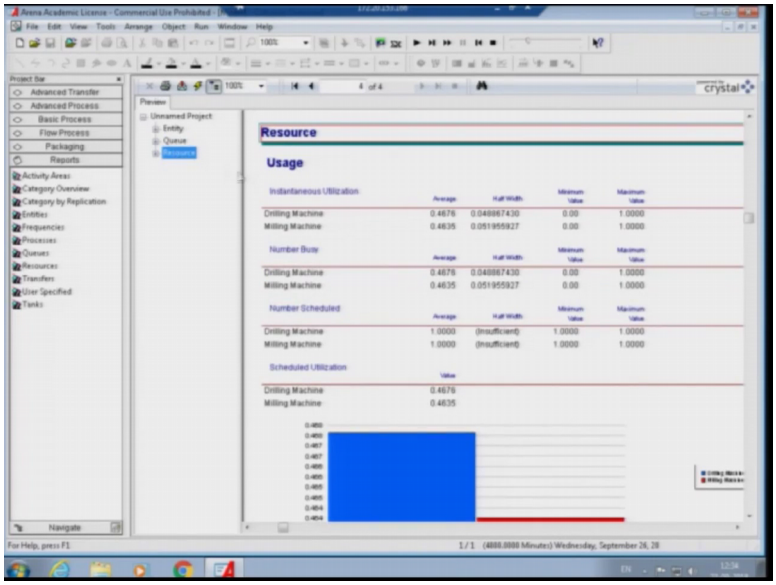

And if you look at the resource utilization you can say that these resource utilizations are which were shown as 39 or something in 480 has now stabilized to 46 percentage on an average. So, ideally the average time the mean time is 50 the expected time is 5 minutes, which means the other one is ten. So, you are supposed to have the resource being utilized for 50 percent of the time, but you are only seeing in the utilized for 46 of the time. And this is one reason one of the examples of what is variability does through the system uncertainty and variability together to a large extent do reduce your productivity from what is expected out of it. Your expected productivity was both the machines to be busy for 50 percent of the time.

And slowly and sadly this regard we can see that is not 50 it is only 46 percent of the time 4 percent reduction in the utilization on the machine is being seen purely because of the variability in the system ok. So, with this what I will do today is that I will call this as a good enough session for you guys to model how to use arena based simulation models or simulation software to build models and use those models to conduct systematic experiments with systems. So, that you can understand the behavior of the system.

Unless you build a model like this and play around with it and step by step change the aspects of the system and try to correlate what is going on the analyze the behavior of the system, and try to introduce your hypothesis and check in with the data. Only then you will be able to understand the inherent behavior of the system. The inherent aspects of the system and slowly you will it will be clear in your mind how uncertainty and how variability together results in the system changes the system behavior what happen is there is only variability and no uncertainty, what happens if there is only uncertainty no variability what happen when both of them come together.

And now it you will be able to appreciate the need of probability in statistics. Because you know now know that both uncertainty and variability put together is one of the biggest enemies of your of reaching the expected productivity and your productivity actually reduces. That is one of the reasons why people do lot of practices in industry to reduce variability and reduce uncertainty. So, that the productivity of the system is high and you can get maximum value for the money that you have invested in the business ok. Thank you for your patient listening and we will meet again later with more concepts of probability and statistics.

Thank you.