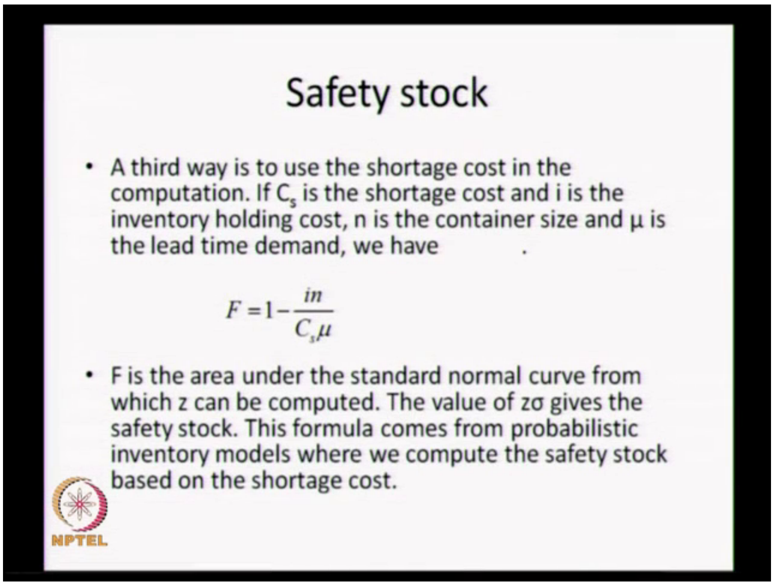
# Manufacturing Systems Management

**Prof. G. Srinivasan**
**Department of Management Studies**
**Indian Institute of Technology, Madras**

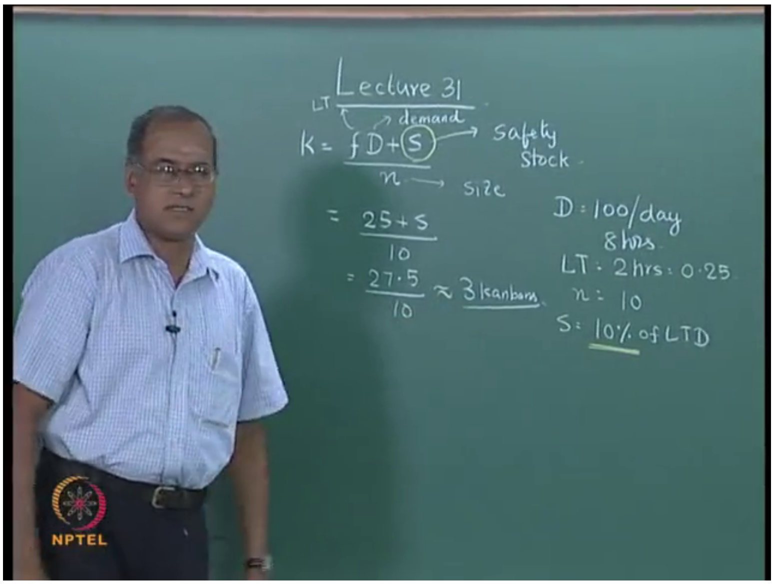
## Lecture - 31
## Models in JIT

(Refer Slide Time: 00:09)




In this lecture we look at Safety Stock Computations in Kanban.

(Refer Slide Time: 00:19)

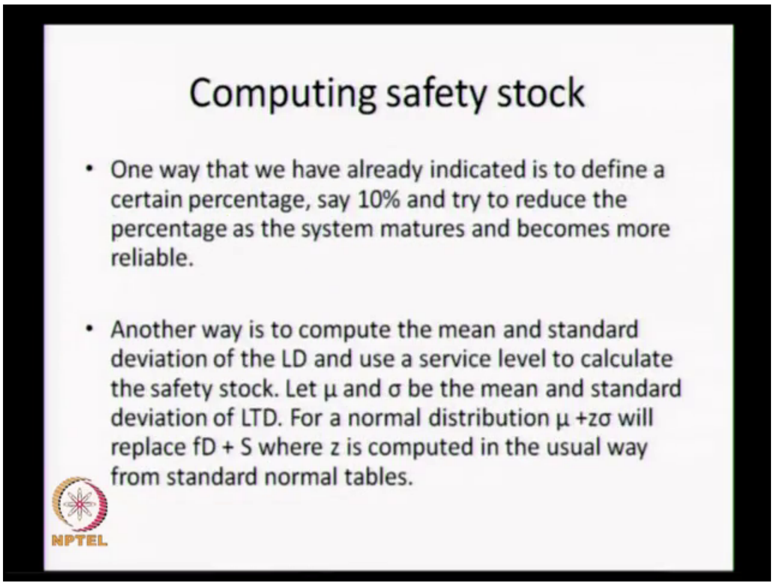


In the previous lecture we looked at this formula using which we computed the number of Kanbans. So, here n is the Kanban size S is the safety stock that we give, D is the demand and f is the lead time or the fraction of demand that we are considering. So, if we take an example and say that the demand is 100 per day, comprising of 8 hours per day, lead time in this case is 2 hours which is 0.2 5 for this example.

So, this will become 0.2 5 into 100 25 plus S by 10 if n is equal to 10, now this S is the safety stock that we provide. So, if we assume that this S is 10 percent of the lead time demand then this will become 27.5 by 10 which will be approximated to 3 Kanbans.

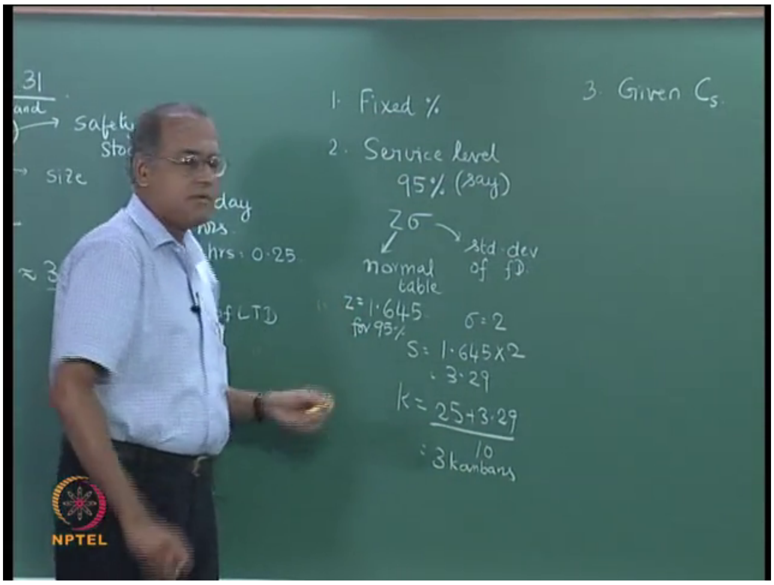
So, this led us to how do we fix this S or safety or how do we fix this 10 percent. So, if we assume a 10 percent safety stock then we get 3 Kanbans in this example.

(Refer Slide Time: 02:20)




We looked at some ways of fixing the safety stock 1 is to try and take a fixed percentage such as 10 percent for the computation and then as the system progresses or as we start implementing the system we get better control over, the withdrawal and the kanban system and the percentage can actually come down from 10 percent as we implement this system.

(Refer Slide Time: 03:03)

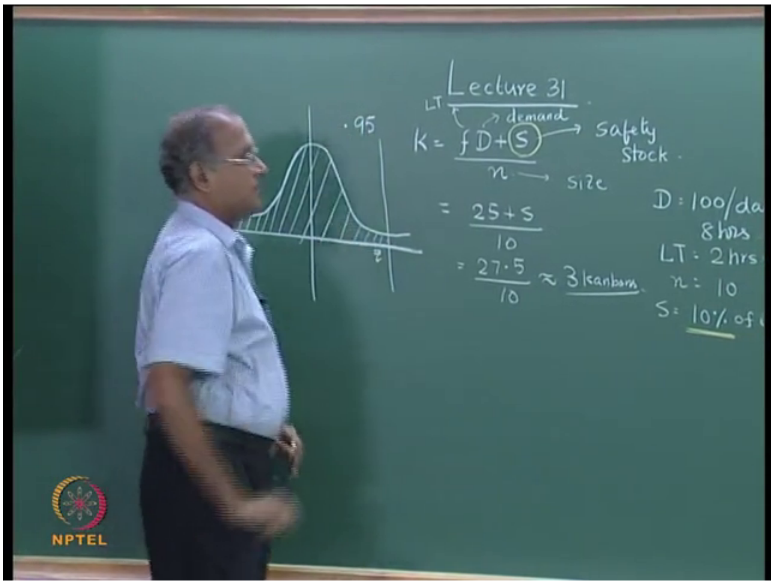



The second one is to decide a predetermined service level say we will have a 95 percent service level say and once we have 95 percent service level then the safety stock will be taken as Z into sigma if we assume that the distribution is normal. So, Z comes from the normal table and sigma is the standard deviation of fD or the lead time demand.

If we use 95 percent Z becomes 1. 645 times sigma, this 1.645 comes from the standard normal distribution. So, if we say in this case that the standard deviation of the lead time demand let us say is 2, if sigma is found as 2 later we will show a procedure as to how we compute the sigma. So, if sigma is 2 then we would have service S is equal to safety stock will be equal to 1. 6 4 5 into 2 which will be 3.29 and K will become 25 plus 3. 2 9 by 10 which will give 3 Kanbans the third way to do is for a given shortage cost.

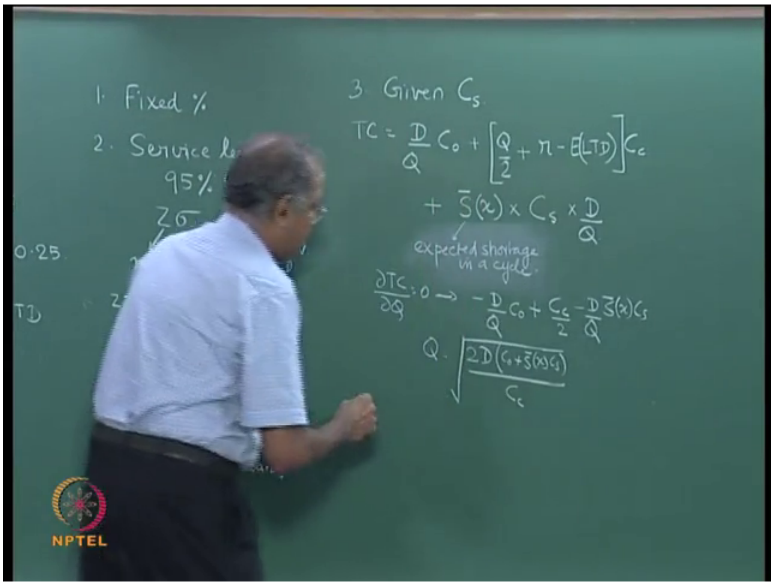
We find out the area under the normal curve and then we use the Z is computed from the normal curve for a given C S for a given shortage cost this is computed; in this example the service level was predefined. So, based on the service level the Z was computed here we looked at the standard normal distribution.

(Refer Slide Time: 05:48)




And if we said that the service level is 95 percent then we are going to find out Z for which this area is 0.95 and then using that Z, we computed the number of Kanbans. Here what we do is we for a given value of the shortage cost we can compute the Z value and then from the Z value we can compute the number of Kanbans. We will now do that derivation for this derivation we go back to probabilistic inventory models.

(Refer Slide Time: 06:47)



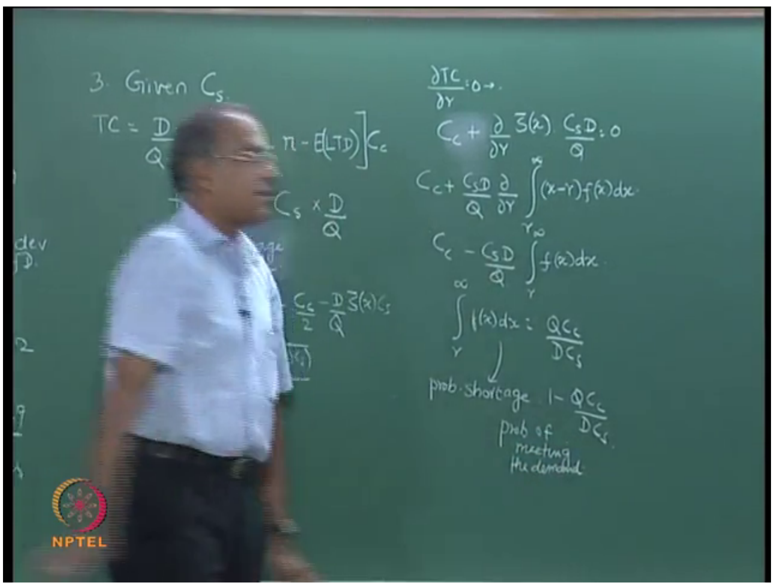

Where the total cost of inventory is given by D by Q into C 0 D is the annual demand, Q is the order quantity, C 0 is the order cost per order so D by Q into C 0 will give us the total ordering cost plus Q by 2 into Q by 2 is the average inventory that we hold in this system plus there will be a safety stock. So, if the reorder level is r minus expected value of lead time demand will be the safety stock that we have in this system.

So, the reorder level will be more than that of the expected value of lead time demand and this represents the safety stock this safety stock is always carried and therefore, it is not divided by 2 so r minus expected value of lead time demand into cc into inventory holding cost plus the shortage cost so in this shortage cost now S bar of x is the probability of shortage happening in a cycle, which means the demand exceeds the S bar of x is the expected shortage; S bar of x is the expected shortage it is not the probability of occurrence it is expected shortage.

So, it is the expected value of the shortage. So, S bar of x into C s is the shortage cost per unit short into D by Q because D by Q is the number of cycles in a year. So, S bar of x is the expected shortage in a cycle C s is the shortage cost per unit chart D by Q is a number of cycles in a year. The best value of Q and r are obtained by differentiating this expression dou T C by dou Q equal to 0 gives minus D by Q square C 0 plus cc by 2 minus D by Q square S bar of x C s equal to 0 from which Q equal to root of 2 D C 0 plus S bar of x C s divided by CC.

This expression is similar to the economic order quantity formula except for a term involving S bar of x which is the expected shortage.

(Refer Slide Time: 10:27)

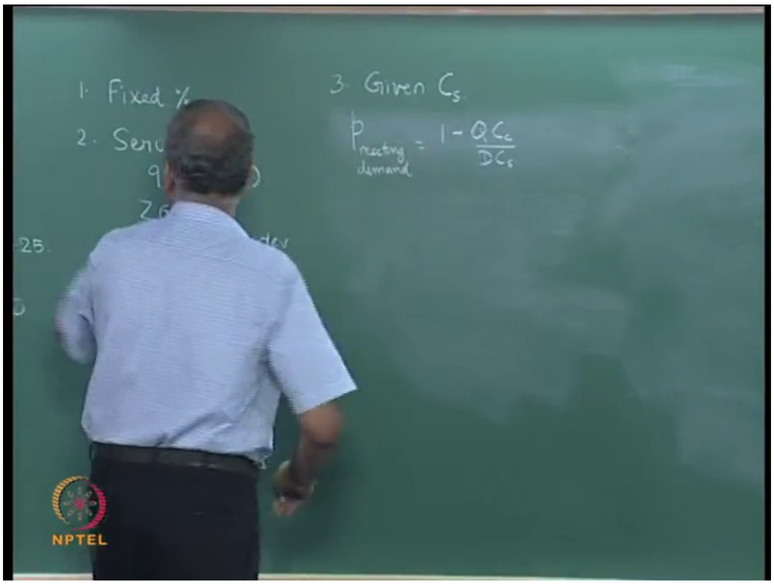


Now, partially differentiating this with respect to r dou T C by gives this will be a constant. So, the first time r comes in is here r plus differentiating with respect to r this will be C C plus C s into D by Q to dou by dou r of S bar of x so plus dou by dou r, S bar of x into cs into D by Q equal to 0. So, this will give us C C plus C s D by Q dou by dou r. Now S bar of x is the expected shortage in a cycle. So, this will be integral r to infinity x minus r fx dx.

Now r is the reorder level x is the actual demand. So, when the demand exceeds a reorder level the shortage is x minus r the probability of occurrence of that comes from the distribution. So, x minus r fx dx. So, this when we differentiate we will get C C minus the minus comes from this C s D by Q integral r to infinity fx dx, from which integral r to infinity fx dx is equal to Q C C by D C s. Now this represents the probability of shortage probability of shortage is given by Q C C by minus Q C C divided by D C s. Now if we look at the units Q is demand Q is the order quantity this is rupees per unit per year this is in units. So, this is rupees per year this is rupees per unit short this is units per year.

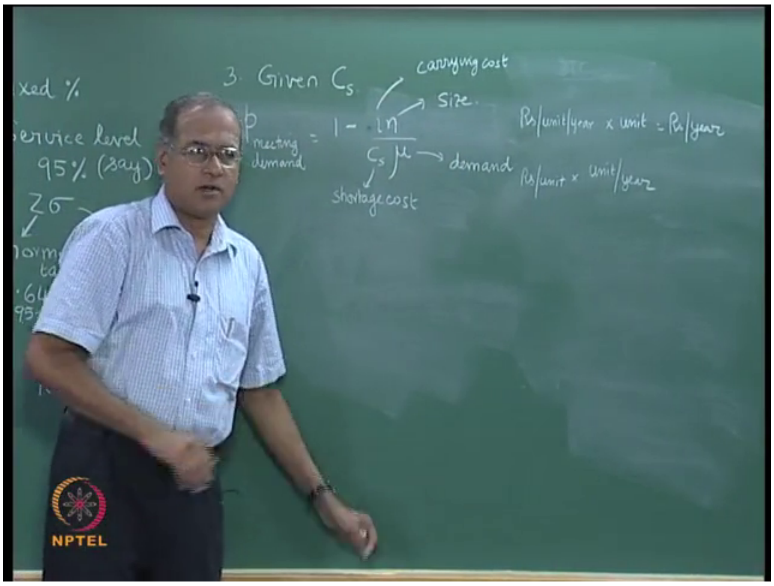
So, this is also rupees per year. So, Q C C by D C s does not have any dimension it is just a number and 1 minus Q C C by D C s is the probability of meeting the demand is the probability of meeting the demand. So, this is how we derive this one minus Q C C by D C s.

(Refer Slide Time: 13:56)



So, from this we have probability of meeting the demand or no shortage is equal to 1 minus Q C C by D C s, now this is given in the slide as one minus I n by C s mu where the notations are now changed for the Kanban system.

(Refer Slide Time: 14:27)

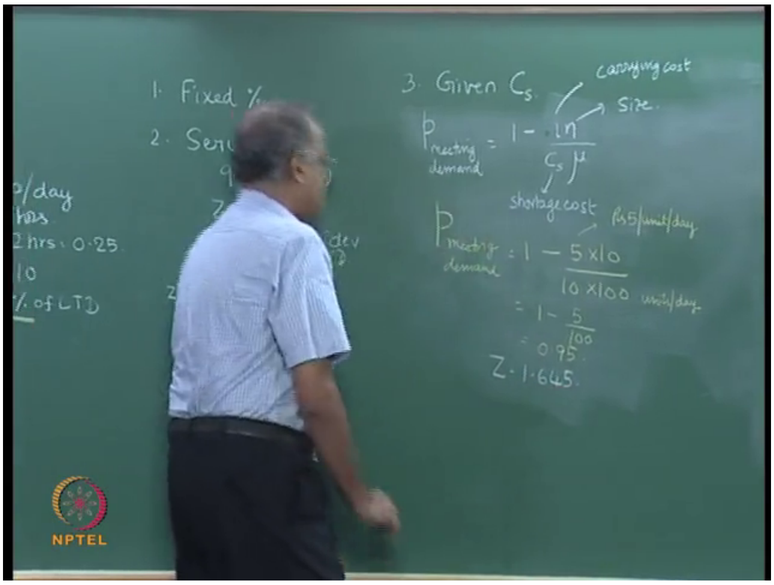



So, we write this as I n by C s into mu I n by C s into mu now n represents the Q. So, if this is the container size I represents the carrying cost C s represents the shortage cost and mu represents the demand.

Now in order to be consistent this is in units this is rupees per unit per year or rupees per unit per hour or rupees per unit per time period. So, together this will be rupees per unit this is rupees per unit short this should be rupees per. So, this n is size which is units. So, rupees per unit per year multiplied by unit is equal to rupees per year or per time period this is rupees per unit short so rupees per unit. So, this should be unit per time period. So, mu is actually the demand for the item.

If we take this formula and then we go back and substitute here.

(Refer Slide Time: 16:09)

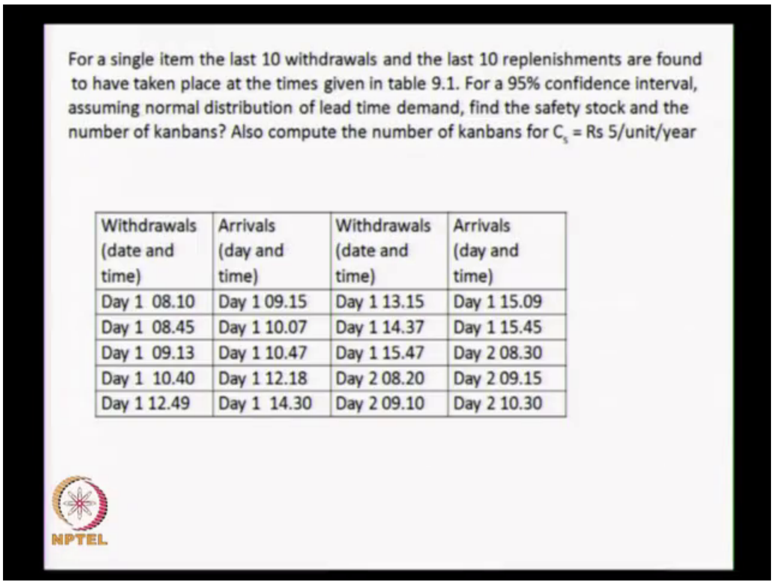



Now for our example, probability of meeting demand or no shortage will be 1 minus, now we assume a kanban size of 10 by if we assume that our daily demand is 100 per day. So, mu will be 100 per day if we say that this is C s is 10 C s is 10 and if the inventory holding cost is let us say rupees 8 per unit per day say this is this is say inventory holding cost is rupees 5 per unit per day.

So, this is rupees 5 per unit per day this is 100 units per day. So, this will be 1 minus 5 by 100 which is 0.9 5. So, given the C s we would calculate this 0.9 5. So, once again we go back to the normal distribution and find out Z for which probability of meeting the demand is 0.9 5. So, Z will become 1. 6 4 5 and the number of kanbans the safety stock will be 1.6 4 5 into 2, which is 3.2 9 and the number of kanbans will become 3 as in this example.

Now here the mu is actually taken from the given data and is assumed to be 100 units per day, now there is another fourth method by which we actually compute the mu mu depending on depending on what actually happens in the factory to explain that we take another example.

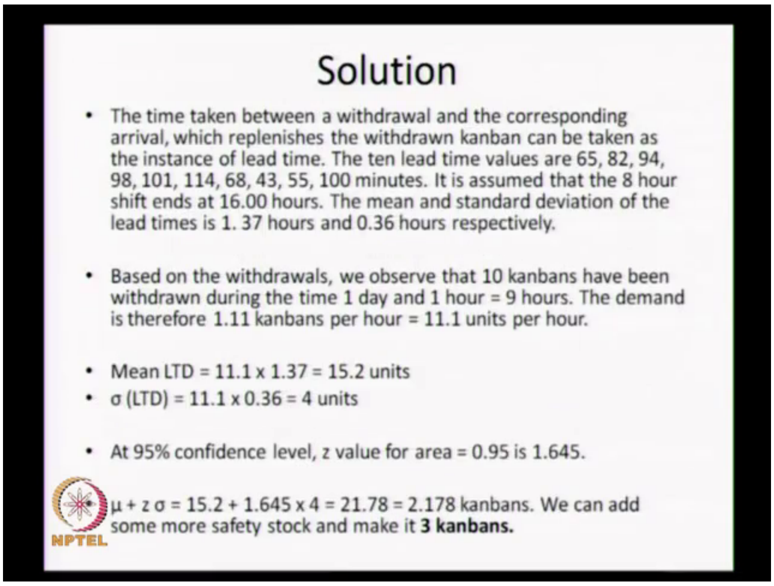
(Refer Slide Time: 18:33)




Now, we have shown some data which says for a single item the last 10 withdrawals and the last 10 replenishments are found to have taken place in the times given in the table, for a 95 percent confidence level assuming normal distribution find the safety stock and the number of kanbans also compute the kanban for C s equal to rupees 5 per year.

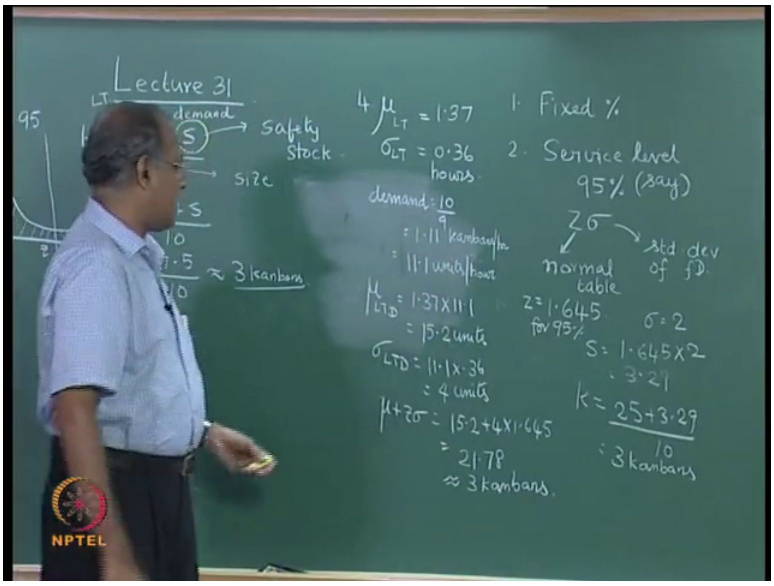
So, there are 10 withdrawals and 10 arrivals are given.

(Refer Slide Time: 19:06)




So, from the 10 withdrawals and 10 arrivals the time taken between a withdrawal and the corresponding arrival which replenishes the withdrawn kanban is taken as an instance of a lead time. So, the 10 lead values calculated or 65 82 etcetera and for the 8 hour shifts ends at 16 0 0 hours. So, the mean and standard deviation of the lead times calculated from these 10 values are 1.37 hours and 0.36 hours.

(Refer Slide Time: 19:41)




So, we assume that mu of the lead time mean of the lead time and sigma lead time from calculation comes from for example, the 65 time units are taken from this day 1 time 8 10.

Day 1 time 15 is 65 time units like this the 10 time units are chosen they are mean and standard deviation is 1.3 7 hours and 0.3 6 hours respectively. So, 1.37 hours is roughly about 80 minutes and 0.3 6 hours respectively. Now what is that demand. So, the demands are calculated based on withdraws we observe that 10 Kanbans have been be withdrawn during a time period of 9 hours. So, demand is 9 is 1.111 Kanbans per hour. So, 10 combines are taken in 9 hours. So, demand is equal to 10 by 9 Kanban per hour 1.11, kanban per hour which is elven 0.1 units per hour because each Kanban has 10 units. So, 11.1 units per so mean lead time demand.

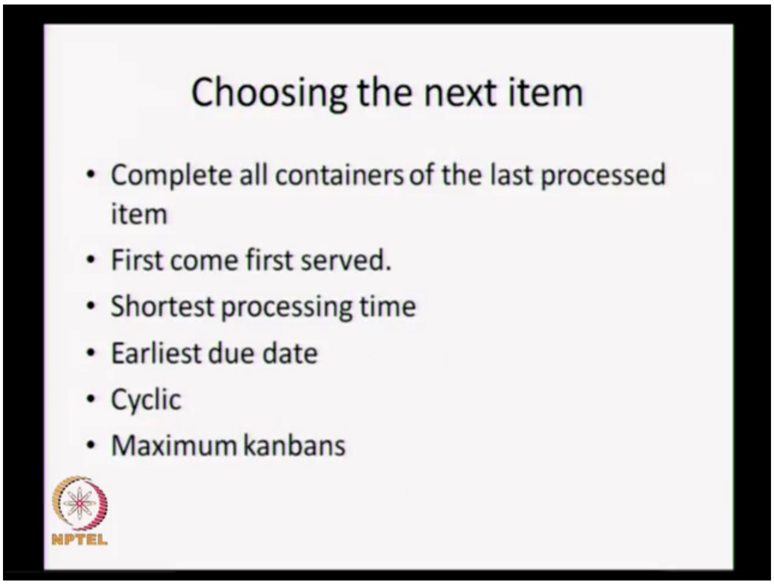
So, mean lead time demand mu ltd lead time demand is equal to 1.3 7 into 11.1. So, time demand is 15. 2 units 15.2 units, now sigma of lead time demand. So, sigma of lead time demand is 11.1 into point 3 6 hours so 11.1 in to 0.36.

This is 4 units. So, at 95 percent confidence level; if we have 95 percent confidence level, now Z is equal to 1.645. So, mu plus Z sigma is 15.2 plus 4 into 1.645 which is 21.78. So, this is approximately 3 kanbans. So, in all the 4 instances of calculation we had the same value as 3 kanbans, but the way by which we calculated in each of this instance is very very different.

So, in the very first one we assume a fixed number of fixed percentage for the safety, in the second one we assume a certain service level and based on the service level we did the calculations, the third one we took a C s a shortage cost and based on the shortage cost we borrowed results from inventory models and computed that probability of meeting the demand in this case turns out to be 0.9 5. And then we went into the normal distribution and got it. In the fourth one this is very similar to the second one because the 1.6 4 5 is taken from a 95 percent service level. So, here we do not use the shortage cost instead we use the service level the only difference of course, is that demands and the standard deviations are now computed. So, we have shown a way by which we compute the standard deviation.

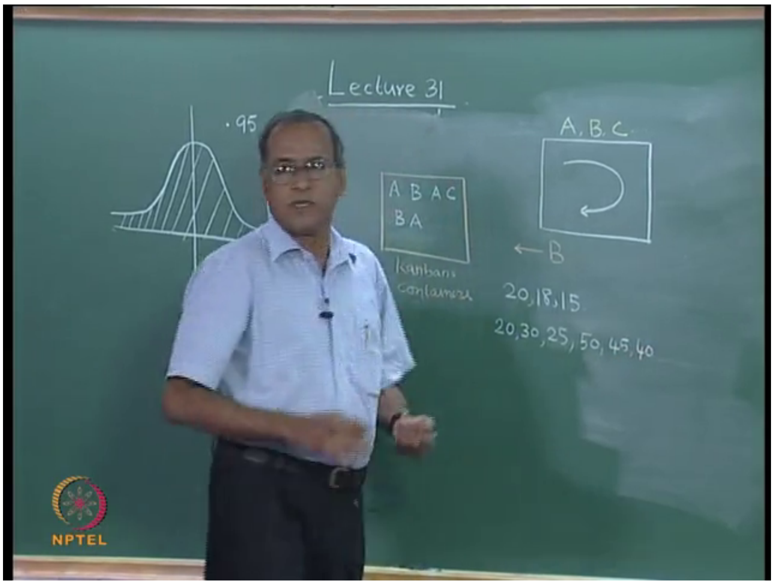
Here we assumed that sigma is equal to 2 here we computed the sigma and sigma actually happened to be 4 units in this case. So, all these computations help us in trying to find out the service the safety stock that we have to include in this calculation now mu plus Z sigma will directly replace fD plus S, this mu is mu LTD lead time demand is mu will directly replace fD plus S and divided by n. So, mu will be the fD this is the S and n is ten. So, we get 3 kanbans in this computation. So, this is how we can compute the safety that is to be incorporated in the kanban calculations.

(Refer Slide Time: 24:59)




Then we move into couple of other models for kanban which is this.

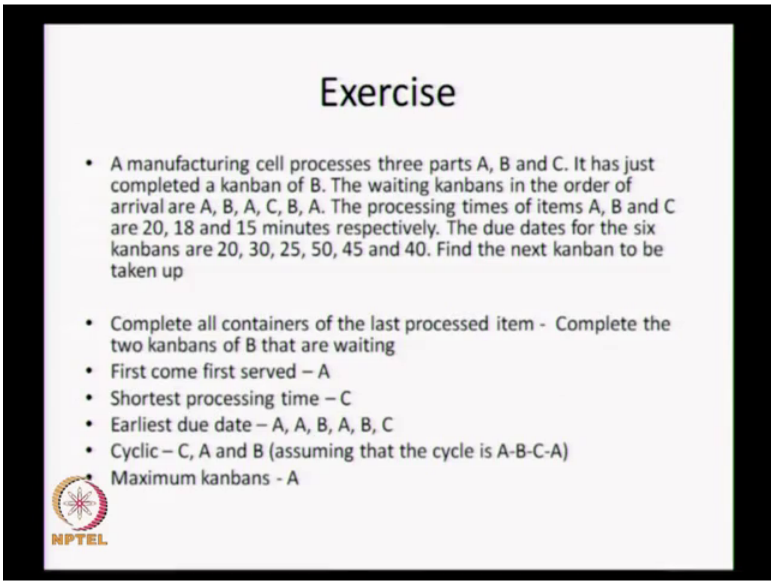
(Refer Slide Time: 25:38)




Now we described in in an earlier lecture that the manufacturing cell could be like this following unidirectional flows it might be handling multiple products we could call them A, B and C etcetera.

We also said that let us say if A is being done then one kanban of A is completed and there could be an area outside, where these kanban are available or containers are some kind of a container storage area. So, then one particular item is completed then now this has to go and it has to be replenished. Now how do we choose the next item to be replenished is another model that will dictate the completion times of the various items that we are looking at. So, some simple thumb rules are complete all the containers of the last processed item another rule could be first come first served, the third could be shortest processing time, the fourth could be earliest due date. Fifth could be A cyclic rule, and the sixth would be to choose one which has maximum number of kanbans. So, these are some of the rules that we could use and depending on the rule that we use the performance of the system is defined. So, we just illustrate it with an example a manufacturing cell processes 3 parts A, B and C.

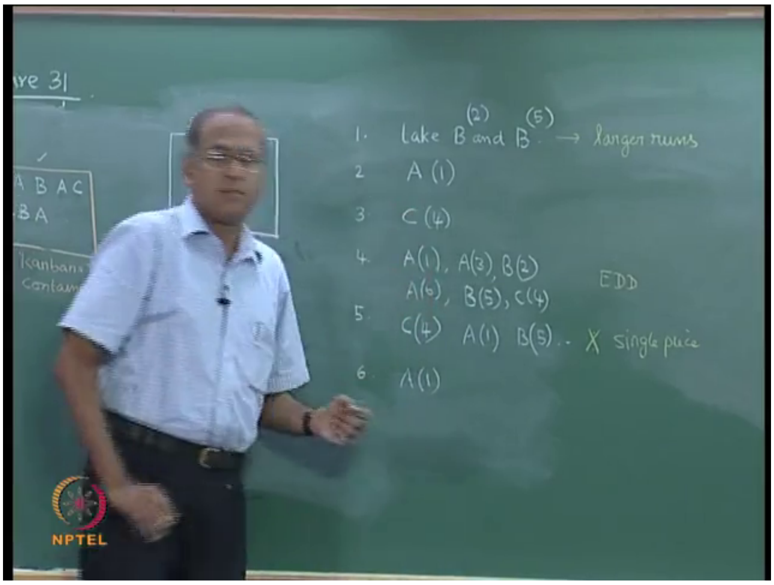
(Refer Slide Time: 27:26)




It has just completed B. So, it has just completed B So, B is coming out of this the waiting kanbans in the order of arrival are A B, A C, B A, A B, A C, B A are all here in the order of arrival A B A C B A the processing times for A B and C are 20 18 and 15.

So, processing times are 20 18 and 15 and the due dates for these 6 kanbans are 20 30 25 20 30 25 50 45 and 40. So, how do we choose the first 1? So, we want to complete all the containers of the last processing which is our first role. Since B has been completed we will take these 2 B S to begin with we will take these 2 B S to begin with.

(Refer Slide Time: 28:47)



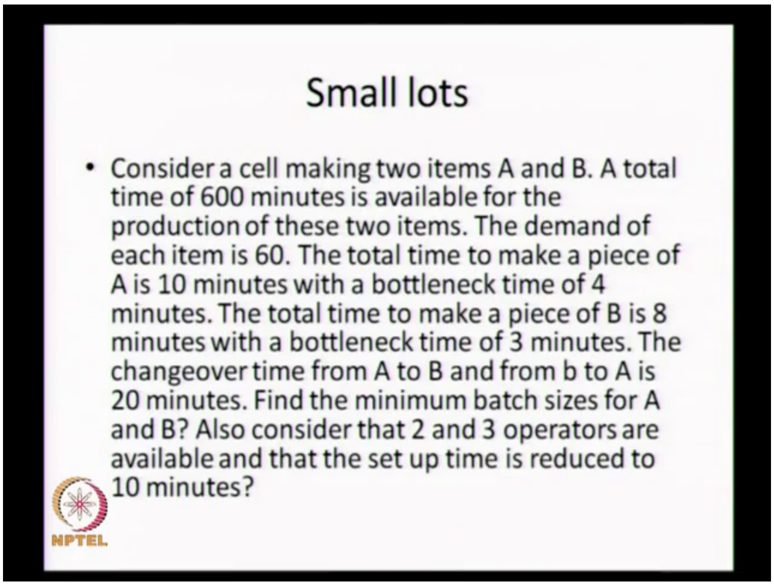

So, first one will say take B and B, second one would be first come first served. So, this came first. So, take and I will say take a one here I will say take B 2 and B 5. The third rule would be the one based on shortest processing time. So, we will end up looking at the processing times C has the smallest processing time. So, take this C take C 3, the fourth one would be to do the earliest due date. So, if we take the earliest due date we first look at this is the earliest due date.

So, this corresponds to this. So, take a one then the third one. So, A 3 then this B 2 then this A 6 then B 5 and then C 4, what I mean by A 3 is this A, A 3 is this A, A 6 is this a there are 6 kanbans waiting. So, I call this as A at position 6. So, A 6 this is A at position 3. So, it is a 3 fifth 1 is if we look at a cyclic method and follow the cycled ABC. So, B is completed. So, we will take C first. So, we will do C 4. So, this should be C 4 and then followed by A. So, A 1 and then B 5 etcetera. So, the cycle will be B C ABC and so on, the last one is if I have choose the 1 which has maximum kanbans.

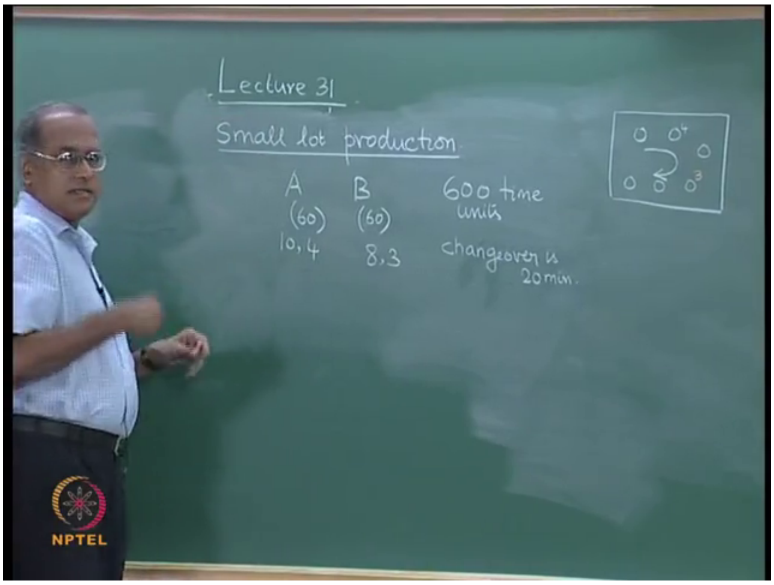
So, A has maximum kanbans. So, choose A 1, now each of this rule has a certain effect on the system. Now these rule the first one where complete all the containers of the last processed one will actually take us away from small runs. So, this will end up having slightly larger runs, because we will be continuously doing the B is still they are exhausted and then move to the other one. Now in a way cyclic is the best in terms of single piece flow this will produce items at very short runs. So, cyclic is a very good role sometimes to meet due dates we start looking at earliest due date rules. So, EDD can still give us as in this case 2 consecutive containers of A to be processed which actually takes us away from the idea of a single piece flow or a small or short run and so on.

Choosing maximum kanbans is again a very conservative rule which prevents an inventory buildup of a certain item in this place. So, this is something which choosing shortest processing time choosing maximum number of kanbans are more of internal conveniences. So, if we have a large pile up of a then we have to understand somewhere else that they are not following either a cyclic rule or the correct type of rule, but these dispatching rules also help us understand how the system is performing. So, simulation studies have been carried out which take into account the various dispatching rules and then try to model the system based on the dispatching rules to understand the performance of the system for various dispatching rules.

(Refer Slide Time: 33:10)



(Refer Slide Time: 33:41)



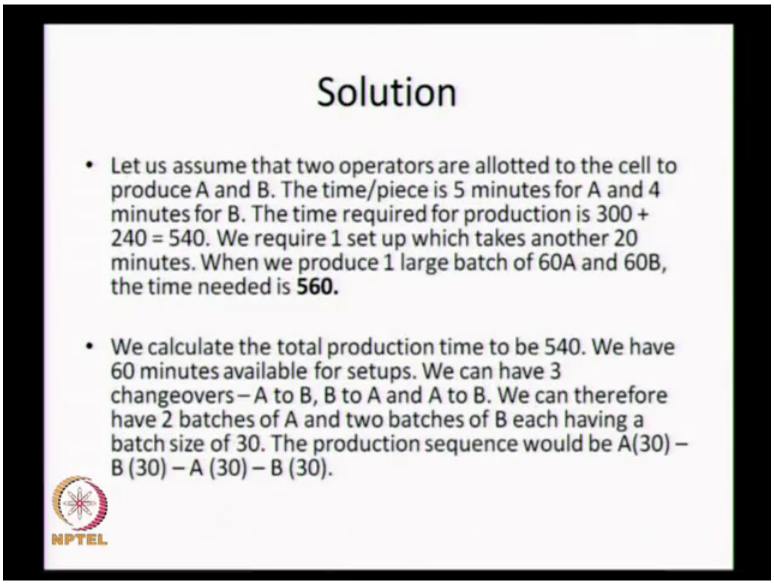

Now, we look at one more model under JIT which talks about small lot production talk about small lot production. So, consider a cell making 2 items A and B. So, there are 2 items A and B that are made.

And 600 time units are available we could take these as minutes 600 minutes are available the demand for each item is 60. So, A S demand is 60, B S demand is also 60, the total time to make a piece of A is 10 minutes with a bottleneck time of 4 minutes. So, 10 comma 4 and to make B it is 8 minutes with a bottleneck time of 3 minutes.

So, we could assume that there is the cell there are multiple machines there is unidirectional flow. So, when it is making 10 the sum of the individual times are such that the maximum is 4 and the total is 10 whereas, when it is making B the total is 8 and say the maximum is 3.

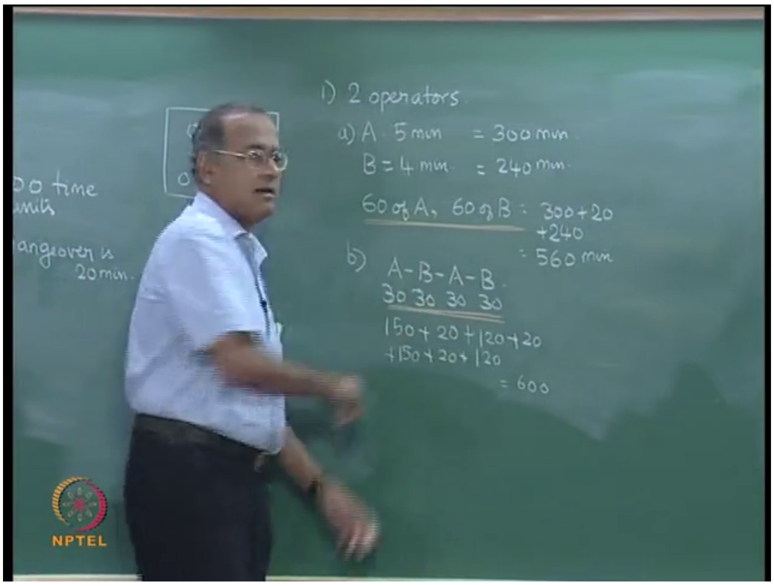
So, this is written as 8 comma 3 the change over time from A to B and B to A is 20 minutes change over time is 20 minutes, find the minimum batch size for A and B consider that 2 and 3 operators are available and the set up time is reduced to 10 minutes.

(Refer Slide Time: 35:46)




So, 2 operators are available and 3 operators are available set up time is reduced to 10 minutes. So, 2 operators are allotted to A and B. So, we look at a case one case one there are 2 operators.

(Refer Slide Time: 35:55)



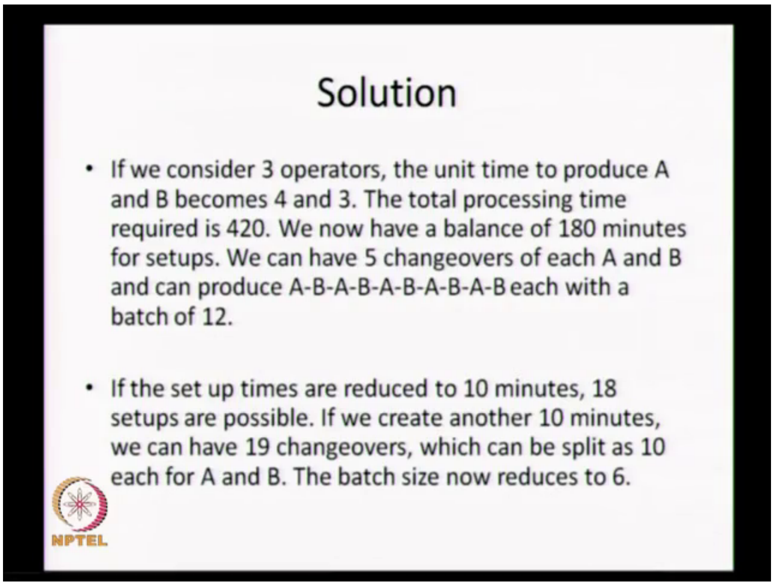

So, if 2 operatorsare allocated when we make a then this is the maximum time this is the bottleneck time. So, time taken to make a is 10 by 2 which is 5 minutes and time taken to make B is 8 by 2 which is 4 minutes, if we assume that there is rabbit chasing. So, total is 8. So, when there are 2 operators at steady state 8 2 4 minutes is the time for each of them the demand is 60. So, 5 minutes per piece. So, this requires 300 minutes and this requires 200 and 40 minutes 200 and 40 minutes. Now this if we assume that it is already set up for A, then we can start producing A we can produce 60 of a we produce 60 of B and the time taken will be 300 plus 20 to changeover plus 200 and 40, which is equal to 500 and 60 minutes.

Now you can call this as case A now we look at case B, now with 2 operators working for A and B we require a processing time of 500 and 40 units. So, 60 units are available with which we can make 3 changeovers.

So, we can now produce A B A B and if we do that so the production batches will be 50 30 30 30 30. So, we first to produce thirty we need 150 plus a changeover of 20 plus 34 S are 120 plus another 20 changeover, plus another 150, plus another 20 changeover plus 120. So, this will be 150 170 290 310 460 480 plus 120 is 600. So, we use up all the 600, but we are able to produce 4 lots of 30 each, whereas here we produced 2 lots of 60 each.

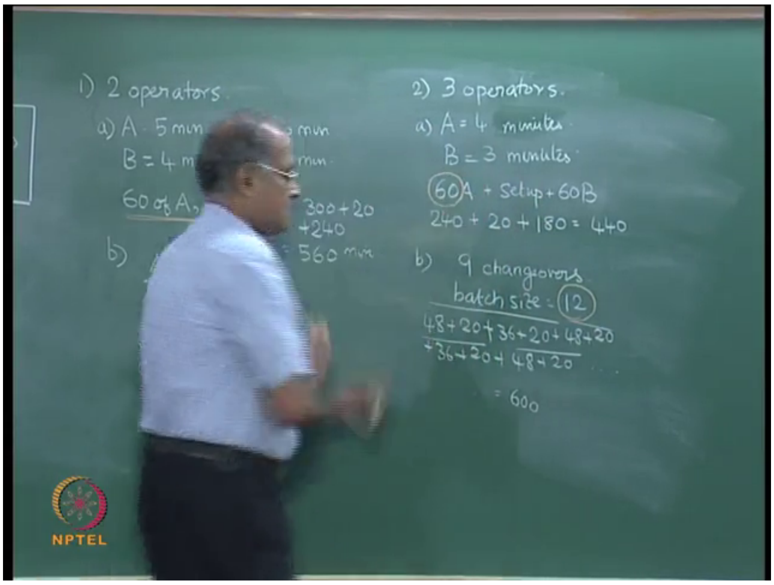
So, if we use the time available correctly then we will be able to get smaller run production.

(Refer Slide Time: 39:21)




Now, if we consider 3 operators now time taken to produce a will be 10 by 3 which is 3.3 3, but the bottleneck is more than that. So, time taken to produce a will be 4 units.

(Refer Slide Time: 39:44)

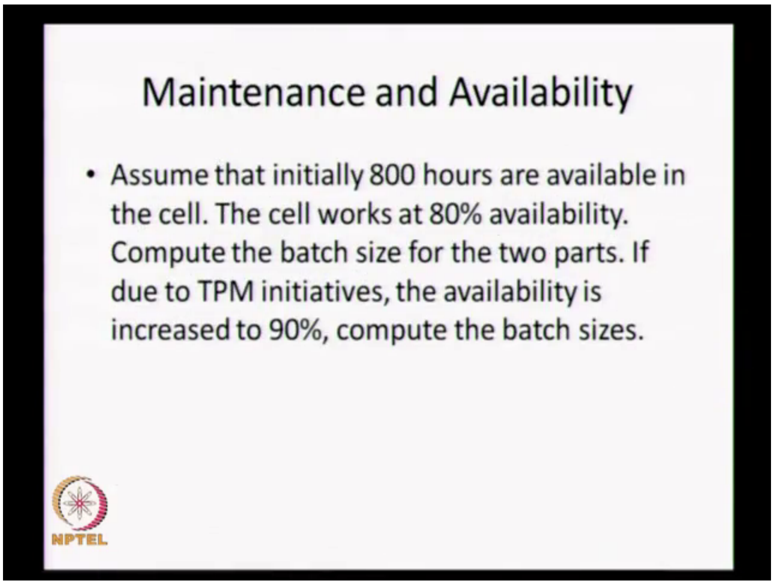



Similarly, time taken to produce B 8 by 3 is 8 by 3 operators is 2.6 6 which is smaller than the bottleneck time 3 or the maximum time 3. Therefore, the time taken will be this 3. So, B will be 3 minutes. So, time taken to produce 60 of a 60 of B plus setup plus 60 of B will be 60 in to 4, 200 and 40 plus 20 plus 60 in to 3 180. So, this is 400 and 40 we will be able to finish this 4 into 60 is 240 plus 20 plus 180. So, now, the time available is time required for manufacture is 240 plus 180 which is 420.

So, 420 time units are required for the manufacture 100 and 80 time units are now available and we can do 9 changeovers. So, we can do 9 changeovers which means we can produce 5 batches of A and 5 batches of B. So, batch size becomes 12 12 batch size becomes 12. So, we start with 48 12 in to 4 4 8 plus 20 plus 36 plus 20 plus 48 plus 20 plus 36 plus 20 plus 48 plus 20. So, this is the first batch.

This is the second batch, this is the third batch, like that 5 batches are there and the total time will be 600 the most important thing is the batch size has come to 12 as against batch size will be 60 in this case. So, the batch size would become 12 now in the same case if the set up time is not 20, but the set up time is 10.

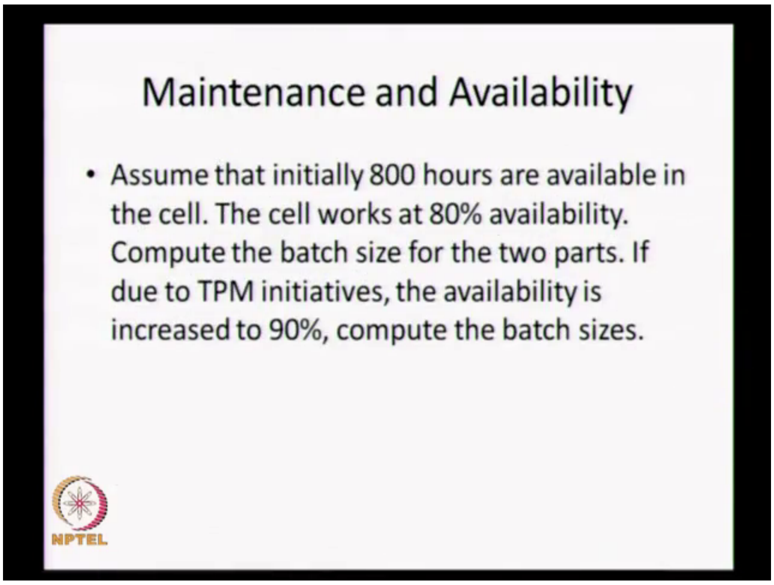
(Refer Slide Time: 42:38)




So, if set up time is 10 set up time is 10 the total in this situation of 4 and 3 operators for A and B which gives us 4 minutes to produce A and 3 minutes to produce B. So, the time required is 400 and 20.

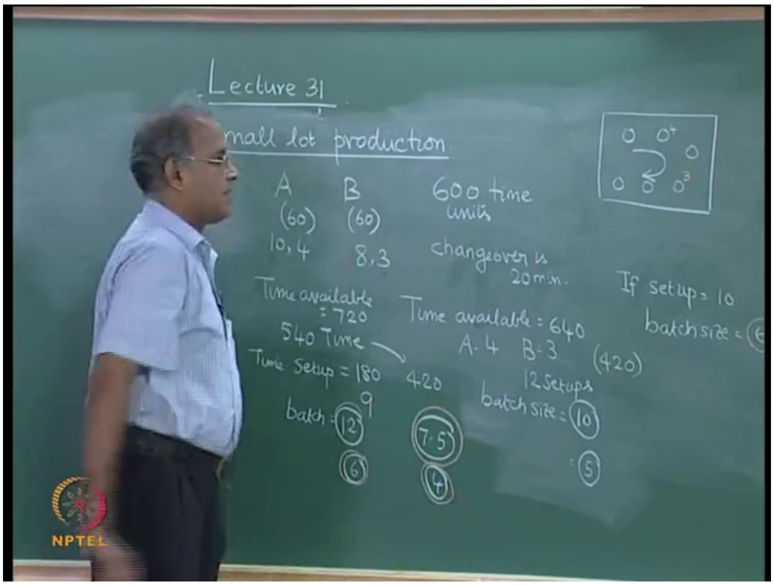
So, maximum time is 600. So, 180 is available if the set up time is 10 minutes 18 setups are possible. So, if we create another 10 minutes from somewhere we can have 19 changeovers which means the batch size can become 6; batch size can become 6. In some sense this is a very good situation because the changeover times are 20 the production times for the batch are 48 36 and so on, but if we can create another 10 minutes we can make it very tight and have very short runs of 6 of A followed by 6 of B and that is done 10 times. So, the batch size reduces to 6.

(Refer Slide Time: 43:57)



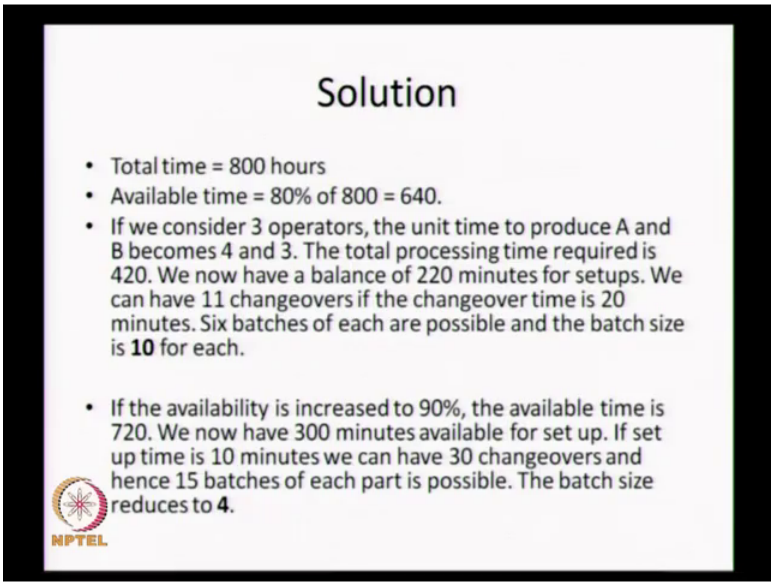

We could also look at maintenance and availability. So, now, we could say for the same problem here we assumed that 600 time units are available for the production, now if we assume that 800 units were available in the cell, but the cell is working at 80 percent availability.

(Refer Slide Time: 44:23)




Which means time available becomes 600 and 40. So, when time available becomes 600 and 40 and we consider 3 operators. So, times for A is 4 units and times for B is 3 units total processing time required is 400 and 20 so now, we have 200 and 40 units of time available for setup and if the set up time is 20 then we could have for 200 and forty we could have 12 setups.

(Refer Slide Time: 45:14)



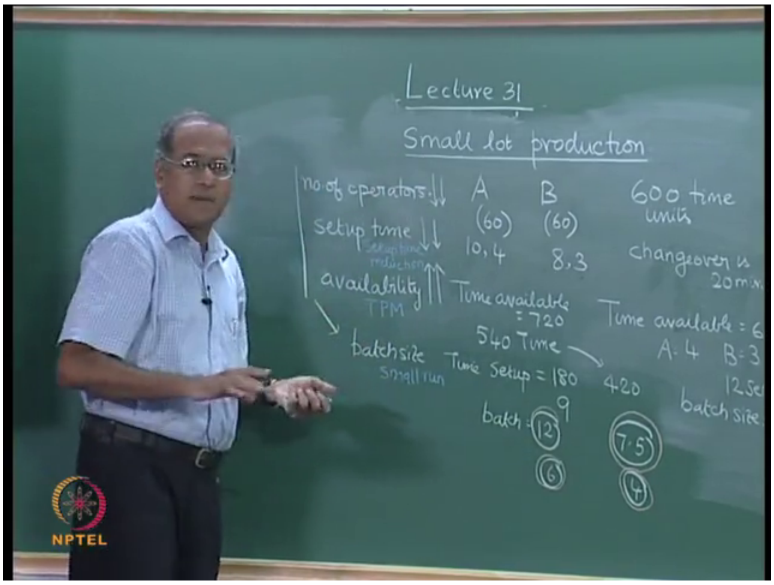

So, when we have 12 setups then we could produce 6 times A and 6 times B and the batch size will be now 10 batch size will become 10 and if the set up time from 20 it becomes to 10 then the batch size will become 5. We have another aspect to this problem which says that due to TPM initiatives the availability increased to 90 percent now compute the batch size. So, when the availability increases to 90 percent now time available is equal to 720. So, we have more time available.

So, let us go back and see what happens to the 2 operator case 2 for A and 2 for B if we take this case total time required is 500 and 40 540 is the time required. So, we have time for set up time available for setup is equal to 180, if the set up time is 20 9 changeovers are possible. So, 5 batches of A and 5 batches of B are possible. So, batch size is equal to 12 of course, when the set up time is half the batch size will become 6.

If we had 3 operators working there then the time required is only 420. So, 300 time units are available. So, 300 by 20 is 15 8 batches are possible. So, batch size is roughly 7.5 and here it will be 4 or 3.7 5 when the set up time reduces further. So, essentially what have we seen now we have seen let me also circle all the batch sizes ordinarily we will be very very happy with this because with minimum operators 2 operators minimum number we have a little bit of time available for changeover we use that 600 minutes are available we use 560. So, we are happy the only thing is that we are producing large batch size of 60 in this now this if the only thing we can do is we can bring down from 60 to 30 when we allow multiple setups in the remaining time available.

So, the best scenario is thirty increasing the number of operators from 2 to 3 creates extra time available for change overs and automatically the batch size from 30 becomes 12 it dramatically reduces to 12. So and further reduction in changeover times can bring the batch size up to 6, from 30 we have moved to 6 now by making time available due to TPM initiatives availability is increased batch size comes to 4. So, these are the 2 or 3 important parameters with which we have control.

(Refer Slide Time: 49:15)




One is the number of operators, set up time, and availability, all these 3 impact the batch size. So, if we want to make smaller runs the batch size should be small. So, in order to do this the availability has to go up and we also for we also in this lecture series have seen that TPM is an extremely important aspect of J JIT systems. So, having good TPM systems increases the availability which in turn helps us to achieve smaller batch size and smaller run, reducing the setup times creates extra time available for set ups because of which smaller runs are possible and the batch size reduces.

So, there is always effort in set up time reduction, decreasing the number of operators either through automation or dedication or rabbit chasing would help us again create extra time. So, decrease decreasing the number of operators.

Increases the time required increasing the number of operators decreases the time required. So, the number of operators is the constraint that we have and these number of operators have to be used correctly. So, that by constantly trying to reduce setup times and increase availability small runs are possible, many times the number of operators is also less and it is fewer than the number of machines that we have.

So, this example helps us understand the role of these 3 parameters on the batch size and the understanding that important initiatives such as set up time reduction and TPM impact the batch size one can help us produce smaller runs, number of operators is a constraint which has to be handled judiciously. So, that this is not affected by the non-availability of operators.

In the next lecture we will look at CONWIP which is another way to have manufacturing control in manufacturing cells and factories.