Production and Operation Management
Professor Rajat Agrawal
Department of Management Studies
Indian Institute of Technology, Roorkee
Lecture 50
Facility Layout-III (Layout design and Precedence diagram)

Welcome friends. So, in our last two sessions we discussed about various concepts related to facility layouts and in those we discussed about process, product and their combinations in the form of cellular layout, where in detail we discussed the concepts of how to develop the cells and how cellular layouts offer you advantage of both product and process layouts.

And finally, we also discussed the layout for service organizations where we discussed that how the degree of customization and degree of customer contact are two very important aspects in designing your service layouts. So, based on whether you have high degree of contact or high degree of customization or low degree of contact or low degree of customization, you have different types of combinations for layout designing. And finally, we also discussed that the role of different types of symbols, signs, artefacts, etcetera are also important in designing of your retail outlets.

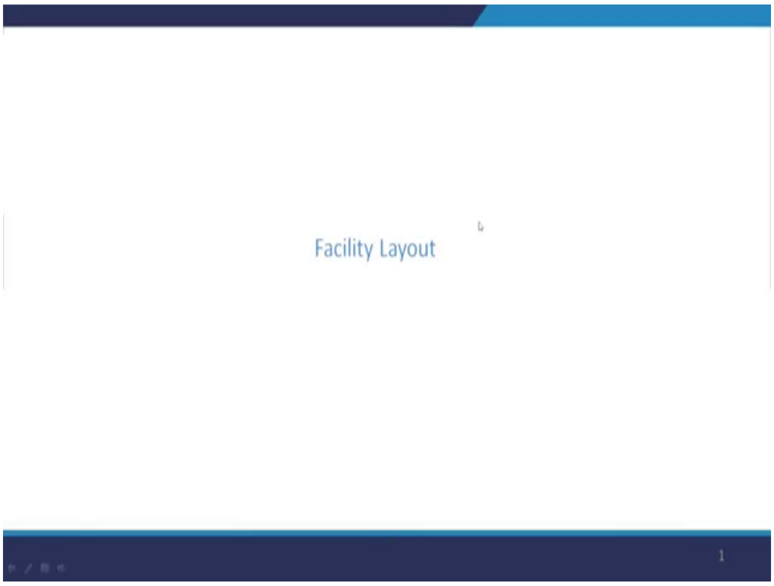
Now, in our one of the discussion in the layouts, we discussed about product layouts and one very common example of product layout is assembly line. When various operations are being perform in a regular sequence and particularly like if I am talking of assembly of engines, so that is a very common example that different parts move on a conveyor belt and this conveyor belt moves from various work centres and there are particular task to be performed at a particular workstation and that is to be done within a particular time limit because the belt is continuously moving.

And therefore, it is a very well thought, very scientifically developed movement of that belt so that the each worker, those who are performing in that, movement of the conveyor belt, they should be able to complete their task as long as that product is within their range. If you go to places like London or Singapore, these places have very interesting giant wheels and these are known “Singapore Eye” and “London Eye”.

Now, when they are putting passengers into that trolley or that chamber, so it is a very systematic that when that wheel is coming down and they have to open the gate of the trolley. So that is a particular station, immediately the passengers will come out. Then at the second station there are some cleaning activities and the security check and at the third new passengers will get into the.

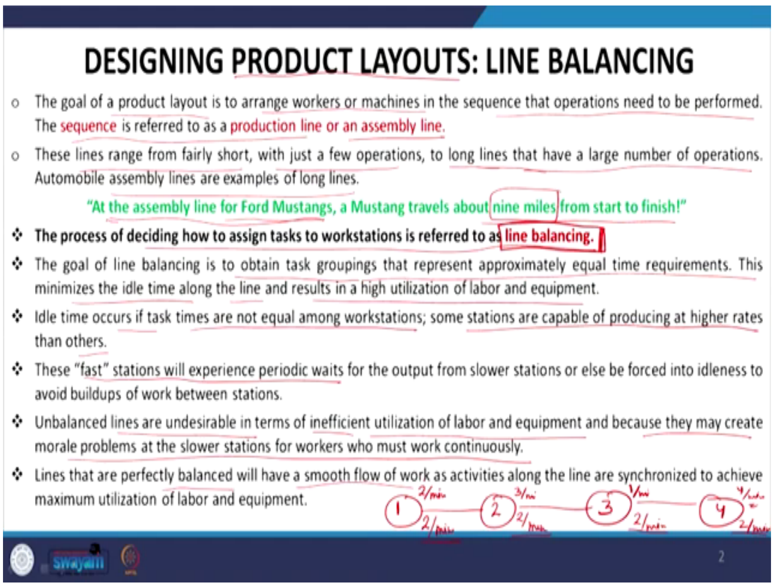
And all these activities because the wheel is continuously moving, so all these operations you have to perform during the movement of the wheel itself. So, at each of these three stations, wheel will be there only for, let us say fraction of minutes and they have to perform their jobs within those fraction of minutes. So, that is a very good example of the system which our product layouts are working.

(Refer Slide Time: 4:33)



So, to perform or to develop a good product layout, we need to understand how scientifically we need to design all these activities so that there is a situation of complete balancing of that product layout and that is also known as line balancing and that is the topic of our discussion that what is this line balancing and therefore, I can also write this title as line balancing.

(Refer Slide Time: 4:51)



Now, in this line balancing there are some important, you can say, theoretical aspects that what is the objective, what is the process, what are the formula we have to use. And then we will see with the help of some numerical example that how line balancing is done because this is one very important aspect of operations manager to develop a good line. Good line means a good product layout. So, when I am saying the line, it automatically means product layout.

Now, the goal of a product layout is to arrange workers or machines in the sequence that operation need to be performed, so that we already know. The sequence is referred to as a product line or assembly line. These assembly lines range from fairly short, with just a few operations to long lines like a few operations, I mentioned about this Singapore, London Eye where only three operations are there, but it is an example of assembly line.

Or you have very long lines of assembling the engine of some car and that may take up to hundreds of operations to a long line that have large number of operations. So, automobile assembly lines are example of long lines where more than hundred operations are being performed. Now, it is an example of Ford company because whenever we are talking of assembly line, we must take the name of Ford car company because Ford was the first company to introduce the concept of assembly lines.

And assembly line that is also very important that this assembly line system is basically the starting point of mass manufacturing. Before that the concept of mass manufacturing was totally absent. Ford started the concept of assembly line and as a result of assembly line, the mass manufacturing started, as a result of that concept of economies of scale came into picture and as a result of that cost of manufacturing started decreasing.

So, it became a very important kind of revolution in the development of entire manufacturing philosophy. So, what is mentioned that with respect to this Ford Mustangs, it travels around 9 miles from start to finish, so that itself gives you an idea that it is a fairly long movement because you have to perform more than 100 operations during the entire assembly of this Mustangs and therefore, it is travelling around 9 miles.

Now, process of deciding how to assign task to workstation is referred as line balancing and that is what we are going to do today. This line balancing is the important thing. Because what type of operations need to be performed, which operation will be first, which operation is second, which is the third that is the duty of design engineers, that is the duty of industrial engineers but as operation manager putting the, those various operations together on a particular work centre, so that you have a balanced assembly line that is your job that comes under line balancing.

The goal of line balancing is to obtain task groupings that represent approximately equal time requirements, this minimizes the idle time along the line and results in high utilization of labour and equipment. So, as we have these different types of tasks which are grouped, so this is workstation 1, this is workstation 2, this is workstation 3, workstation 4, so what we are actually trying that the output of these workstations are coming at the similar rate.

So, if output is coming at the rate of 2 products per minute, so we want that almost 2 products per minute should be the rate of output from all the workstations. And if it is so, we say that it is a balanced line, but if one machine is giving at the rate of 2, another at the rate of 3, another at the rate of 1, another at the rate of 4, now what will happen, in front of some workstations you will have a que, like in the case of third workstation, in the revised estimates you will have que in front of that workstation.

While the workstation 4 will always be having some kind of idleness. There will be a situation of starvation in front of workstation 4, because it will not be properly fed as workstation 3 is giving 1 product in 1 minute and workstation 4 is producing 4 products in 1 minute. So, for around 75 percent of the time, workstation 4 will remain idle. There is no job to work on.

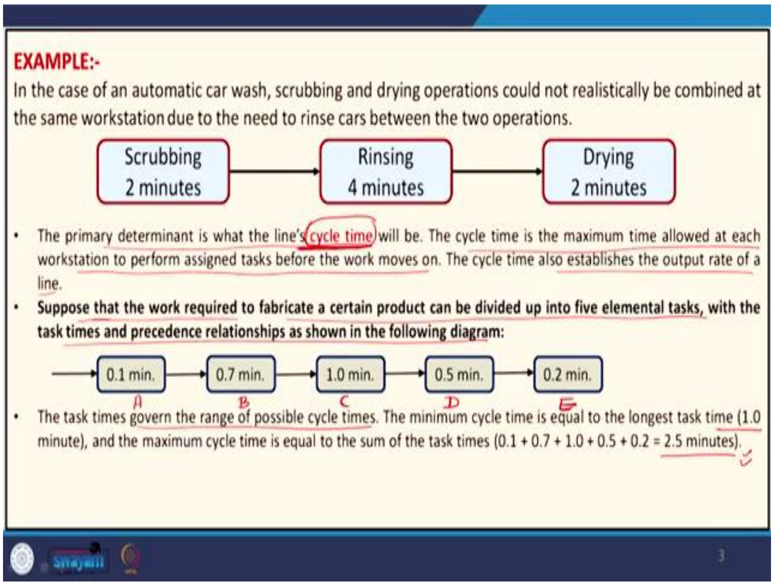
So, we want that such type of situation should not happen and this situation that 2 work pieces per minute kind of thing should be applicable. So, idle time occurs if task times are not equal among workstation. Some stations are capable of producing at higher rates than others, these "fast" stations will experience periodic waits, like this in this case fourth station will have periodic wait or you can have the situation of starvation.

The unbalanced lines are undesirable in terms of inefficient utilization of labour and equipment and because they may create morale problems at the slower workstations for workers who must work continuously. So, there will be few workers like worker at workstation 3 who is continuously working and worker at workstation 4, he is working only one fourth of his actual time of work. So, there will be a problem of morale because worker at workstation 3 will say that, "I am working for continuously 8 hours then only I am able to fulfil the requirement".

Worker at workstation 4 is only working 25 percent of the entire working time, so now the rate of output because of the unbalanced line, this kind of problems will create some kind of motivational issues, there may be some kind of resentment among the workers that they are not equally treated.

So, lines which are perfectly balanced will have a smooth flow of work, as activities along the lines are synchronized to achieve maximum utilization of labour and equipment. So, you have good amount of utilization, the highest utilization is only possible when the line is properly balanced. As line is not balanced the utilization percentage, more balance line more utilization, less balance line less utilization of your resources. So, it is very important criteria that how to have more productivity of your layout, so you have to have a more balanced line.

(Refer Slide Time: 12:59)



Now, with this simple example, you can understand the meaning of balancing. Now, we have 3 operations, scrubbing, rinsing and drying. Now, scrubbing takes 2 minutes, the rinsing takes 4 minutes and drying takes 2 minutes, so these 3 operations are taking different amount of time. Now, here you see the primary determinant is what is the line's cycle time. The first important thing is the cycle time determination.

Now, what is this cycle time, please remember this term because in operation management we have some kind of terms which will be used sometime in this context, sometime in some other context also, so you should know that what is the meaning of cycle time. Now, the cycle time is the maximum time allowed at each workstation to perform assigned task before the work moves on, so, how much is the maximum time allowed at each workstation to perform assigned task before the work moves on.

The cycle time also establishes the output rate of a line, that how much output you can expect from this line in a particular hour or in a particular shift that is also being determined by this cycle time. And suppose, just to give you more meaning of this cycle time, suppose that the work required to fabricate a certain product can be divided up into 5 elemental task, these are the 5 elemental task and different task are taking different amount of time. With the task time and precedence relationship as shown in the following diagram.

So, these are the precedence relationship that this is task A, B, C, D, E that E can only happen when D has happened, D can only happen when C has happened, C can only happen when B has happened and B can only happen when A has happened. So, this type of relationship that what is the sequence of operations that is known as precedence relationship. Then how much time operation is taking, how much time each operation is taking that is known as task time.

So, like operation A is taking 0.1 minute, operation B is taking 0.7. In the earlier case, scrubbing taking 2 minutes, so that is the task time for the scrubbing. Rinsing was taking 4 minutes that was the task time for rinsing and so on. So, now the task time govern the range of possible cycle times. The task times are giving you a possibility of the cycle time.

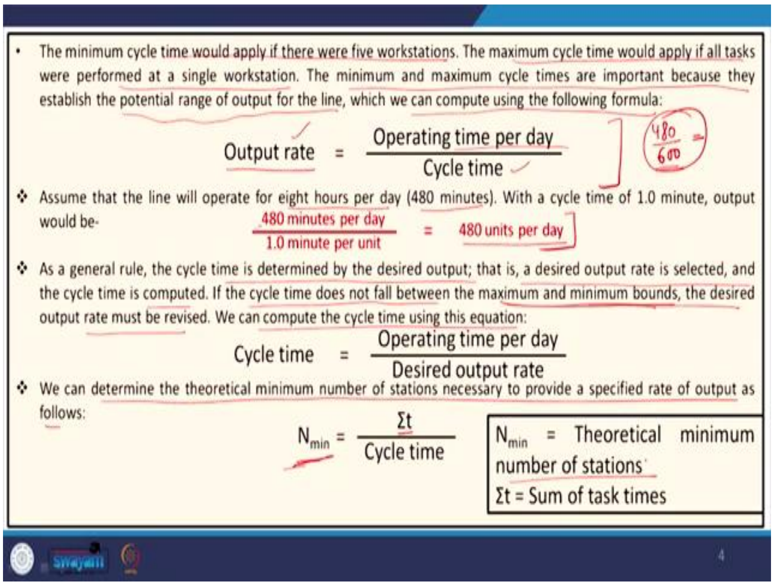
Now, if you develop your system, if you develop your system in such a manner, if you develop your system in such a manner that continuously products are flowing from this system of A, B, C, D, E. In that case, you can easily understand, without reading the bottom line, you can easily understand that the timings are in such a manner that the minimum possible cycle time is 1 minute because first operation is taking 0.1 minute and out of these 5 operations, the maximum time is taken by operation C that is 1 minute.

So, only after 1 minute, only after 1 minute you will get a product because 1 minute is the maximum time taken by any particular operation. So, the cycle time becomes 1 minute that is the minimum possible. Now, if you do not have this kind of continuous system, you say, "Okay, I will insert one input from A site and when this input goes to the finished state then only I will put another input, so that that can be processed".

So, in that case the maximum cycle time will be the sum of all these task times, so that will be 0.1 plus 0.7 plus 1 plus 0.5 plus 0.2 that is 2.5 minutes. So, these are the ranges of cycle time that either you can have the cycle time which is the maximum task time of any particular task or you can have the second situation where the cycle time is the sum of all the task time where you are not putting products regularly into your system, whenever you want you are putting 1 product and you are getting the output.

So, when you do not have the regular production requirement, in that case the cycle time can be as high as 2.5 minutes, but when you are having a regular system of production, continuously inputs are coming and there is a regular production activity then in that case the cycle time will be 1 minute. So, you can have different combinations of cycle time.

(Refer Slide Time: 18:24)



Then another important term which is to be understood that is the output rate, now the minimum cycle time would apply if there are 5 workstations, the maximum cycle time would apply if all task were performed at single workstation. The minimum and maximum cycle times are important because they establish the potential range of output for the line which we can compute using the following formula.

So, operating time per day that how many hours, how many minutes, you are having in a particular shift divided by the cycle time, so like if you are having 8 hour shift per day, you have 8 hours shift, 8 hours of working time, so 8 into 60 480 minutes are the total time available for the operation, so 480 minutes. And if I consider the minimum cycle time that is 1 minute per day, so that makes 480 units per day.

Now, I want to produce, somebody says that, “Can you produce 600 units per day”? So, in that case I have to revise my cycle time. I can produce with this particular arrangement, right now my output is 480 units per day, but if somebody says that you have to produce 600 units, the market requirement is 600 units per day, so 480 divided by 600 and in that case you can easily understand that my cycle time will be less than 1 minute.

So, I have to develop a new line, a new assembly line where the cycle time is now less than 1 minute. So, cycle time affects the output rate and output rate can also affect my cycle time. So, we will see with the help of numerical example that how these things happen, but there is a close relationship between the output rate and the cycle time.

Now, or you can increase the, the other way is if you want to have 600 as output and you are not in a condition to reduce the cycle time, in that way, in that condition, you should increase your operating time per day from 480 minutes to 600 minutes, so that you have enough time for producing the 600 units. So, in that case we go with overtime that we have discussed in case of our MRP calculations that will force us to go for the overtime.

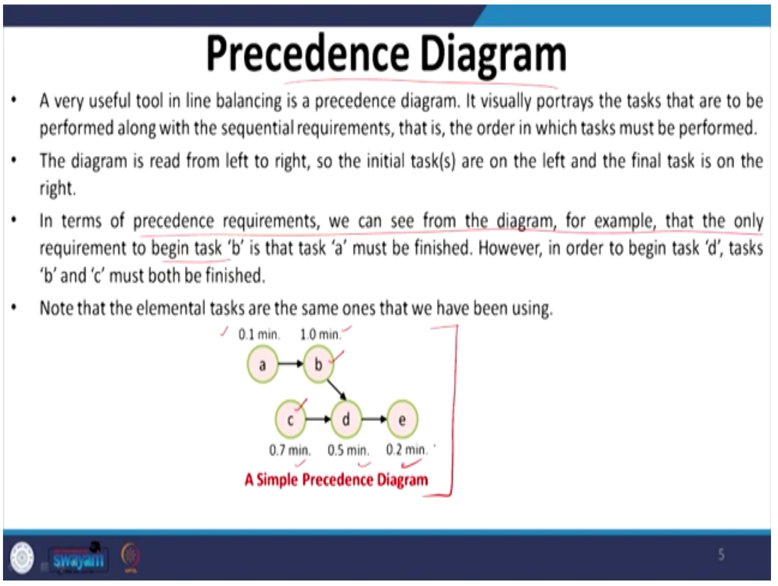
Now, as a general rule, the cycle time is determined by the desired output as I just mentioned that is a desired output rate is selected and the cycle time is computed. If the cycle time does not fall between the maximum and minimum bounds the desired output rate must be revised. We can compute the cycle time using this following equation, so that we have already done.

Now, we can determine the theoretical minimum number of work station to provide a specified rate of output as follow. Now, we are getting a cycle rate which is not within this maximum and minimum bounds, like I am giving this example that I want 600 outputs in 8 hours, so now this is less than the cycle time which is possible that was of 1 minute.

So now, I have to rearrange, I have to rearrange my assembly line and therefore, I need to calculate that how many number of workstations are possible or how many number of workstation should be there, so that I can achieve this cycle time. For that purpose, I have to do sigma t that is the sum of all the task time that is 2.5 in this particular case divided by cycle time, the cycle time which came because of particular output requirement.

So, this will give me theoretical number of workstations in my assembly line, but theoretical number of workstations and the actual number of the workstations may not be the same, that depends upon the line balancing. If theoretical and actual numbers are same then the line is 100 percent balance, but it will not happen that way, there will certainly be more number of workstations, you cannot have workstations in decimals, in fractions, and therefore, you can only have workstations either 1, 2, 3, 4, 5 that means integers and therefore, efficiency will not be 100 percent all the time.

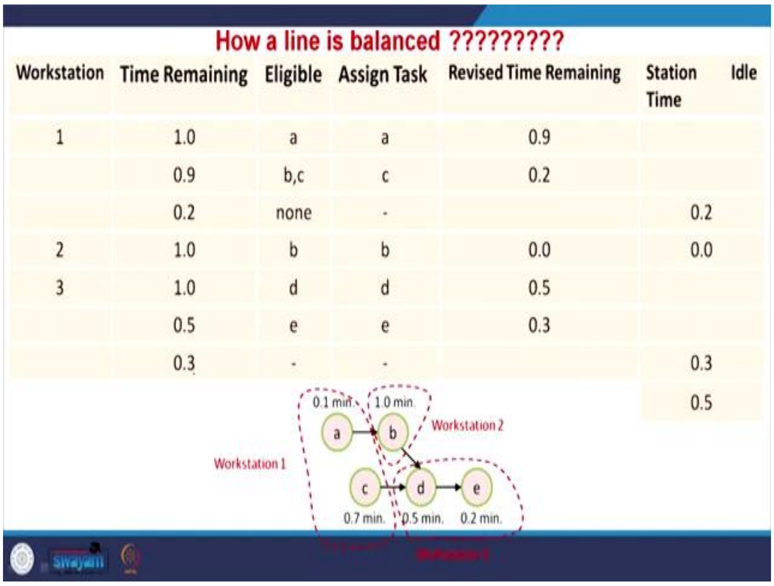
(Refer Slide Time: 23:20)



Now, in this particular case, with this example, we will see how to develop the precedence diagram. Now, for developing a precedence diagram, you see that we can see from the diagram that the only requirement to begin task ‘b’ is task ‘a’ and for task ‘d’ the requirement is that task ‘b’ and task ‘c’, both must be completed then only task ‘d’ can start, but task ‘c’ can start independently because there is no task before task ‘c’.

So, for b a is the precedence, for c there is no precedence, for d b and c both are precedence. Unless until b and c both are finished, you cannot start d and then for e d is the precedence and for each task you have the task times, these are the task times for different tasks, so this is a simple example that is giving you the idea of precedence diagram. Now, based on this precedence diagram, we can calculate the number of work centres or we can balance our line.

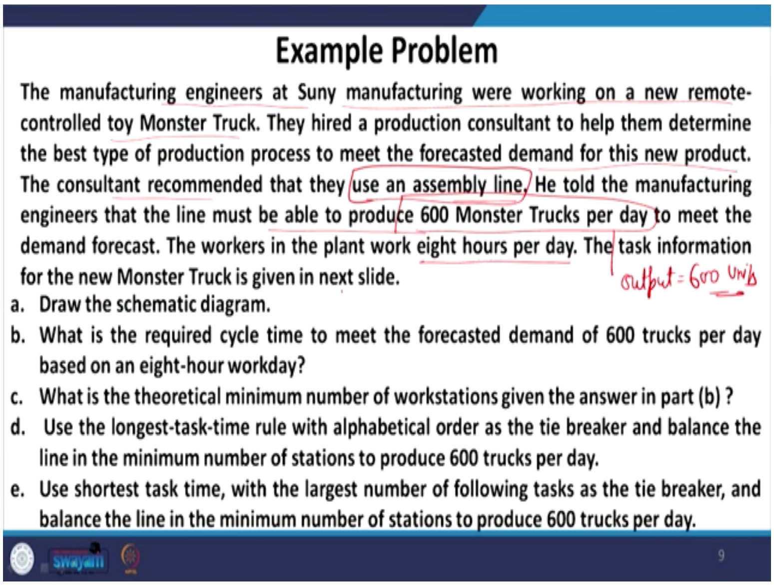
(Refer Slide Time: 24:45)



Workstation	Time Remaining	Eligible	Assign Task	Revised Time Remaining	Station Time	Idle
1	1.0	a	a	0.9		
	0.9	b,c	c	0.2		
	0.2	none	-			0.2
2	1.0	b	b	0.0		0.0
3	1.0	d	d	0.5		
	0.5	e	e	0.3		
	0.3	-	-			0.3
						0.5

Now, here these are the values and we have these calculations available here, but we will show, we will do a more robust calculation which will give you a better idea of how to do and we will select some level of output also in that particular case.

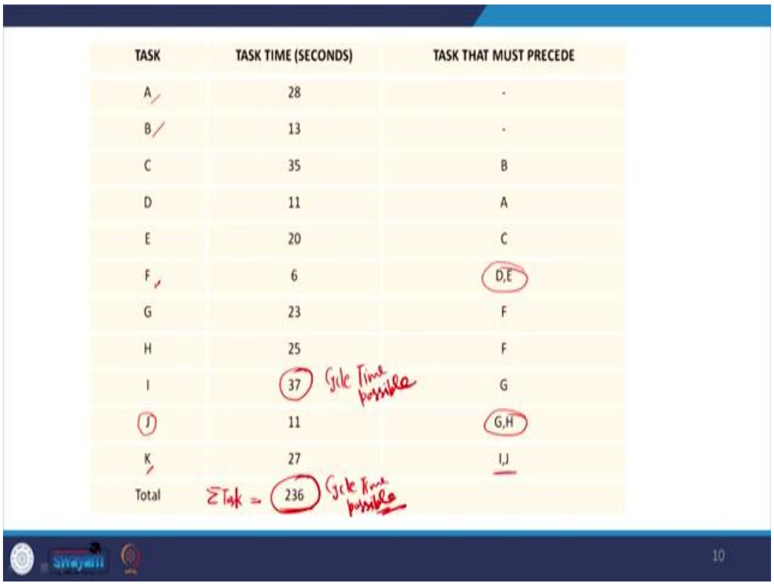
(Refer Slide Time: 25:08)



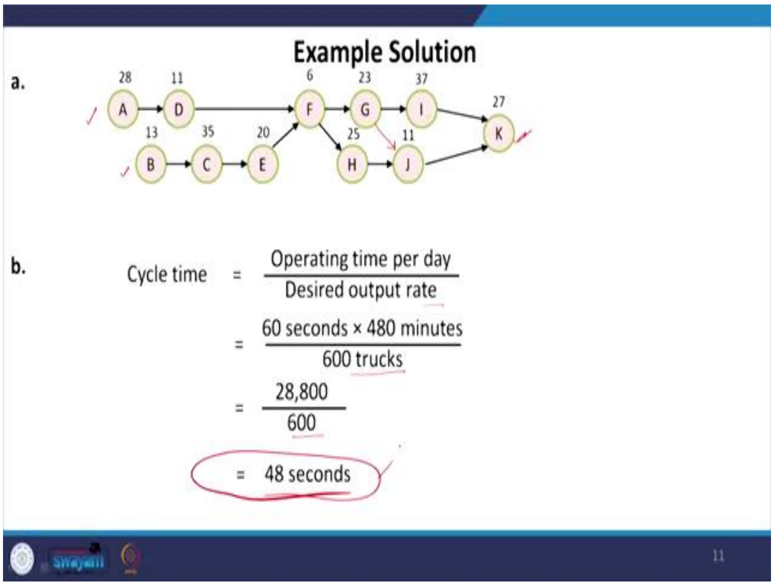
Now, for that purpose we have this example with us, here the manufacturing engineers at a particular company are working on a new remote control toy truck. They hired a production consultant to help them determine the best type if production process to meet the forecasted demand for this new product. The consultant recommended that they use an assembly line, so now it is a question of development of assembly line.

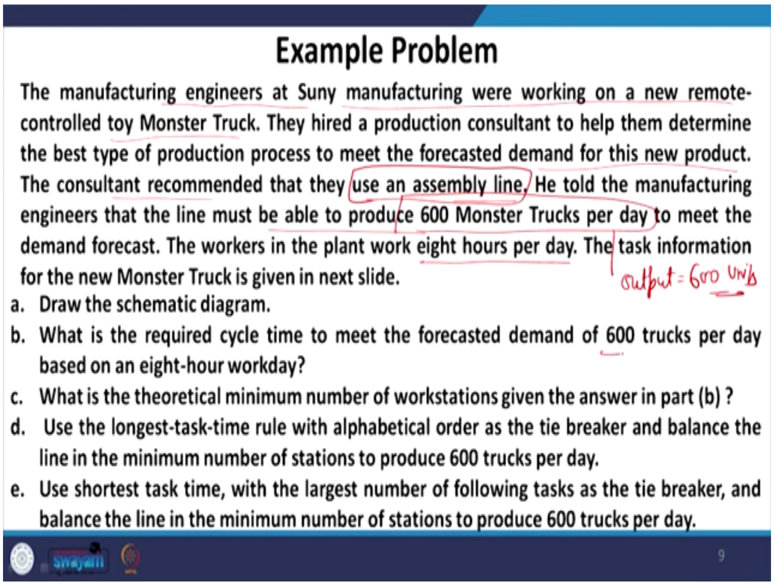
He told the manufacturing engineers that the line must be able to produce 600 trucks per day to meet the line. So, the output is 600 units. The workers in the plant work 8 hours per day.

(Refer Slide Time: 26:01)



TASK	TASK TIME (SECONDS)	TASK THAT MUST PRECEDE
A	28	-
B	13	-
C	35	B
D	11	A
E	20	C
F	6	D,E
G	23	F
H	25	F
I	37	G
J	11	G,H
K	27	I,J
Total	236	





The task information for the new truck is given in this slide and here you see that these are the different task from A to K and for each task, we have the task time. And then you have the conditions, you have the restriction about the precedence. So, the first important thing we need to do that is to prepare a precedence diagram, to prepare a precedence diagram. So, you just remember this thing that for A and B there is no precedence, there is no precedence, A and B can start independently.

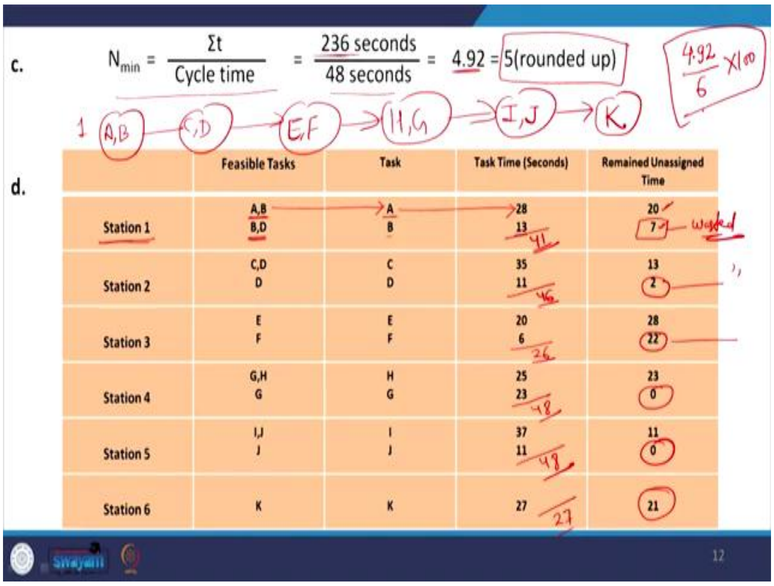
So, here you see that A and B, these two task are starting independently, there is no precedence for them. Then you see for C it is B and for D it is A, so for C it is B and for D it is A then for E it is C and for F E and D, you see for F D and E, both are the precedence. Similarly, if you see for J G and H , for J G and H, both are required and then only you can start this particular activity, so for this particular case J G and H, so G is also to come here and then only this is possible.

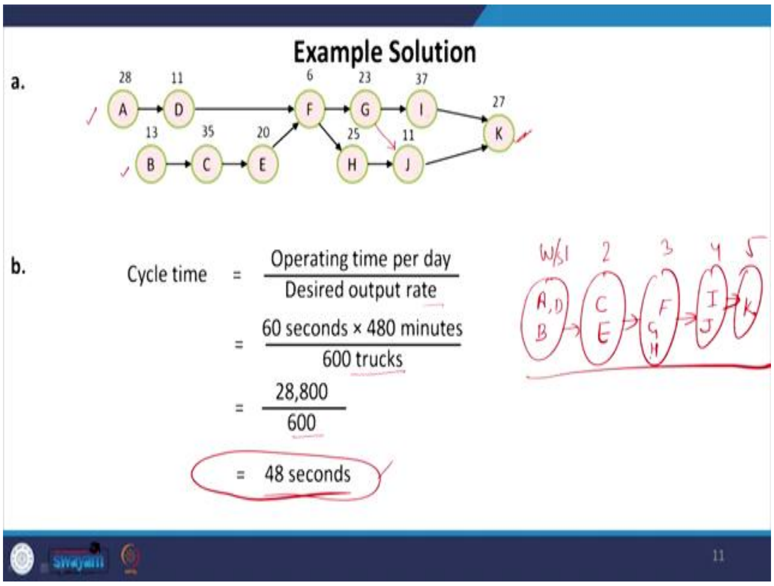
And similarly, you see for K I and J both are required, so K can only be completed when I and J both are completed, so in this way this precedence diagram is prepared. Now, the second thing is to calculate the cycle time. Now, the sigma T, sigma of task time equals to 236 seconds, so our output rate is mentioned as 600 trucks per day for 8 hours day, 8 hours means you have 480 minutes and 480 into 60 seconds, so 28800 seconds you have in all in a particular day.

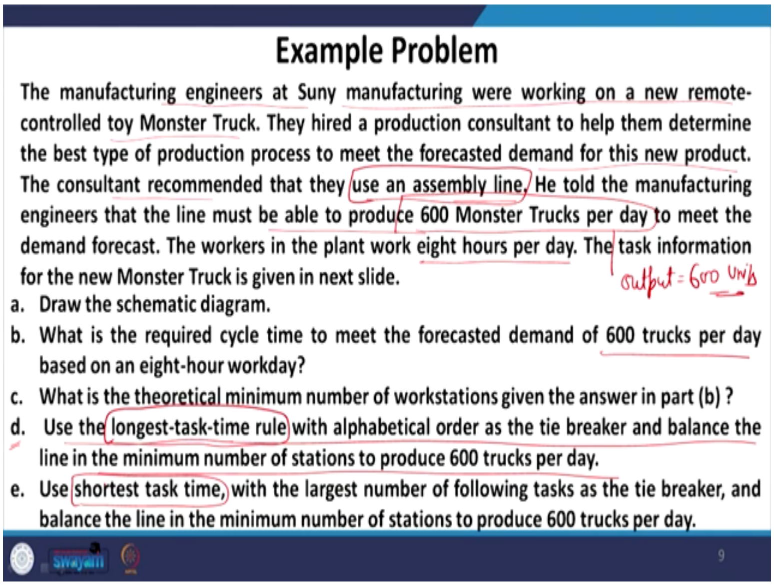
And the desired output rate is 600 trucks, so 48 second is the cycle time, 48 second is the calculated cycle time. Now, if you see the minimum cycle time for any of this thing is possible that is going to be the maximum of these values, so maximum of these values is 37, maximum of these values is 37, so one type of cycle time possible. And the sum of task time is 236 that is also cycle time possible.

Now, 37 is the cycle time possible when all these task are independent and 236 is the cycle time possible when you are putting all these tasks into a single work station, but we require a cycle time of 48 second, it means it is between of 37 and 236 and therefore you have to find some kind of suitable combinations of these thing. And for that purpose our next calculation is to calculate the theoretical number of workstations.

(Refer Slide Time: 29:58)







So, the theoretical number of workstations will be 236 that is the sigma of task time divided by cycle time, so it is 4.92, so 4.92 is the actual number of workstations, that means theoretical number of workstations. But now you can easily understand that 4.92 workstations are not possible, so the nearest workstation, if I am going with this calculation, the nearest number of workstations which are possible is 5. As soon as I go for 5 workstations, my efficiency will go down from 100 percent. 100 percent efficiency is only possible when I have 4.92 workstation, but that is practically not possible.

So automatically, even if I am following what is the best possible scenario, but even in that case, the efficiency will be less than 100 percent, so that is a natural problem, I cannot do anything for avoiding this natural, but yes, if number of workstations are coming to 6 or 7 when we will do the calculations that is something which we need to see, can we reduce it to 5, so that I can have the maximum possible efficiency in this particular case.

Now, for that purpose, let us go back to the problem statement. Now, this problem statement says, now we are coming to the part d of this problem, use the longest task time rule with alphabetical orders as the tie breaker and balance the line in the minimum number of workstations to produce 600 trucks per day.

We have to develop a line that means the idea is that I have to develop some number of workstations, workstation 1, 2, 3, 4, 5, and these workstations will be developed in such a manner that maybe at workstation 1, I have task A, D and B, here I have C, E, here I have F, G, H, here I may have I, J, here I may have K. So, this grouping of tasks on various workstation is the part of development of the line. I am not sure whether it is correct or not, but this type of shape will finally come when we will do.

Now, there are different types of rules through which you can assign these different task to a workstation. There are different types of rules and the rule suggested to us in this particular case is to use the longest time task time rule. So, you can create multiple type of rules and like in the next part e it is the shortest task time. So, either we can use longest task time, shortest task time then how many task are behind you, so there are different types of rules which are possible.

Now, when we are using the longest task time rule, so let us see, now we are developing the station 1, we are developing the station 1 and at station 1 you see the task which are there A, B the A, B these are the initial task. Since, it was mentioned in the problem that you select the task in the alphabetical order, I have selected task A, out of A, B I selected A.

Then the task time is 28 seconds. I can use maximum 48 seconds, that is the cycle time for a particular work station. So, I still have 20 seconds available with me, so I can assign 1 more task to this 1 or 2 more task, I do not know how many will come in this 20 seconds, but I can assign. Now, I will go to next assignment category and I have taken B, and D. B is here and D is here because B is followed by C and A is followed by D, so in that way I am moving ahead that the longest task times are there, so 13 and 11, because after this the task times are less, so B and D are the feasible task.

Now, out of these two in the alphabetical orders B is coming before D, it is taking 13 seconds, so 7 seconds are still idle. Now, you can take, you can take C or D task, you can take C or D task for the third category. Now, the C and D task, both are taking more than 7 minutes, so you cannot have any further task to be added here. So finally, the 7 seconds remain wasted, you will not be able to use these 7 seconds of your task 1, as work centre 1 and only these 41 seconds you are able to use.

Similarly, you see for the workstation 2, you are able to use 46 seconds and 2 seconds are wasted. For the third, we are able to use only 26 seconds, 22 seconds are wasted, a very high level of wastage for the third workstation. For the fourth workstation, you are able to use complete 48 second and there is no wastage, again for the fifth 48 no wastage and for the last workstation, you are using 27 and 21 seconds are the wastage.

So, in this case, now you see that finally we have 6 workstations and these 6 workstations are arranged in a manner that station 1 where task A and B will be performed, then station 2 where task C and D will be performed, then station 3 where task E and F will be performed, then station 4 where task H and G will be performed, then station 5 where task I and J will be performed and finally station 6 where only one task K will be performed.

So, you have the 6 stations and then you can calculate the efficiency also, the theoretical number of workstations were 4.92 and the actual number of workstations are 6, so that is giving you the efficiency of your total system of this line balancing. So, you can see that it is certainly less than 100 percent with your best efforts of balancing the line.

(Refer Slide Time: 37:44)

	Feasible Tasks	Task	Task Time (Seconds)	Remained Unassigned Time
Station 1	A,B A,C	B A	13 28	35 7
Station 2	C,D C	D C	11 35	37 2
Station 3	E F	E F	20 6	28 22
Station 4	G,H H,I	G H	23 25	25 0
Station 5	I,J I	J I	11 37	37 0
Station 6	K	K	27	21

Similarly, with another type of idea that how many number of tasks are following a particular task, you can develop the same kind of arrangement and even in this kind of arrangement we saw that 6 workstations are needed. So, again the same efficiency up to part C the problem is same, D and E are 2 parts to demonstrate you that how different decision rules can be used for development of the balanced lines.

Now, with this we come to end of session where we discussed that how line balancing is done. And during this line balancing issue, we discussed two, three very important terms, one is the cycle rate, then the second is the efficiency of your line balancing and third is the work centre, so these are the three very important terms which you remember all through your life because in practice in professional life, these terms are used to discuss our technical contents of the production floors and therefore if you are not aware of these terms, you will not be able to understand the meaning of what is being discussed. So, with this we come to end of this session. Thank you very much.