Decision Making with Spreadsheet
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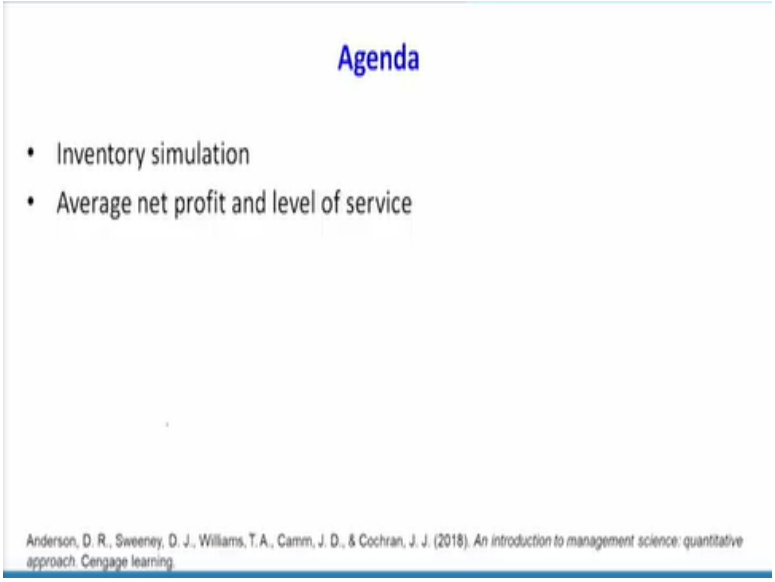
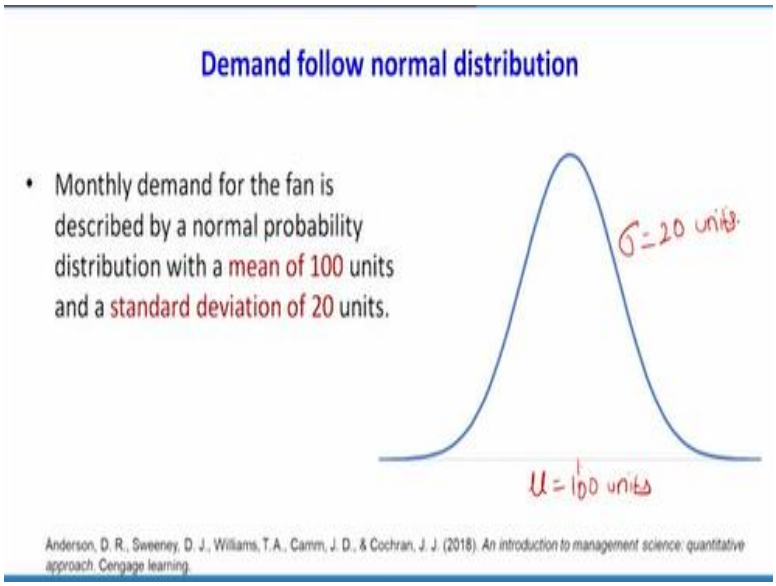
Lecture - 43
Inventory Simulation

Dear students, in the previous class I have discussed about risk management using simulation. I have taken 1 example in the previous class the launching of a new product. What is the possibility of risk whether it is going to be success, or it is going to become loss? In this lecture I am going to take another example that is inventory management using simulation.



So, today the agenda for this lecture is how to use the simulation tool for inventory management. So, during the simulation, we are going to consider two output measures. One is the average net profit and the level of service for different types of inventory policies. Ultimately, we are going to suggest what is the right replenishment level; otherwise, what is the right inventory policy?

Simulation for inventory policy. In this lecture we will learn how simulation can be used to establish an inventory policy for a product that has an uncertain demand. The product is a home ventilation fan distributed by an electrical supply company. Look at this picture; it is a ventilation fan. Each fan costs 75 dollars and sells for 125 dollars. Thus, the company realizes a gross profit of the difference in selling price - cost; 125 - 75 = 50 dollars for each fan sold. So, the profit of selling one fan is 50 dollars.

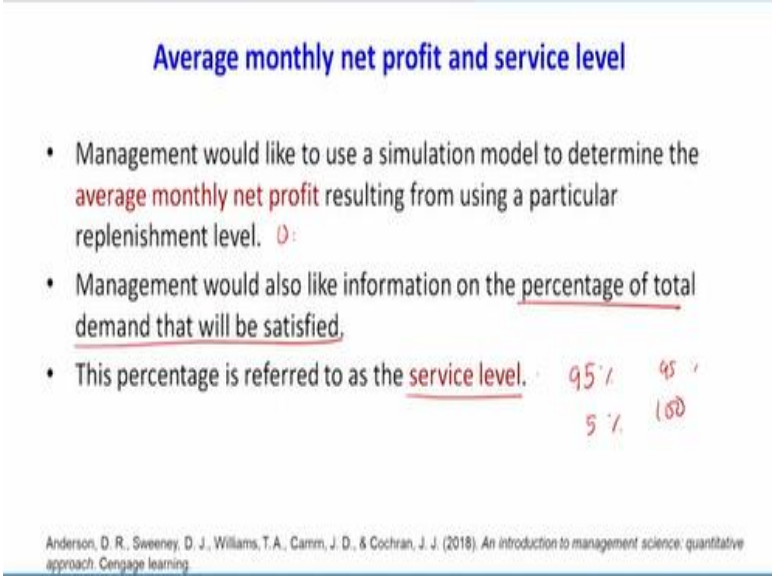


The demand follows normal distribution for this product. So, monthly demand for the fan is described by a normal probability distribution with a mean of 100 units and u = 100 units, and the standard deviation is 20 units.

So, we are going to consider what is the appropriate replenishment level Q holding cost and shortage cost. The company receives monthly deliveries from its supplier, and it replenishes its inventory to a level Q. So, the inventory replenishment level is Q at the beginning of each month. The beginning inventory level is referred to as the replenishment level. If monthly demand is less than the replenishment level, that is, if the demand is less than Q, an inventory holding cost of 15 dollars is charged for each unit that is not sold.

So, we are considering the inventory holding cost, which is 15 dollars. However, if monthly demand is greater than the replenishment level when the demand is more than Q, a stock-out occurs, and a shortage cost is incurred. Because the company assigns a goodwill cost of 30 dollars for each customer turned away, a shortage cost of 30 dollars is charged for each unit of demand that cannot be satisfied.

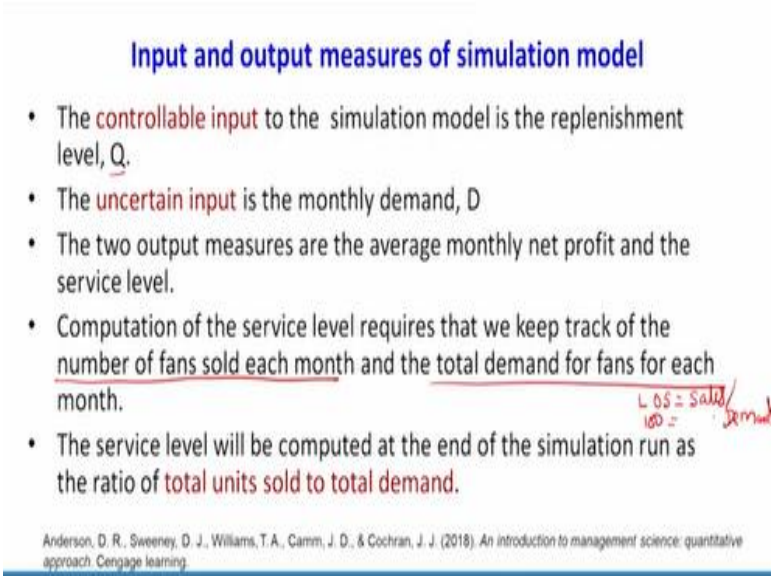
So, what we are considering? The inventory holding cost is 15 dollars, and the shortage cost is 30 dollars.



So, we are going to consider 2 output measures for this simulation. One is the average monthly net profit and the service level. Management would like to use a simulation model to determine the average monthly net profit resulting from a particular replenishment level. So, here replenishment level is Q. So, we have to suggest the correct Q so that the average monthly net profit is maximum.

Management would also like information on the percentage of total demand that will be satisfied. This percentage is referred to as the service level. Here are only two output measures we are considering. One is the average monthly net profit, and the other one is the service level. What is the service level? The percentage of total demand that will be satisfied. Say, for example, when we say the service level is 95%.

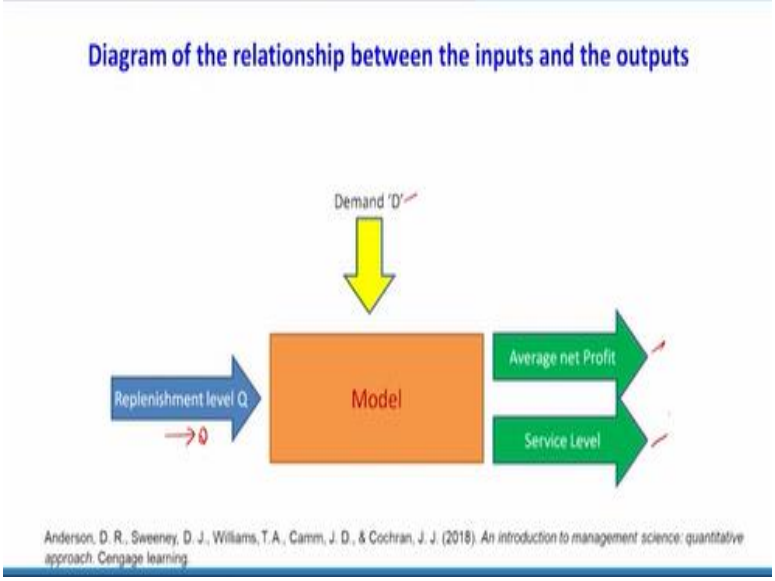
So, what is the meaning? Out of 100 times, 95% we are satisfying the demand. So, the remaining 5% is called your stock-out level. So, the permissible stock-out level is 5%. Here, what is the meaning of service level? Her service level is 95%. That is the percentage of total demand that will be satisfied.



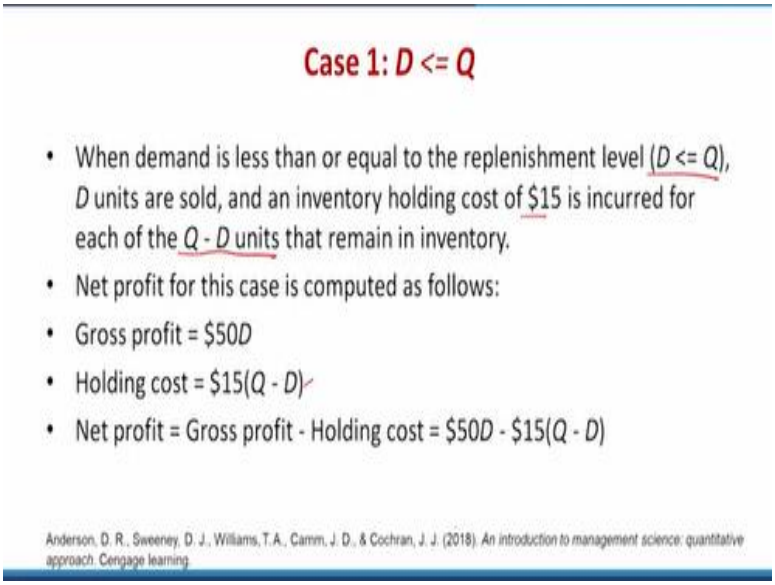
Next, we will consider what are the inputs and output measures for the simulation model. The controllable input to the simulation model is the replenishment level Q. So, the Q is our controllable input, which we can change. The uncertain input is the monthly demand. We have seen that the demand for this product follows normal distribution, which is uncertain. The two output measures are the average monthly net profit and the service level as I discussed in the previous slide.

The computation of the service level requires that we keep track of the number of fans sold each month and the total demand for fans for each month. So, how we are calculating the service level? Number of fans sold each month and divided by the total demand for fans for each month. Sales upon demand. So, service level, sometimes we call it a level of service. Sales upon demand. So, what level of service when it becomes 100%? When sales are equal to demand.

The service level will be computed at the end of the simulation run as the ratio of total units sold and the total demand.



The diagram of the relationship between the inputs and the outputs. As we have seen previously, the controllable input is our replenishment level Q. Uncertain input is a demand that follows a normal distribution. What are the output measures? Average net profit and the service level.

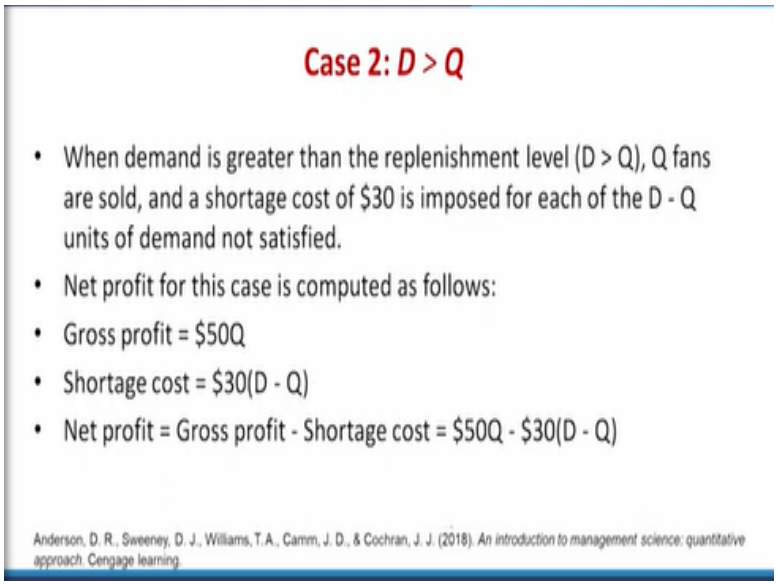


In case 1, what will happen when the demand is less than your replenishment level is less than or equal to Q? When the demand is less than or equal to the replenishment level, that is when the demand is less than or equal to Q, what can we do? D units are sold, and an inventory holding cost of 15 dollars is incurred for each of the (Q – D) units that remain in inventory. Because now the demand is less, but we stocked more, there will be an inventory holding cost.

How many units will be held in the inventory? (Q – D). So, the net profit for this case is computed as follows; we know the gross profit is 50 dollars. We have seen previously by selling 1 fan, the gross profit is 50 dollars. Since the demand is uncertain, there is a possibility that demand may become lesser than Q. So, the holding cost number of units and per unit holding cost will be 15 multiplied by (Q – D).

So, net profit is gross profit - holding cost. That is 50 dollars, 50 D, here D is the demand - 15 into (Q – D)

Net profit = Gross profit - Holding cost = $\$50D - \$15(Q - D)$

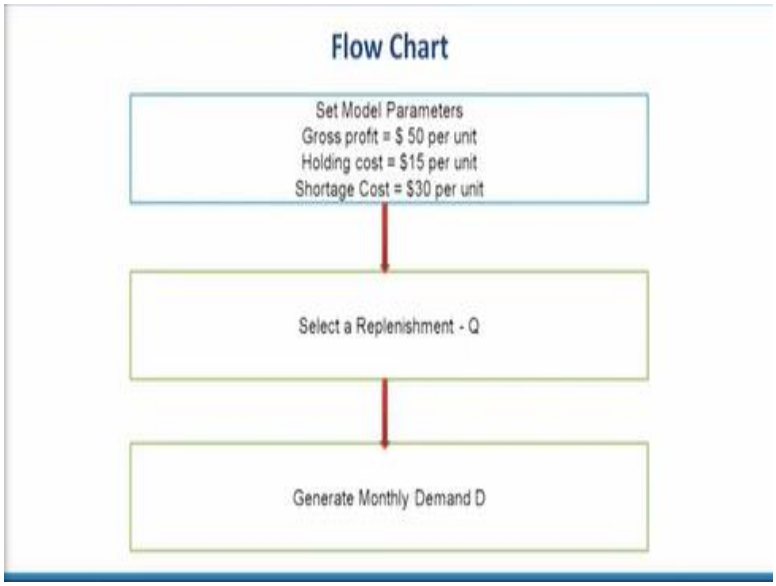


In the other case, the demand is more than the Q. When demand is greater than the replenishment level D greater than Q, we can sell only Q fans. Q fans are sold, and a shortage of 30 dollars is imposed for each of the (D – Q) units of demand not satisfied. In the second case, the demand is more than Q. So, there will be a situation where a shortage will occur. We know there is a shortage cost.

So, we have to multiply by the shortage cost. So, we will get the overall shortage cost. Now, the net profit for this case is computed as follows: we know the gross profit is 50Q. Remember, previously, it is a 50 D, and now it is a 50 Q. Because even though demand is more than Q, we can sell a maximum of Q units. Now, the shortage cost is a difference in demand and the replenishment level (D – Q) multiplied by 30. So, in this case, the net profit is gross profit - shortage cost.

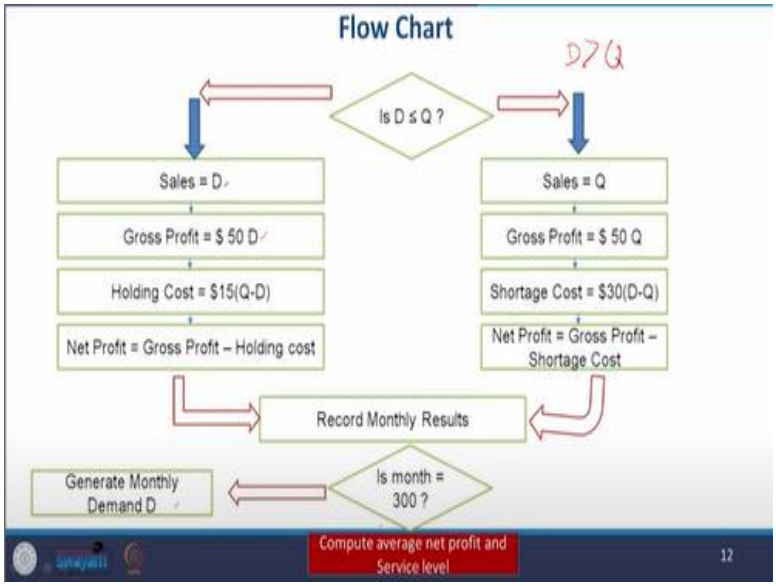
Net profit = Gross profit - Shortage cost = $50Q - $30(D - Q)

That is 50Q - 30 multiplied by (D – Q). Any one case can occur at a time whether the demand is greater than Q or less than Q. So, in the overall model, you may get shortage cost or holding cost but not both—that concept you need to remember.



Now, the simulation, if you put it in the form of a flow chart, is easy to understand. So, what are the model parameters? So, the gross profit is 50 dollars per unit. The holding cost is 50 dollars per unit, and the shortage cost is 30 dollars per unit. This is fixed in advance. Later, when we discuss sensitivity analysis, we can change the holding cost and shortage cost, and then we can see how our net profit and service level are affected that we can see.

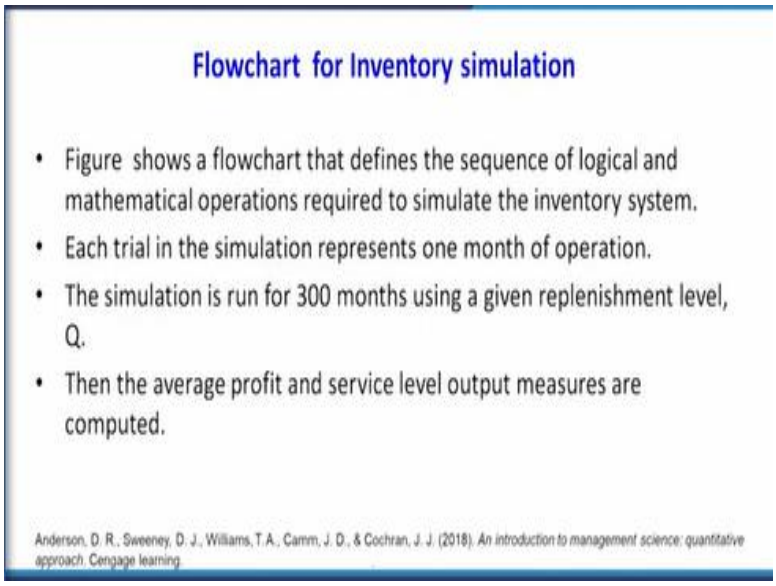
So, at present, we are given the data we are assuming. The parameters are fixed. So, select a replenishment level that is Q. Generate monthly demand.



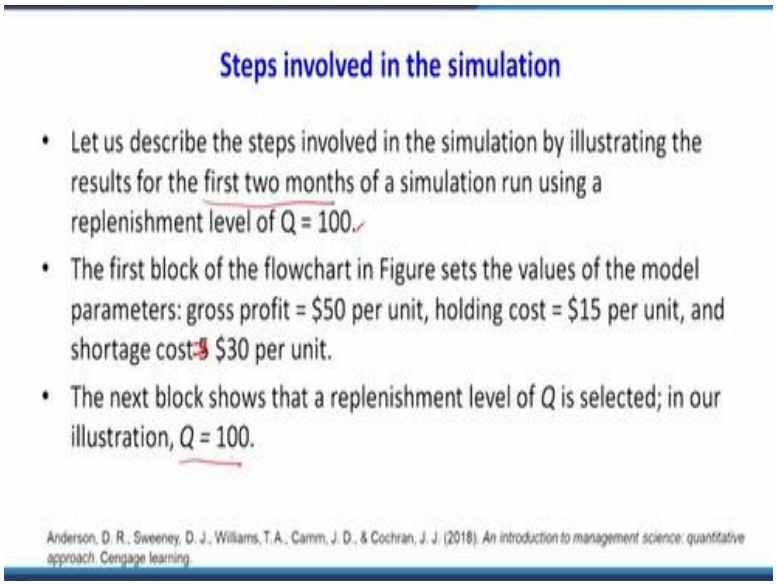
So, when you generate a monthly demand, two possibilities may arise. If the demand is less than or equal to Q, demand is less, but you stocked more. The sales will be D. We know the gross profit is 50 D. When the demand is less than Q; there will be an inventory holding cost. So, 15 in Q - D. So, net profit is gross profit - holding cost. Suppose this condition is not valid, so what is the meaning of how? Now the demand is more than the Q.

So, when the demand is more than Q, we can sell only Q units. The gross profit is 50 Q. Now the shortage cost is 30 dollars multiplied by demand - Q. So, the net profit is gross profit - shortage cost anyone can incur. So we can record the monthly results. What are the monthly results? What is the net profit? And what is the service level? So, we have to see the monthly results for month 1. We are going to repeat these iterations for 300 months.

So, month 1, one iteration is over. Then you go to month 2, month 3, and month 4, up to 300 months, we are going to repeat these iterations. So, this is a month 1 calculation, and then you generate another demand for month 2 demand. Then, you will get another monthly result and the second month's result. Then go to the third month, then we will get the third month's result.

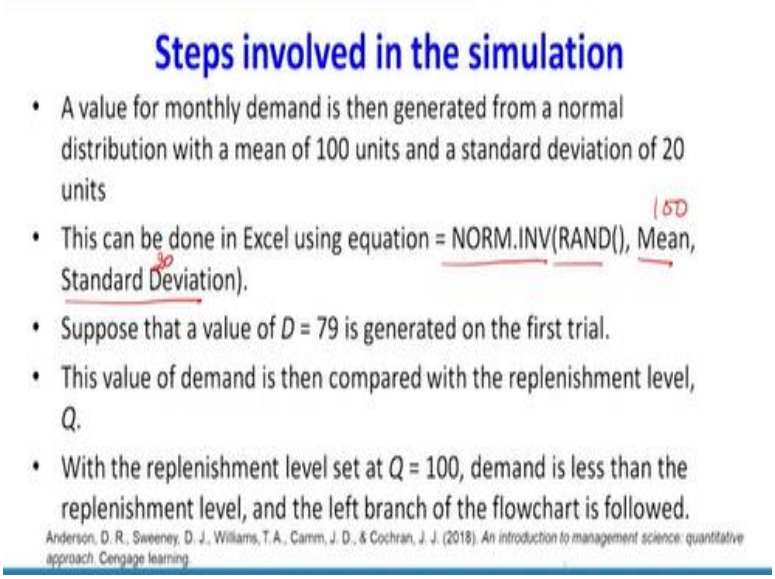


So, the figure shows a flow chart that defines the sequence of logical and mathematical operations required to simulate the inventory system. Each trial in the simulation represents one month of operations. The simulation is run for 300 months using a given replenishment level Q. After that, we will find the average profit and the service level. Service level output measures are computed.



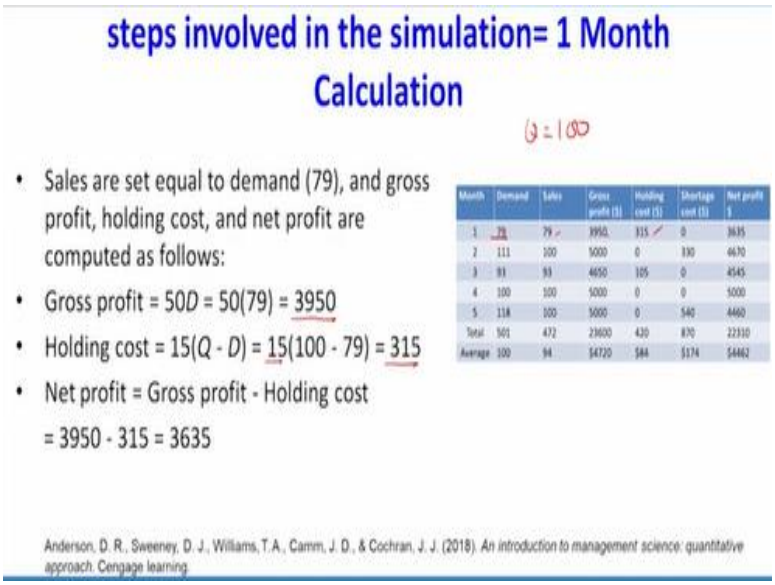
Now, I am going to explain the steps involved in the simulation. Let us describe the steps involved in the simulation by illustration. The result for the first two months of your simulation run using a replenishment level of Q = 100. So, I am going to explain the first two months how this simulation is going to work. The first block of the flowchart in the figure sets the value of the model parameters. What are the values for the model parameter? The gross profit is 50 dollars.

The holding cost is 15 dollars, and the shortage cost is 30 dollars. The next block shows that the replenishment level Q is selected; in our illustration, the Q = 100.



A value for monthly demand is then generated from a normal distribution with a mean of 100 units and a standard deviation of 20 units. In the previous class also, I have explained how to use excel to generate the numbers which follow normal distribution whose mean is 100 and the standard deviation is 20. So, this can be done in Excel using the equation this NORM.INV RAND mean value and standard deviation value.

So, here, just to replace 100, standard deviation 20, then you can drag for all 300 months. Suppose that the value of the demand is 79 is generated on the first trial assume that we got 79. So, this value of the demand is then compared with the replenishment level Q. So, Q is 100 here. So, with the replenishment level set at Q = 100, now the demand is less than the replenishment level, and the left branch of the flowchart is followed. Because now the demand is less than the Q, there is going to be inventory holding cost.



Sales are set to equal the demand 79, and the gross profit, holding cost, and net profit are computed as follows; please look at the table on the right-hand side. Now we have a demand of 79. So, Q = 100. So, what will happen? We can sell only 79 units. So, what will be the gross profit? We know it is a 50 D. So, 50 into 79 = 3950 dollars. Now, the holding cost is a difference in demand and the Q.

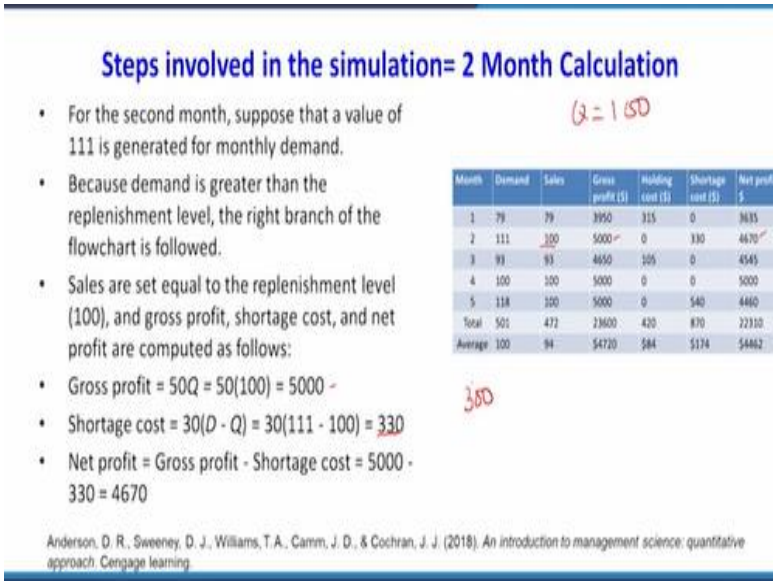
Gross profit = 50D = 50(79) = 3950

That is the Q - D that is 100 - 79 multiplied by per unit holding cost. So, you are getting 315. Now the net profit is gross profit - holding cost that is 3635. You see that only the holding cost occurs. There will not be any shortage cost. This is our month 1 iteration. The same procedure will be repeated for the month 2.

Holding cost = 15(Q - D) = 15(100 - 79) = 315

Net profit = Gross profit - Holding cost

= 3950 - 315 = 3635



Those steps involved in the simulation for the second month. Assume that the second month suppose the value of the demand is 111. But we stocked only 100 units because the demand is greater than the replenishment level the right-side branch of the flowchart is followed. Now the sales are set equal to the replenishment level because we can sell only 100 units because our Q = 100. But our demand is 111 but we can sell only Q units.

Gross profit = 50Q = 50(100) = 5000

Shortage cost = 30(D - Q) = 30(111 - 100) = 330

So, now, what will be the gross profit, shortage cost, and net profit? So, the gross profit is 50 multiplied by Q. That is 5000 this 5000. There will not be any holding cost, but there will be a shortage cost; net profit is gross profit - shortage cost is 4670. This is our iteration 3, which is month 2. Similarly, for month 3, the demand is 93, which is less than the Q. So, the sales will be 93.

Net profit = Gross profit - Shortage cost = 5000 -
330 = 4670

Then we can find the gross profit then there will be a holding cost. There will not be any shortage cost. Then we can get the net profit. This, I have repeated for five months. So, I find the total demand for five months. Then they find the average. With the help of Excel, we are going to do 300 iterations.

Calculation of monthly average net profit and level of service

- Results for the first five months of the simulation are shown in Table
- The total shows an accumulated total net profit of $22,310, which is an average monthly net profit of $22,310/ 5 = $4462.
- Total unit sales are 472, and total demand is 501.
- Thus, the service level is 472/501 = 0.942, indicating that company has been able to satisfy 94.2% of demand during the five-month period.

Month	Demand	Sales	Gross profit ($)	Holding cost ($)	Shortage cost ($)	Net profit $
1	79	79	3950	315	0	3635
2	111	100	5000	0	330	4670
3	93	93	4650	105	0	4545
4	100	100	5000	0	0	5000
5	118	100	5000	0	540	4460
Total	501	472	23600	420	870	22310
Average	100	94	$4720	$84	$174	$4462

Anderson, D. R., Sweeney, D. J., Williams, T. A., Camm, J. D., & Cochran, J. J. (2018). *An introduction to management science: quantitative approach*. Cengage learning.

The results for the first five months of the simulation are shown in this table. The total shows an accumulated total net profit that is 22,310. See this total net profit which an average of monthly net profit is divided by 5. So, what do we do? When you do the average, it will be 4462. The unit sales are 472, and the total demand is 501. Now the service level is, you see, that is a very important point. The service level is total sales divided by total demand.

So, the total sales are 472 total demand is 501. So, the service level is 0.942, indicating that the company has been able to satisfy 94.2% of demand during the five-month period. That is an interpretation of your level of service. That is the service level.

Inventory simulation results for five trials with $Q = 100$

Month	Demand	Sales	Gross profit ($)	Holding cost ($)	Shortage cost ($)	Net profit $
1	79	79	3950	315	0	3635
2	111	100	5000	0	330	4670
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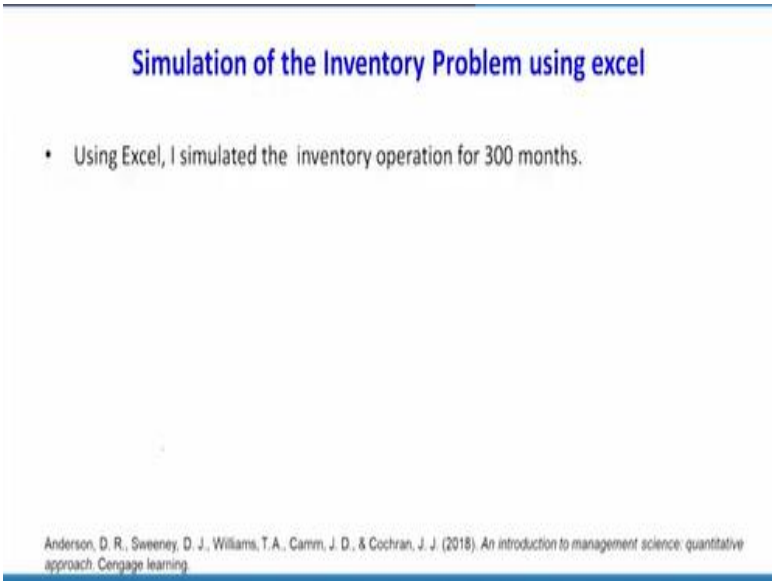
Now I brought the whole table. We have done this for five months. Then we found the total net profit, then the average net profit, and then we can find out the service level. What is the service level? 472 sales upon demand divided by 501.



Now, I am going to open an Excel sheet. In the Excel sheet, I am going to replicate it for 300 months. Now, I will open the Excel sheet.

Now, I am going to explain how to use Excel for doing this inventory simulation. So, what is the information given to us? Gross profit is 50 dollars, holding cost is 15 dollars, and shortage cost is 30 dollars. Assume that the initial replenishment level is 100 units. The demand follows a normal distribution mean of 100 and a standard deviation of 20. So, in the first five months, I have already done it manually without randomly generating the demand.

Now, for the next six months, I am going to generate the demand. So, the formula that I have used for generating the demand whose mean is 100 standard deviation is 20, which follows a normal distribution, is NORM.INV RAND mean is B10 and the standard deviation is 20. You see that now if I press F9 the value of this 100 will keep on changing F9. Now you see the sales that is C22. So, now we are going to compare this one.

Now what has happened? Now the demand is more than the sales. So, what will happen? Now there is a shortage cost will occur. So, when the demand is more than the sales so I have to fix the sales quantity. So, the sales quantity you see that I am going to use is function. If B22 is less than

or equal to C7, C7 is my replenishment quantity. In this case, this situation is violated. So, if B22 is less than C7, then the sales are B22; otherwise, it is C7.

So, in this situation, this condition is violated. So, the sales are only the Q, which is 100 units. Now, the gross profit is D22. So, the gross profit is sales multiplied by that is C22 multiplied by C3. Then, there will not be any holding costs. But we can write the functions for holding cost. When will the holding cost occur? If B22 is less than C7 that is our replenishment quantity. So, the holding cost unit is the difference between these two.

That is, C7 - B22 multiplied by per unit holding cost is a C4; otherwise, it is 0. But in this case, the condition is violated. So, there will not be any holding costs. Now we will go to the shortage cost. So, when the shortage cost will occur? If the demand B22 is less than C7 but you see this situation it is not C7. If B22 is less than C7, there will not be any shortage cost. If this is violated so there will be a shortage cost.

What is that? The difference in B22 and our replenishment quantity multiplied by per unit shortage cost C5. So, that is, we got 65 dollars. Now you see the formula for net profit G22. So, the net profit is gross profit - holding cost - shortage cost. You remember for each month, iteration either holding cost or shortage cost will be positive; it cannot be both. For example, for the six months, there will not be any holding cost, only shortage cost.

For example, in the third month, there will be a holding cost, but there will not be any shortage cost. So, this is the iteration procedure for the six months. Now I am going to replicate this for 300 months. So, I am going to drag the demand that is B22 I am going to drag it. Now I have explained for the 6 months. From the seventh month onwards, up to 300 months, I am going to repeat these procedures. So, I am going to extend the 6-month calculation up to 300 months.

So, when you double click, then similar sales, similar gross profit, then holding cost, then shortage cost, and the net profit. So, we will go to the bottom. Now you see the total demand. So, you see that the total demand I have considered is only 6 months onwards. Similarly total sales also only

for sixth month onwards. Then, the gross profit for all the calculations is only for 6 months onwards. Now we find the average profit. So, you see B318. So, the average is B22 to B316.

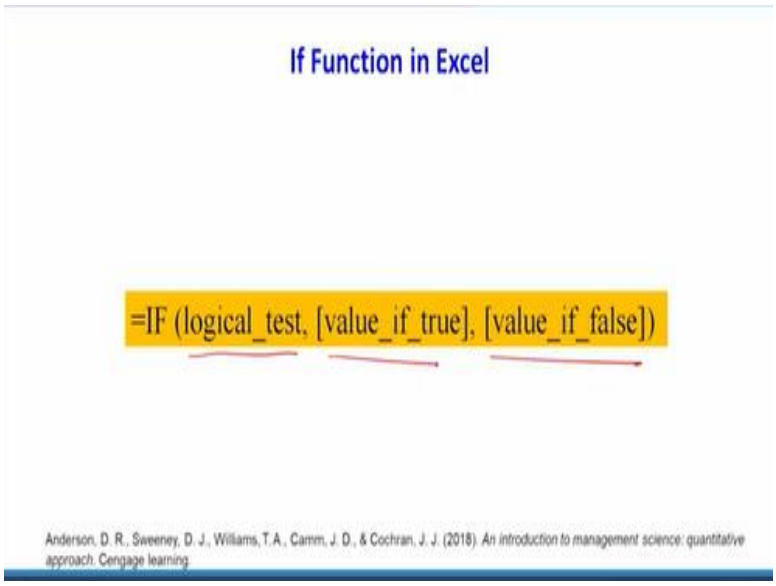
Similarly, I have done average sales, average gross profit, average holding cost, shortage cost, and average net profit. So, the mean net profit is nothing but the same. Now we are going to find the standard deviation. So, the standard deviation is equal to the STD standard deviation for the population. So, from the sixth month onwards, I am going to select the net profit column. Now, similarly, I found the minimum profit.

You see, the formula for minimum profit is equal to a minimum of six months to 300 months. Similarly maximum profit maximum of this one. Now you see the service level calculation. So, the service level calculation is the total sales that is C317 divided by total demand. So, we are getting 92.6. Now, what are we going to do? Our controllable input is Q so, we have done this simulation assuming that Q = 100.

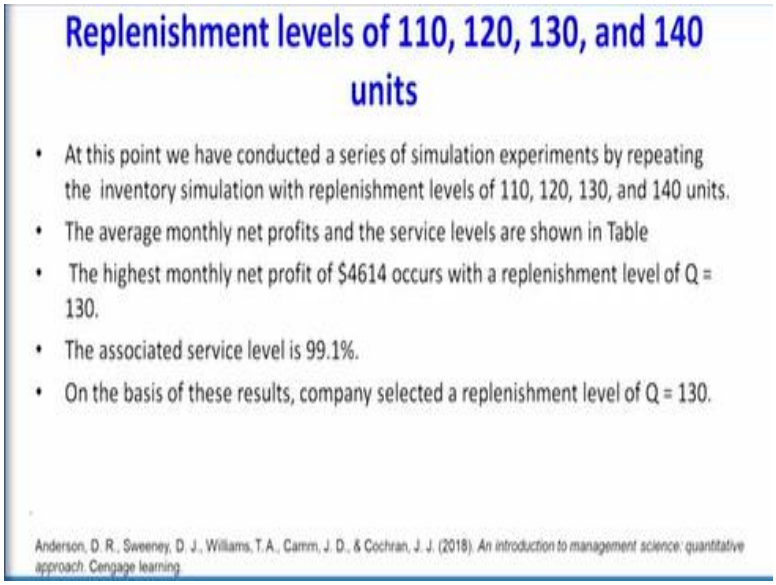
So, for the Q=100, we are going to find out what is the net profit. So, when I keep on pressing F9 you see that my mean net profit keeps on changing see that yes. So, now I have taken Q = 100. So, when I keep on pressing F9 approximately, we can freeze here. The mean net profit is 4284 and the service level is 92. Now, change the Q value to 110. So, keep on pressing F9, so now we will capture 4544.

Now you change the Q value to 120. So, now you keep on pressing F9. Now you see 4559 98.4. Now change the Q value to 130. Now, what have you done? We have changed different Q values then we have found the net profit and service level. So, by looking at this output measures table. So, the value of Q = 130 that time. So, our net profit is 4614 and the service level is 99.10. So, we can suggest to this company.

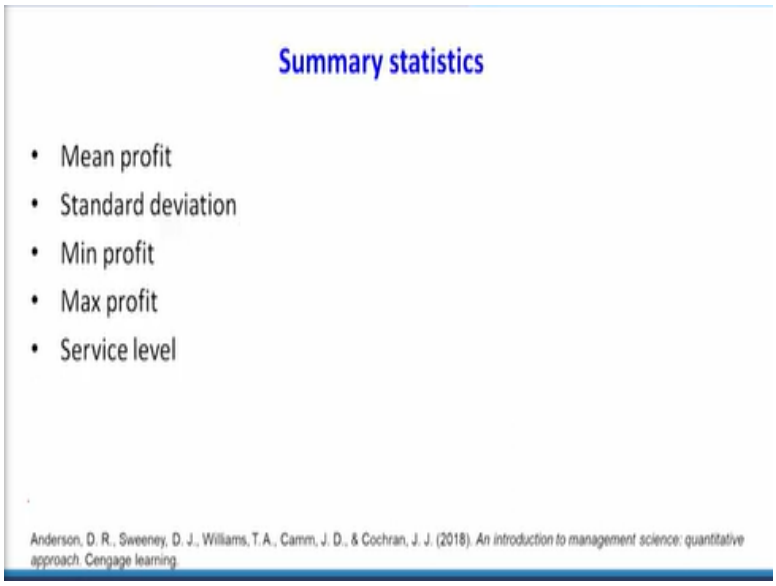
So, the optimal inventory quantity is 130 units. If they stock 130 units, they can achieve a service level of 99.10. We will go back to the presentation.



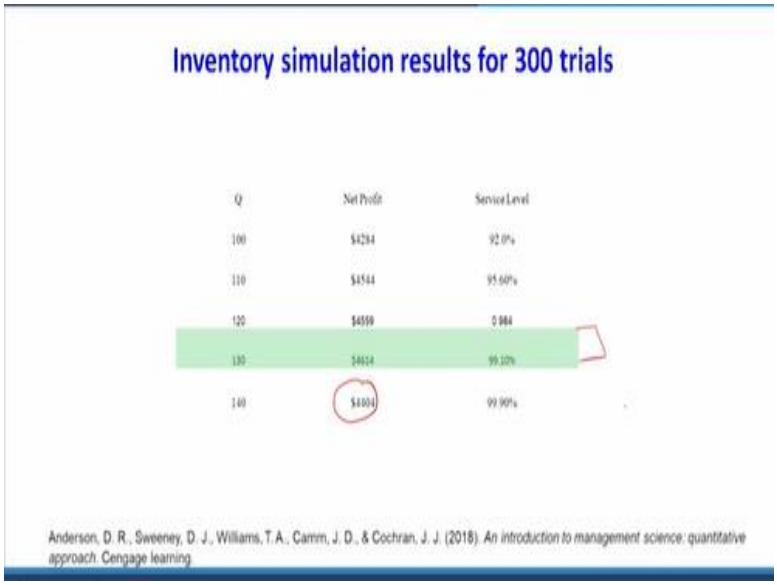
So, I have explained how to use Excel. So, there is an if function. The argument for the if function is first if you have to see the conditions. If the condition is true, this value will be taken. If the condition is false, this value will be taken.



Replenishment level of 110, 120, 130 and 140 units. So, at this point, we have conducted a series of simulation experiments by repeating the inventory simulation with replenishment levels of 110, 120, 130, and 140. The average monthly net profit and the service level are shown in the table. The highest monthly net profit is 4614 when the replenishment level is 130 and the associated service level is 99.1. So, based on this result, a company selected the replenishment level of Q = 130 units.



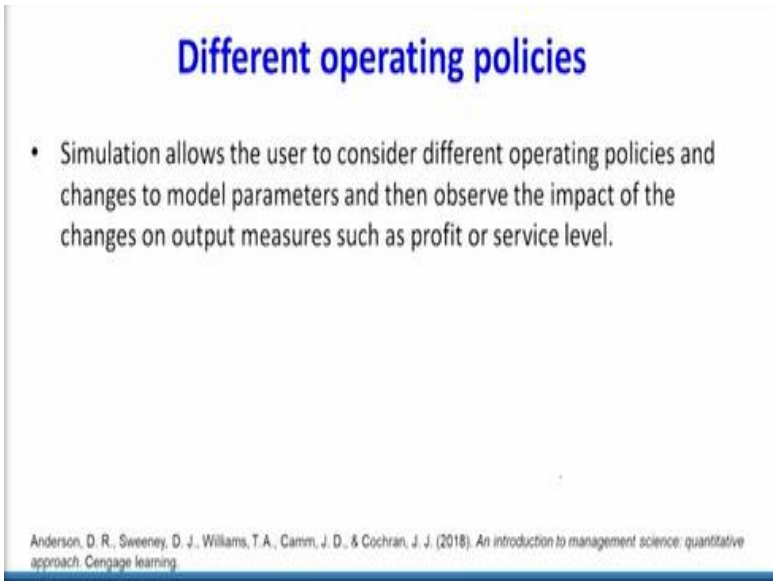
What are the different summary statistics that we have used? We have used mean profit, standard deviation, minimum profit, maximum profit and service level.



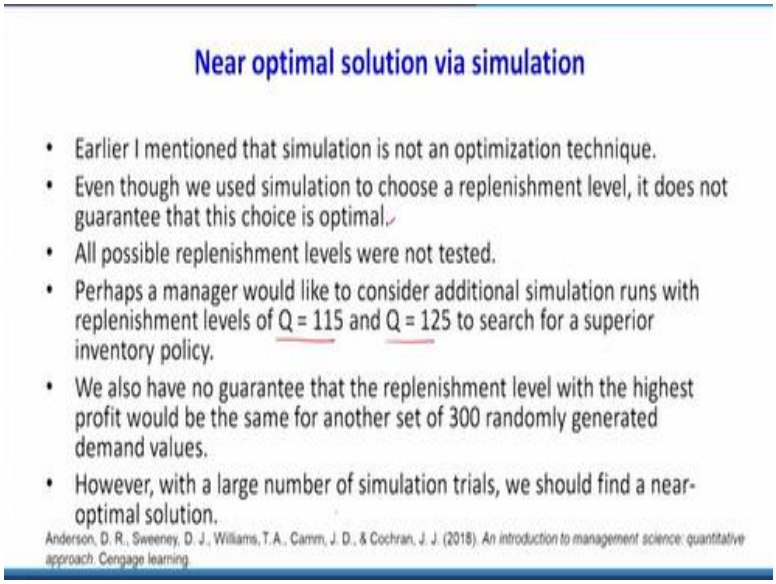
Now you see the net profit. So, when you keep on increasing the Q value it is increasing up to 130. When the Q value goes beyond 130 slightly, the net profit decreases. That is why we stopped with the Q = 130. So, our conclusion is that if the company stocks 130 units, they can maximize the net profit. At the same time, they can achieve a service level of 99.10. What is the meaning of this 99.10? Out of 100 times, 99.10 times, they are able to satisfy their demand.

Then, sensitivity analysis in simulation: Experimental simulation studies, such as those we have done in the company's inventory policy, can help identify good operating policies and decisions. Management used simulation to choose a replenishment level of 130 for this home ventilation fan. With the simulation model in place, management can also explore the sensitivity of this decision to some of the model parameters.

How can they do sensitivity analysis? For instance, we assumed the shortage cost was 30 dollars. For any customer demand if the demand is not met. So, with the shortage cost, if the replenishment level is Q = 130 the level of service is 99.0. So, what we can do? We can change the shortage cost. So, if the management felt a more appropriate shortage cost was 10 dollars per unit, we have to repeat the whole procedure, then we may get some other Q value, which is more appropriate here. So, this way we can do the sensitivity analysis in simulation.



So, the usefulness of this simulation is we can provide different inventory operating policies. So, simulation allows the user to consider different operating policies that are the value of Q, and changes to model parameters, and then observe the impact of changes on the output measures such as profit or service level.



Earlier, I mentioned that the simulation is not an optimization technique in the beginning of this topic. Even though we use the simulation to choose a replenishment level, it does not guarantee that this choice is optimal. Because for different iterations, you may get different net profit values and the service level. So, we did not check all possible replenishment levels were not tested. Perhaps a manager would like to consider additional simulation runs with the replenishment level of 115 units to 125 units to search for a superior inventory policy.

We also have no guarantee that the replenishment level with the highest profit would be the same for another set of 300 randomly generated demand values. However, with a large number of simulation trials, we should find near-optimal solutions. So, the simulation results are not optimal. But it is the near-optimal solution. Dear students, in this lecture, I have explained how to use simulation to suggest different inventory policies that have different replenishment levels.

We have considered two output measures of the simulation. One is the average net profit and the level of service. At the end of the lecture, I also explained how to do sensitivity analysis for this simulation model. In the next class, I will discuss some other examples of this simulation. Thank you very much.