Decision Making with Spreadsheet
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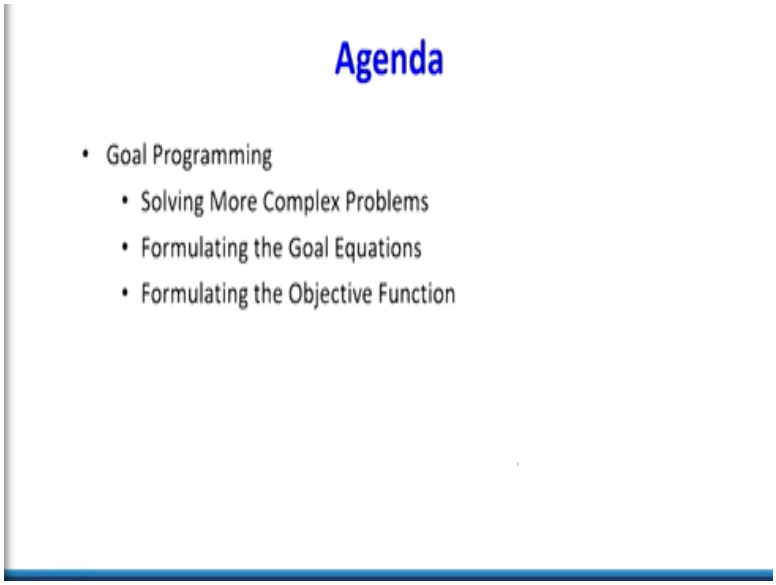
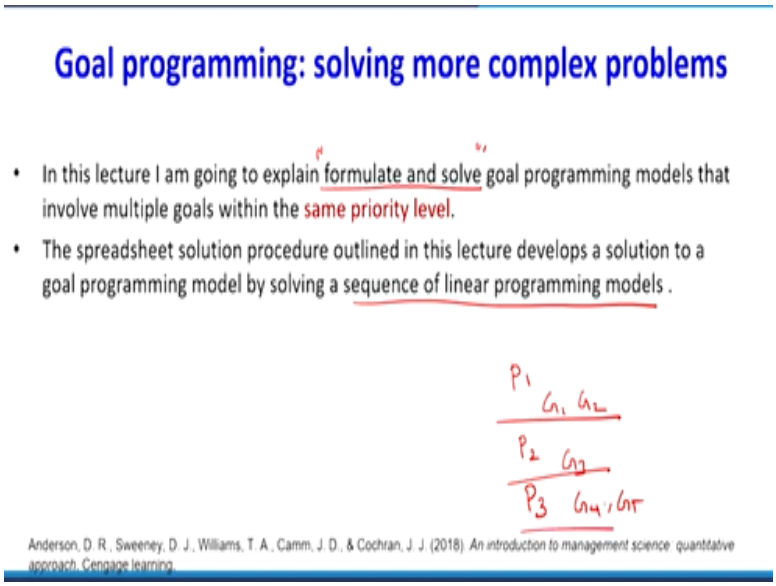
Lecture - 53
Multicriteria Decisions - I

Dear students, in the previous lecture, I discussed solving goal programming using spreadsheets. In this lecture, I am going to discuss a complex problem of goal programming. Here, I will be considering multiple goals with the same priority levels.

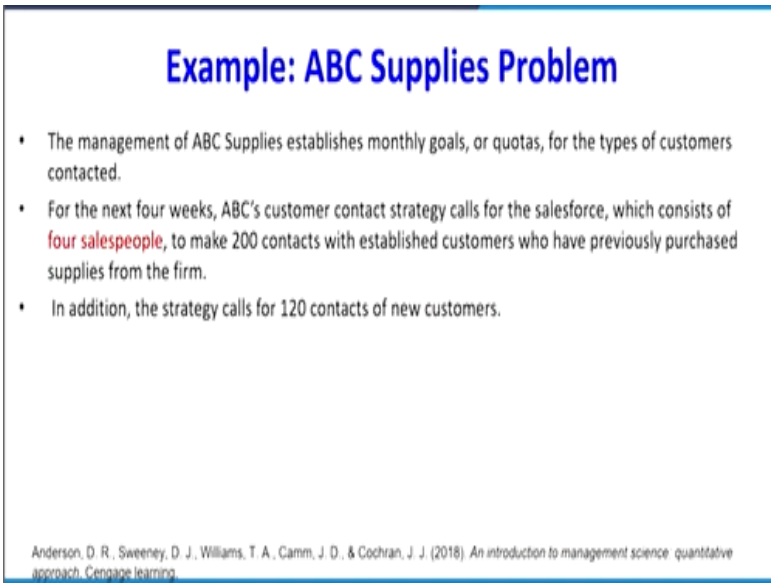


So, the agenda for this lecture is solving more complex problems as usual. We are going to formulate the goal equations, and we are going to formulate the objective functions.



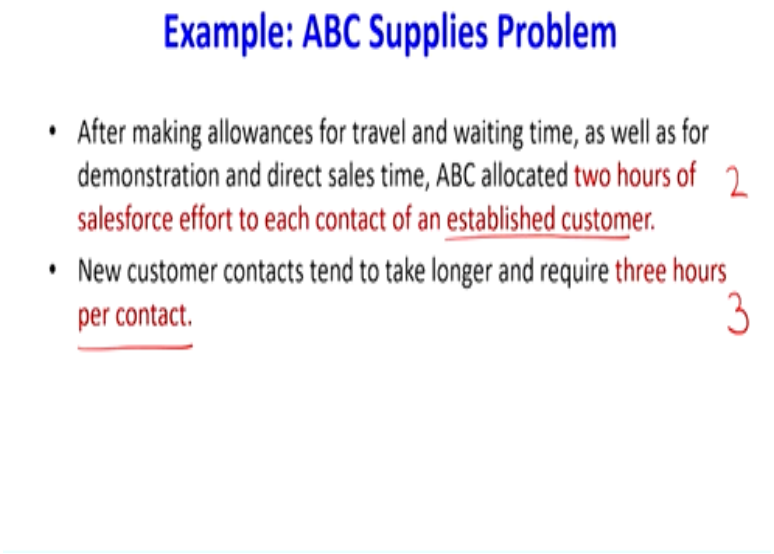
In this lecture, I will explain, formulate, and solve the goal programming models that involve multiple goals with the same priority levels. So, what am I going to do? I will formulate and solve goal programming involving multiple goals with the same priority levels. So, the spreadsheet solution procedures outlined in this lecture develop a solution to a goal programming model by solving a sequence of linear programming models.

So, we are going to solve a sequence of linear programming models. What is the meaning of the same priority level? For example, if we say priority level P1 there may be some goal 1, goal 2. Priority level 2 may be goal 3, priority level 3 may be goal 4, and goal 5. So, what happening? The same priority levels there are different goals. So, this kind of problem we are going to solve in this lecture.

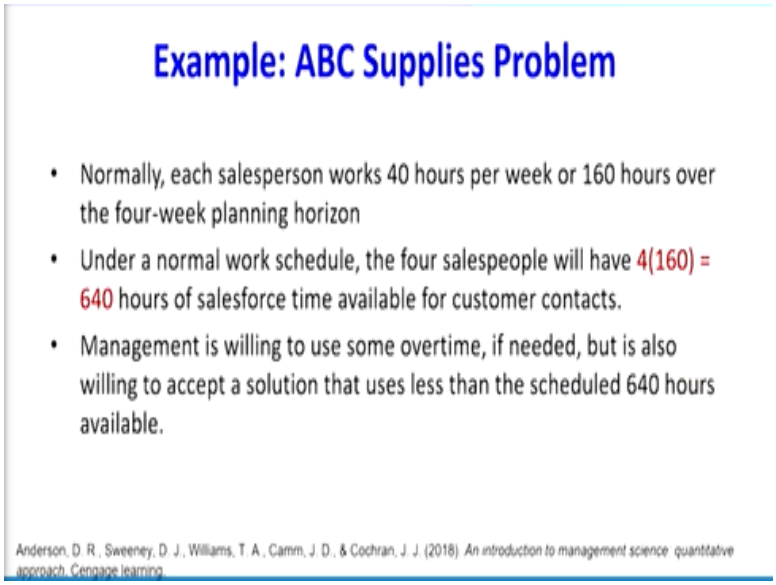


I have taken an example problem. The reference for the book reference for that problem is this Anderson et al. book. The management of ABC supplies establishes monthly goals, or quotas, for the type of customers contacted. A company has a plan to contact some customers. For the next four weeks, the company's contact strategy calls for the sales force, which consists of four salespeople, and make 200 contacts with established customers who have previously purchased supplies from the firm.

In addition, the strategy calls for 120 contacts for new customers. So, the company's target is to call 200 old customers and to contact 120 new customers. They have four salespeople.

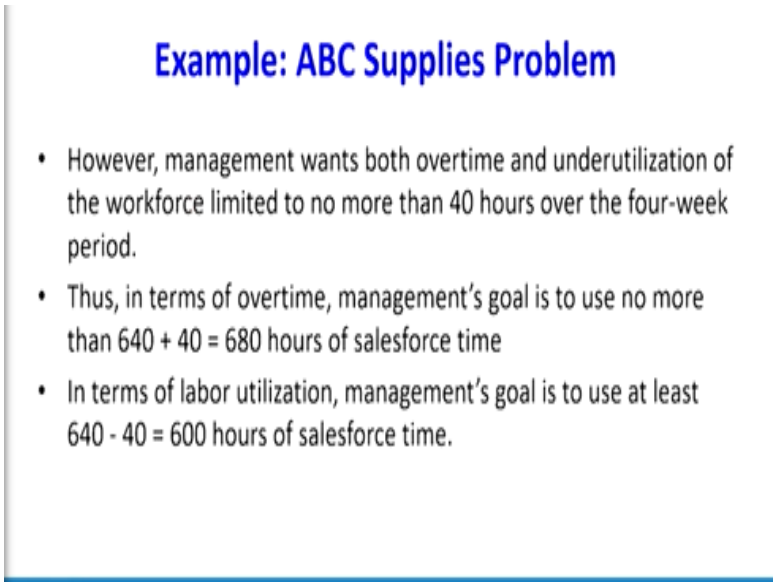


After making allowances for travel and waiting time, as well as for demonstration and direct sales time, the company ABC allocated 2 hours for sales effort to each contact of an established customer. Here, establishment means you may be regular customers' old customers. The time allocated for contacting the established customers is two hours. New customer contact tends to take longer and requires three hours. So, here they are allocating two hours here, allocating three hours for the new customers.



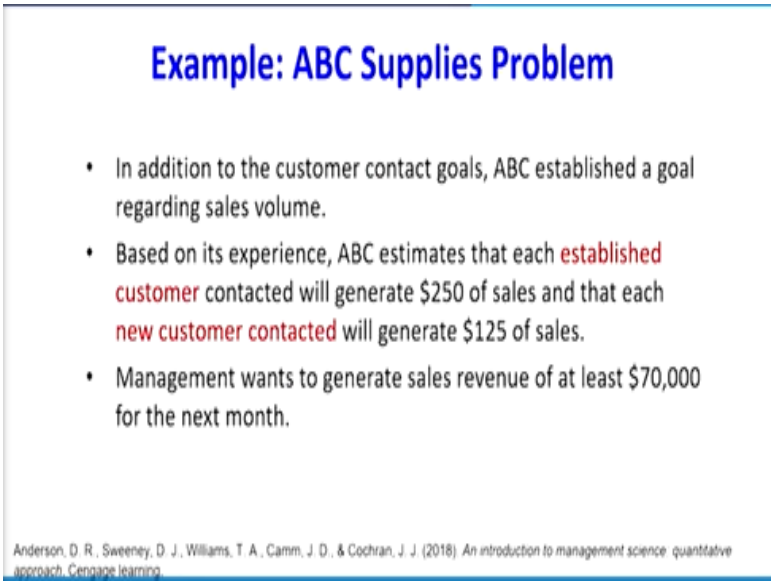
Normally, each salesperson works 40 hours per week, so 160 hours over the 4-week planning horizon. So, 40 multiplied by 4. Under a normal work schedule, 4 salespeople will have because 1 salesperson will have 160 hours. So, they have four salespeople. So, 4 multiplied by 160, they will have 640 hours of sales force time available for customer contacts. So, they are going to contact two types of customers: one is an established customer, and the other is a new customer.

So, management is willing to use some overtime, if needed, but is also willing to accept a solution that uses less than the scheduled 640 hours available. So, they are willing to accept a solution that uses less than the scheduled 640 hours of available, which means they need not work for 640 hours. They may also work less than 640 hours.



However, management wants both overtime and underutilization of the workforce limited to no more than 40 hours over the four-week period. So, they say overutilization and underutilization should be limited to no more than 40 hours. What is the meaning of that? For example, in terms of overtime, the management goal is to use no more than 40 hours. What will happen? So, they already have 640 + 40 = 680, so they can work 680 hours of sales force time.

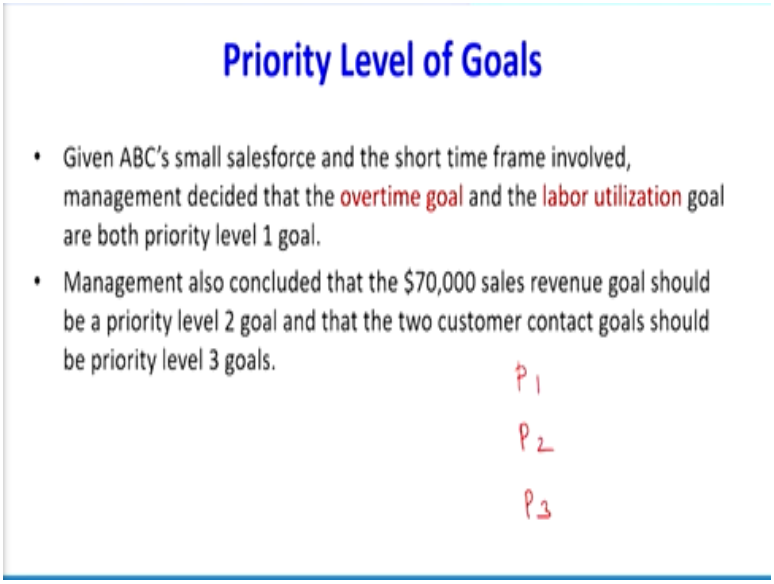
In terms of labor utilization, the management's goal is to use at least because they permit underutilization. So, 640 - 40 they must work at least 600 hours of sales force time.



In addition to customer contact goals, ABC company established a goal regarding sales volume. Based on its experience, ABC estimates that the established customer contracted will generate

250 dollars in sales, and each new customer contracted will generate 125 dollars in sales. The management wants to generate sales revenue of at least 70,000 dollars for the next month; this is also one of the targets.

The first target is to work for 640 hours, but they can work more than 40 hours or less than 40 hours if they accept it. The other goal is that the revenue should be at least 70000 dollars.



Given ABC's small sales force and the short time frame involved, management decided that the overtime goal and the labor utilization goal are both priority level 1. So, the first priority is overtime and labor utilization. Management also concluded that the 70,000-dollar sales revenue goal should be priority level 2, and the two customer contact goals should be priority level three. So, they have three priorities: P1, P2, and P3.

Priority Level of Goals

- Priority Level 1 Goal
  - **Goal 1:** Do not use any more than 680 hours of salesforce time.
  - **Goal 2:** Do not use any less than 600 hours of salesforce time.
- Priority Level 2 Goal
  - **Goal 3:** Generate sales revenue of at least $70,000.
- Priority Level 3 Goals
  - **Goal 4:** Call on at least 200 established customers.
  - **Goal 5:** Call on at least 120 new customers.

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Now, I am going to explain three priority levels and the goals for each priority level. For example, at the priority level 1 there are two goals. One goal is do not use any more than 680 hours of sales force time. Goal 2 is to not use any less than 600 hours of sales force time. This is at a priority level 1; at priority level 2 generates sales revenue of at least 70,000 dollars. In priority level 3, call on at least 200 established customers; in goal 5, call on at least 120 new customers.

This is your period priority level 3, and this is your P2. So, we have this kind of goal programming problem we are going to solve it.

Goal 1: Do not use any more than 680 hours of salesforce time

- Decision variables whose values will be used to determine whether we are able to achieve the goals.

  Let E = the number of established customers contacted

  N = the number of new customers contacted

- Goal 1

$$2E + 3N - d_1^+ + d_1^- = 680$$

- d_1^+ = the amount by which the number of hours used by the salesforce is greater than the target value of 680 hours
- d_1^- = the amount by which the number of hours used by the salesforce is less than the target value of 680 hours

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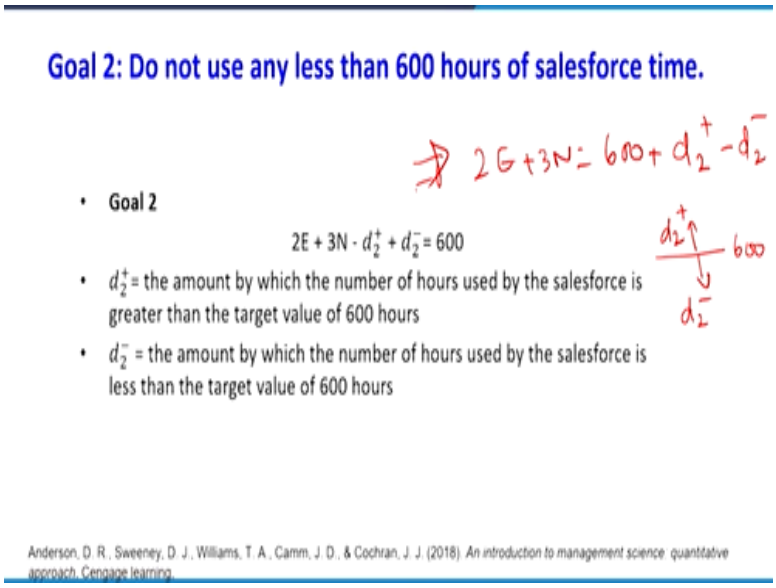
What is the first goal? First, I am going to write how to write the goal equation. What is the goal 1? Goal 1 says do not use any more than 680 hours of sales force time. So, decision variables whose value will be used to determine whether we are able to achieve the goals or not. What are the decision variables we are going to consider? E. E means the established customers contacted; N means the number of new customers contacted.

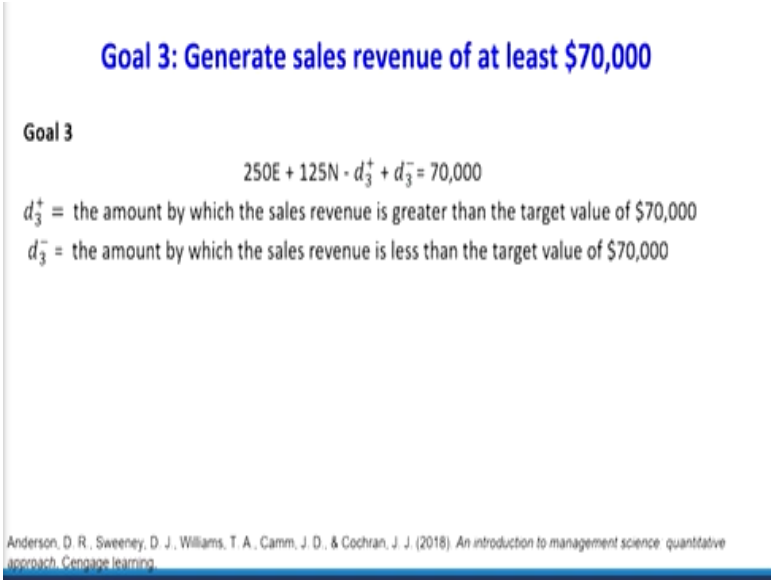
We know that for each established customer, the time required is two hours. So, 2E plus for new customers, the time required is 3 hours, so 3N. So, $2E + 3N = 680 + d_1^+ - d_1^-$ we know how to write the goal equations, which you have discussed in the previous lecture. If I bring my d_1^+ to the left-hand side will become $d_1^+ - d_1^-$. So, d_1^+ is a positive deviation in the amount by which the number of hours used by the sales force is greater than the target value of 680 hours.

d_1^- is the amount by which the number of hours used by the sales force is less than the target value of 680 hours. So, the d_1^+ is a positive deviation, d_1^- is negative deviation.

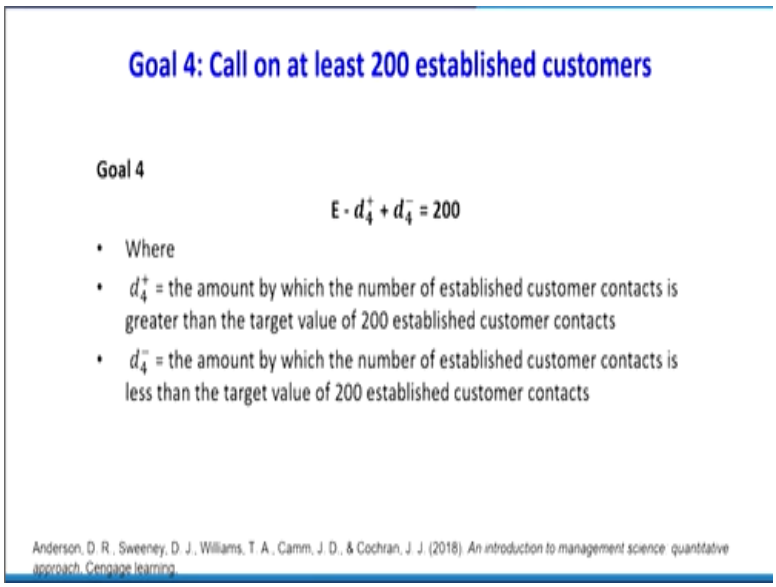


Goal 2: do not use any less than 600 hours of sales force. So, as usual $2E + 3N = 600 + d_2^+ - d_2^-$. So, what will happen? When you bring it to the left-hand side, it will become $-d_2^+ + d_2^-$. So, what is the meaning in another way? For example, say this is 600, so the upper side is d_2^+ positive deviation. See the lower side is d_2^-. So, another intuitive way is that the positive deviation has to be minimized.

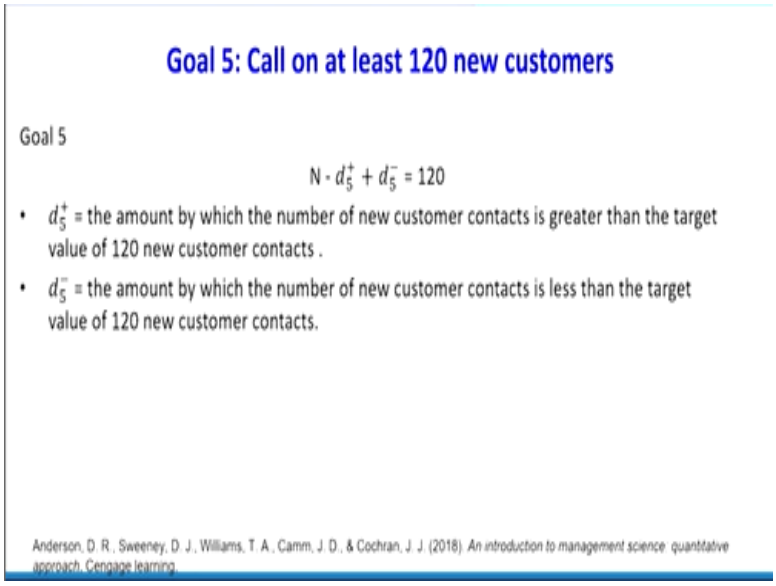
So, that will become 600, and the negative deviation has to be improved so that it will become 600. That is a logic. So, which deviation is more important? We will decide later, but to say why we are writing minus the positive deviation has to be decreased, and the negative deviation has to be improved. So, it will be labeled 600. Otherwise, in this equation, you can see $d_2^+ - d_2^-$ when you bring the left-hand side, it will become $-d_2^+ + d_2^-$.



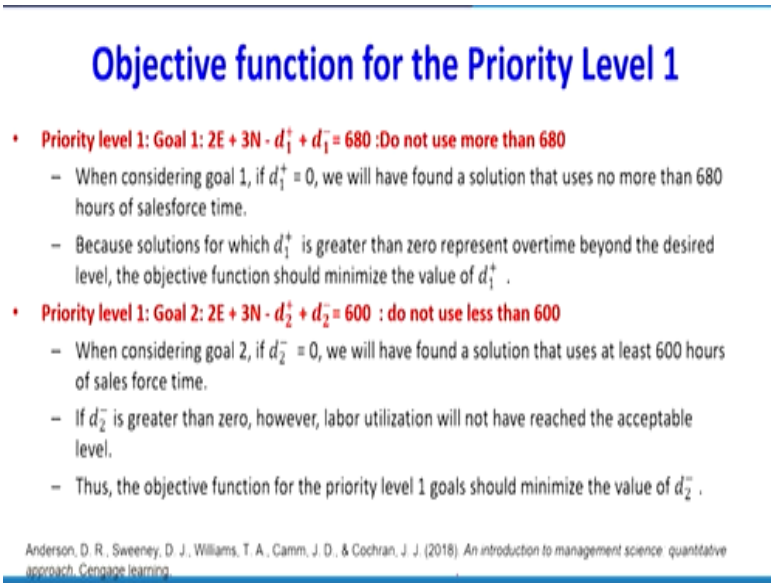
Now we will go to the goal 3. What is the goal 3? Generate sales revenue of at least 70,000 dollars. We know that through one established customer, the revenue is 250 dollars. For one new customer, the revenue is 125 dollars. So, equal to 70 000 + $d_3^+ - d_3^-$. When you bring it, the left-hand side will become - $d_3^+ + d_3^-$. Here, d_3^+ is the amount by which the sales revenue is greater than the target value of 70,000 dollars, and d_3^- is the amount by which the sales revenue is less than the target value of 70,000 dollars.



Now we will go to the goal 4. What is that goal 4? Call on at least 200 established customers. So, $E - d_4^+ + d_4^- = 200$, d_4^+ represents a positive deviation, and d_4^- represents a negative deviation.



Then, in goal 5, call on at least 120 new customers. So, as usual $N - d_5^+ + d_5^- = 120$.

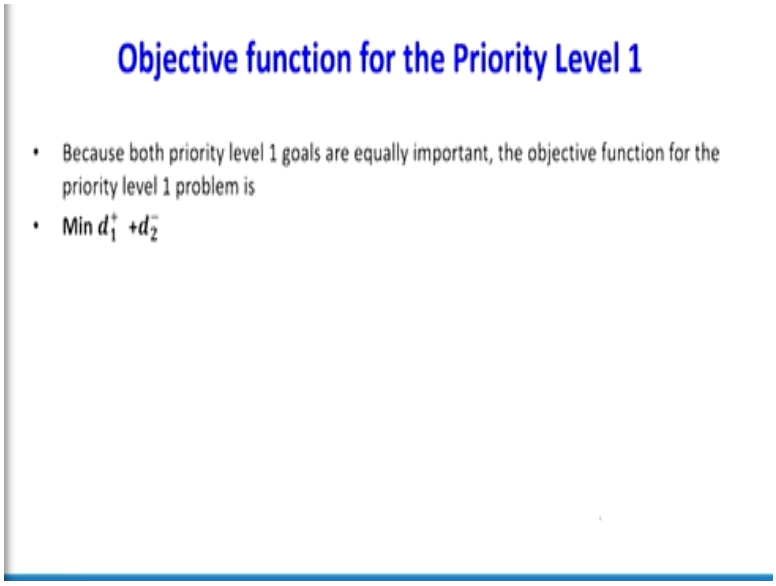


Now, I am going to discuss the objective function for priority level 1. In priority level 1, we have two goals; the first goal is not to use more than 680 hours. When considering goal 1, d_1^+ is a positive deviation. What is the meaning of that? We will have found a solution that uses no more than 680 hours of sales force time. When d_1^+ is 0, we will achieve exactly 680 because solutions for d1 places greater than 0 represent over time beyond the desired level.

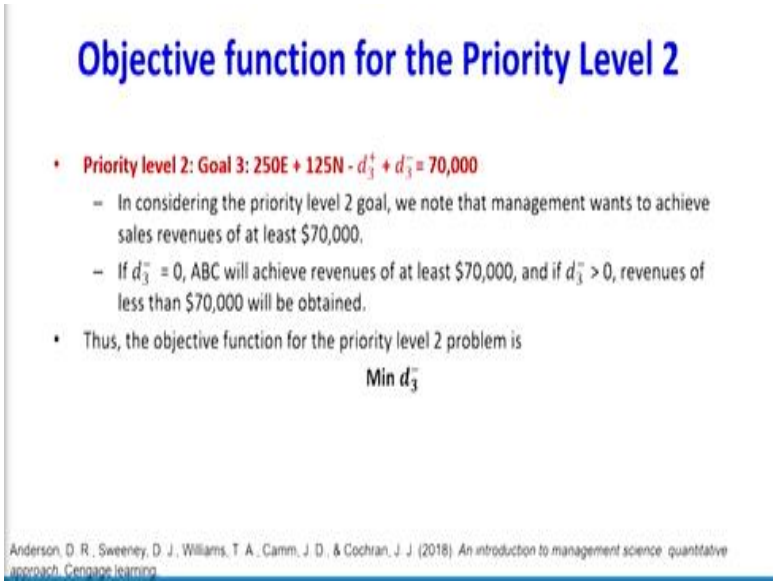
So, the objective function should minimize the value of d_1^+. Why do we have to minimize this d_1^+? Out of d_1^+ and d_1^- which is not desirable. The positive deviation is not desirable because that objective says that do not use more than. So, positive deviation has to be minimized. So, we are going to minimize d_1^+, and we will go to another goal. What is another goal? Do not use less than 600.

So, by looking at the objective of goal 2 itself, it says that the negative deviation has to be minimized. When considering goal 2, if $d_2^- = 0$, we will have found a solution that uses at least 600 hours of sales force time. In case d_2^- is greater than 0, what will happen? The labor utilization will not have reached an acceptable level. Thus, the objective function for the priority level 1 goal should minimize the value of d_2^-.

Because it says not to use less than 600 hours. So, the negative deviation has to be minimized. That is why we wrote d_2^-.



Because both priority level 1 goals are equally important, the objective function for the priority level 1 problem is to minimize $d_1^+ + d_2^-$.



Now we will write the objective function for priority level 2. What does the priority level say? The revenue should be at least 70,000 dollars. So, d_3^+ represents a positive deviation, and d_3^- represents a negative deviation. Which is desirable? If it is a positive deviation, that is acceptable, That means if the revenue is more than 70,000 dollars, it is acceptable. But if the revenue is less than 70,000, that is, if you get some value for d_3^- that is not desirable. So, we have to minimize our negative deviation. That is why we are writing a minimum d_3^-.

Objective function for the Priority Level 3

- **Priority level 3: Goal 4: E - $d_4^+ + d_4^- = 200$:** At least 200 established customers
  - When considering goal 4, if $d_4^- = 0$, we will have found a solution with at least 200 established customer contacts;
  - however, if $d_4^- > 0$, we will have underachieved the goal of contacting at least 200 established customers.
  - Thus, for goal 4 the objective is to minimize d_4^- .

Priority level 3: Goal 5: N - $d_5^+ + d_5^- = 120$: at least 120 new customers

- When considering goal 5, if $d_5^- = 0$, we will have found a solution with at least 120 new customer contacts;
- However, if $d_5^- > 0$, we will have underachieved the goal of contacting at least 120 new customers.
- Thus, for goal 5 the objective is to minimize d_5^- .

Now, we are going to write the objective function for priority level 3. In priority level 3, there are two goals: goal 4 and goal 5. What is the goal 4? At least 200 established customers has to be contacted. In this function, E – $d_4^+ + d_4^-$ when considering goal 4, if $d_4^- = 0$, we will have found a solution with at least 200 established customers. However, if d_4^- is the positive value, we will have underachieved the goal, which means we are not able to contact 200 customers.

So, we have to minimize our underachievement so d_4^-. Come to goal 5, there are over-achievement and under-achievement. So, at least 120 customers, if you overachieve, there is no problem. So, d_5^+ there is no problem, but when you go for underachievement, that is d_5^- that is not desirable, so we have to minimize our d_5^-.

Objective function for the Priority Level 3

- If goals 4 and 5 are equal in importance, the objective function for the priority level 3 problem would be

$$\text{Min } d_4^- + d_5^-$$

- However, suppose that management believes that generating new customers is vital to the long-run success of the firm and that goal 5 should be weighted more than goal 4.
- If management believes that goal 5 is twice as important as goal 4, the objective function for the priority level 3 problem would be

$$\text{Min } d_4^- + 2d_5^-$$

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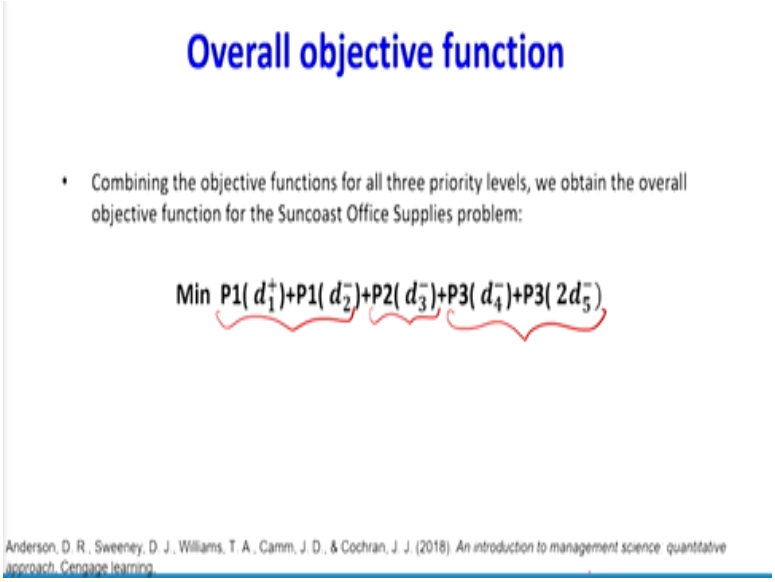
So, for priority level 3, the objective function is to minimize $d_4^- + d_5^-$. However, suppose the management believes that generating new customers is vital to the long-run success of the firm, and that goal 5 should be weighted more than goal 4. So, we are giving more importance to the new customers. If management believes that goal 5 is twice as important as goal as four the objective function for the priority level 3 problem would be $d_4^- + d_5^-$. Because 2 is the higher weightage for the new customers we have to multiply by 2.



Now what is the overall objective function? Combining the objective functions for all three-priority levels, we obtain the overall objective function:

- $\text{Min } P1(d_1^+) + P1(d_2^-) + P2(d_3^-) + P3(d_4^-) + P3(2d_5^-)$,

So, this is our level 1, this is our level 2, this is our level 3. We know that the P1 is not the multiplication factor. It is to show this is the priority level 1. In priority level 1, there are two goals; in priority level 2, there is one goal; in priority level 3, there are two goals.

Complete Goal programming model

- Min $P1(d_1^-)+P1(d_2^-)+P2(d_3^-)+P3(d_4^-)+P3(2d_5^-)$
- s.t.

$$2E + 3N - d_1^+ + d_1^- = 680 \quad Goal1$$
$$2E + 3N - d_2^+ + d_2^- = 600 \quad Goal2$$
$$250E + 125N - d_3^+ + d_3^- = 70{,}000 \quad Goal3$$
$$E - d_4^+ + d_4^- = 200 \quad Goal4$$
$$N - d_5^+ + d_5^- = 120 \quad Goal5$$
$$E,N,d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^-, d_4^+, d_4^-, d_5^+, d_5^- \geq 0$$

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Now, I have brought the complete goal programming model goal. Objective function goal 1, goal 2, goal 3, goal 4, goal 5. So, we are having 5 constraints.

Computer Solution

- The following computer procedure develops a solution to a goal programming model by solving a sequence of linear programming problems.
- The first problem comprises all the constraints and all the goal equations for the complete goal programming model
- However, the objective function for this problem involves only the P1 priority level goals.

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Now, we are going to solve this goal programming problem with the help of a spreadsheet. The following procedure develops a solution to a goal programming model by solving a sequence of linear programming problems. The first problem comprises all the constraints and the goal equations for a complete goal programming model. However, the objective function for this problem involves only P1 priority-level goals.

Computer Solution

- Again, we refer to this problem as the P1 problem.
- Whatever the solution to the P1 problem, a P2 problem is formed by adding a constraint to the P1 model that ensures that subsequent problems will not degrade the solution obtained for the P1 problem.
- The objective function for the priority level 2 problem takes into consideration only the P2 goals.
- We continue the process until we have considered all priority levels.

Again, we refer to the problem as the P1 problem. Whatever the; solution to the P1 problem, a P2 problem is formed by adding a constraint. See that we are adding a constraint to the P1 model. At the time of solving P2, we have to add a constraint for P1 that ensures that the subsequent problem will not degrade the solution obtained by the solution obtained for the P1 problem, which is the meaning of preemptive.

So, the objective function for the priority level 2 problem takes into consideration only P2 goals. But you have to add the constraint of P1. We will continue the process until we have considered all priority levels.

Computer Solution: P1

Min $d_1^+ + d_2^-$

s.t.

$$2E + 3N - d_1^+ + d_1^- = 680 \quad \text{Goal1}$$

$$2E + 3N - d_2^+ + d_2^- = 600 \quad \text{Goal2}$$

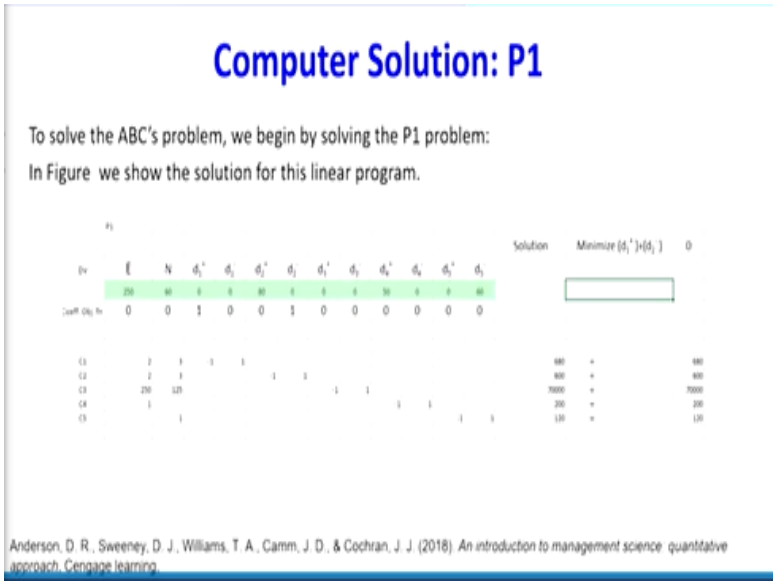
$$250E + 125N - d_3^+ + d_3^- = 70{,}000 \quad \text{Goal3}$$

$$E - d_4^+ + d_4^- = 200 \quad \text{Goal4}$$

$$N - d_5^+ + d_5^- = 120 \quad \text{Goal5}$$

$$E, N, d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^-, d_4^+, d_4^-, d_5^+, d_5^- \geq 0$$

Now, we are going to solve three linear programming models for each priority. Because we have P1, P2, and P3, I first took P1. You see, I have taken only the P1 objective function, but I have considered all the constraints.



So, we are going to solve this problem with the help of Excel.

So, now I am going to open Excel you see, I have written P1. I have written decision variables E, N, d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^-, d_4^+, d_4^-, d_5^+, d_5^-. The cells that are green in color are the changing cells. Then, I wrote one coefficient of the objective function. We only have two coefficients in priority level one: d_1^+ and d_1^+. So, I have written one and another here, and then I have written all the constraints.

So, as usual, I have written the resources utilized, and the equations all are equation types of the right-hand side constraint I have written. Now, if I go to the solver, click on the solver. You see, I have chosen the target cell, I have written the changing cell, and I have written the constraint. When I solve it, the value for E is 250, N is 60, and I look at the value of the objective function. The value of the objective function is minimization; it is 0. So, we have achieved the optimal solutions.

Now, I will go back to the presentation. So, I have attached a screenshot of my Excel solution. So, what we have done? We solved the P1 problem; this was the final solution.

Computer Solution: P1

- The solution shows E = 250 established customer contacts and N = 60 new customer contacts. Because $d_1^+ = 0$ and $d_2^- = 0$, we see that the solution achieves both goals 1 and 2.
- Alternatively, the value of the objective function is 0, confirming that both priority level 1 goals have been achieved.

Now I am going to interpret the output. The output shows we have to contact 250 established customers and 60 new customers. You see that $d_1^+ = 0$ and $d_1^+ = 0$. So, we see that the solution achieves both goals 1 and 2 because the positive deviation value also becomes 0, and the negative deviation value also becomes 0. Alternatively, the value of the objective function is 0, confirming that both priority level 1 goals have been achieved. So, we have achieved goal 1 and goal 2 in priority level 1.

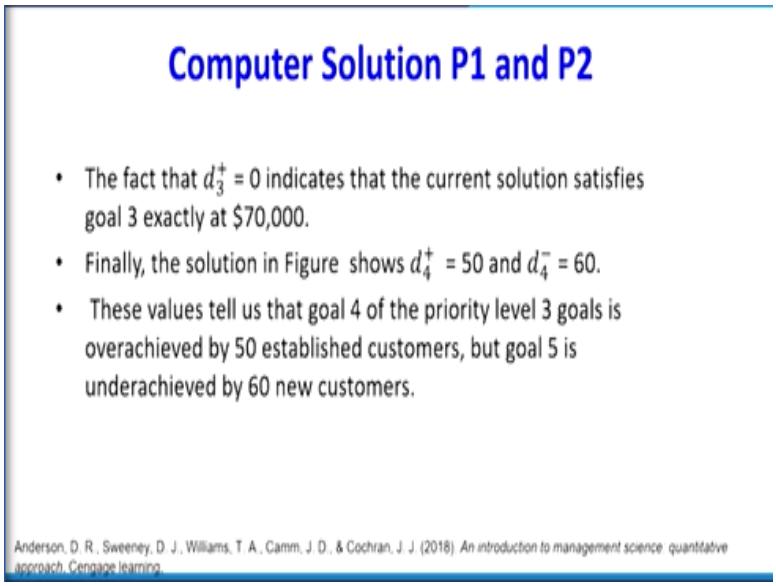
Computer Solution: P2

- Next, we consider goal 3, the priority level 2 goal, which is to minimize d_3^-. The solution in Figure shows that $d_3^- = 0$.
- Thus, the solution of E = 250 established customer contacts and N = 60 new customer contacts also achieves goal 3, the priority level 2 goal, which is to generate a sales revenue of at least $70,000.

Now, we are going to solve another set of linear programming models for level 2, which is a P2. We consider goal 3 the priority level 2 to minimize d_3^-. The solution in the figure shows here in the problem itself. When we solve in the P1, we get $d_3^- = 0$. So, we do not need to solve P2

separately because we already have the solution for P2. How? The value of d_3^- is 0. So, the solution for E = 250 is to establish the customer contacts.

And N = 60 new customer contacts also achieve goal 3, the priority level 2 goal, which is to generate a sales revenue of 7000. So, we need not solve for P2 because when we solve P1, we get the result for P2.



The fact that $d_3^+ = 0$ indicates that the current solution satisfies gold three exactly at 70,000 dollars. Finally, the solutions in the figure show $d_4^+ = 50$ and $d_4^- = 60$. See this. I will go back to this value. So, what is the meaning of this d_4^+? That means we are over-achieving goal 4, and we are under-achieving 60. These values tell us that goal 4 of the priority level 3 goal is overachieved by 50 established customers.

So, we have achieved more than what is required. However, goal 5 is underachieving by 60 new customers.

Computer Solution P3

- Min $(d_4^-)+(2d_5^-)$
- s.t.

$$2E + 3N - d_1^+ + d_1^- = 680 \quad \text{Goal1}$$
$$2E + 3N - d_2^+ + d_2^- = 600 \quad \text{Goal2}$$
$$250E + 125N - d_3^+ + d_3^- = 70{,}000 \quad \text{Goal3}$$
$$E - d_4^+ + d_4^- = 200 \quad \text{Goal4}$$
$$N - d_5^+ + d_5^- = 120 \quad \text{Goal5}$$
$$d_1^+ + d_2^- = 0$$
$$d_3^- = 0$$
$$E, N, d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^-, d_4^+, d_4^-, d_5^+, d_5^- \geq 0$$

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.

Now we have solved for P1 and P2. Now, we are going to solve by P3. What is the P3 priority level? What is the objective function d_4^-? See that we have written two because contacting new customers is two times more important than contacting old customers. Another important thing you have to note is that we have written the P1 objective function and the P2 objective function here.

So, the value of the P1 objective function is 0, and the P2 objective function is also 0. So, these two new constraints has to be added at the time of solving your P3.

Computer Solution P3

- The original five constraints of the P1 problem appear in the P3 problem.
- However, two additional constraints must be added to ensure that the solution to the P3 problem continues to satisfy the priority level 1 and priority level 2 goals.
- Thus, we add the priority level 1 constraint $d_1^+ + d_2^- = 0$ and the priority level 2 constraint $d_3^- = 0$
- Making these modifications to the P1 problem, we obtain the solution to the P3 problem shown in Figure .

Min $(d_4^-)+(2d_5^-)$

s.t.

$$2E + 3N - d_1^+ + d_1^- = 680 \quad \text{Goal1}$$
$$2E + 3N - d_2^+ + d_2^- = 600 \quad \text{Goal2}$$
$$250E + 125N - d_3^+ + d_3^- = 70{,}000 \quad \text{Goal3}$$
$$E - d_4^+ + d_4^- = 200 \quad \text{Goal4}$$
$$N - d_5^+ + d_5^- = 120 \quad \text{Goal5}$$
$$d_1^+ + d_2^- = 0$$
$$d_3^- = 0$$
$$E, N, d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^-, d_4^+, d_4^-, d_5^+, d_5^- \geq 0$$

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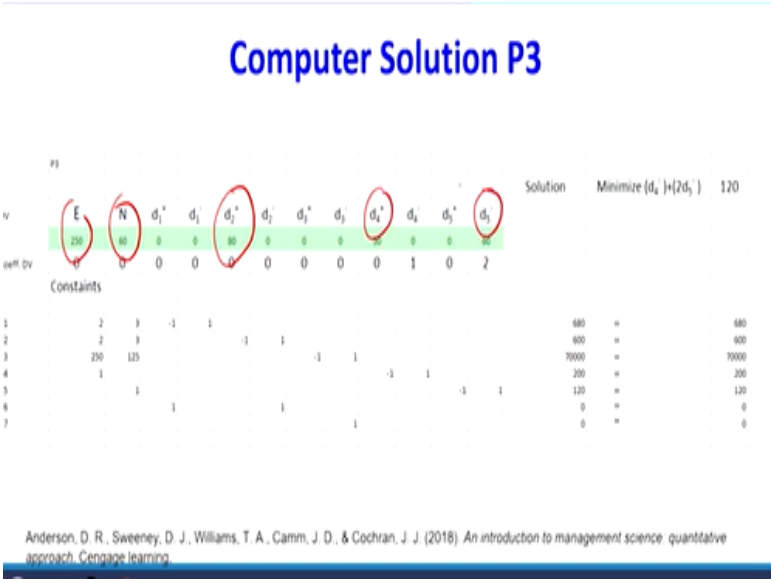
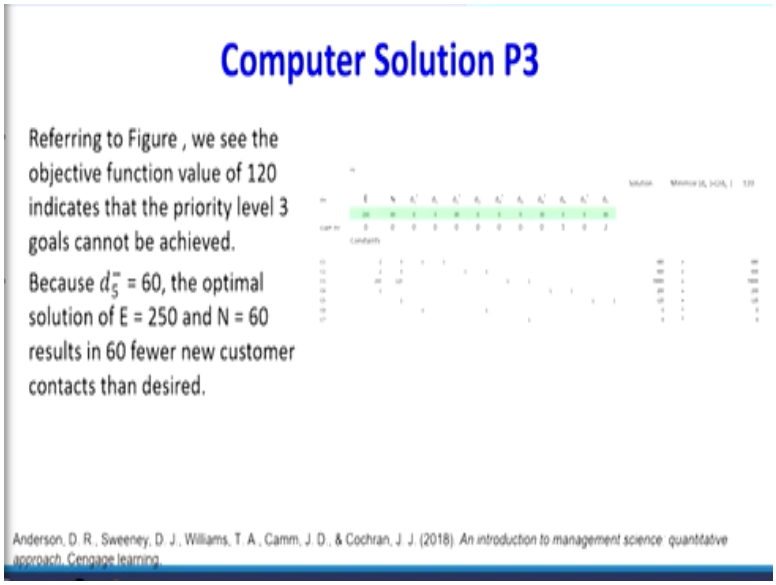
The original five constraints of the P1 problem appear in the P3. However, two additional constraints must be added to ensure that the solution to the P3 problem continues to satisfy P1 and P2 goals. So, we add the priority level 1 constraint d_1^+ and d_2^- = 0 and the priority level 2 constraint d_3^- = 0. By making these modifications to the P1 problem, we obtain the solution to the P3 problem, as shown in the figure. So, now I will go back to Excel. I will be solving the P3. You see this P3 is that initially, there are five constraints, but in P3, I have added 2 more constraints. See C6 and C7, so there are seven constraints. When I solve that, I go to the solver, go to the solver as usual. I have added the target cell minimization problem, changing cells, and the constraint. So, when I solve it, the value of my objective function is 120, and I will interpret the meaning of this 120; actually, we have to have 0.

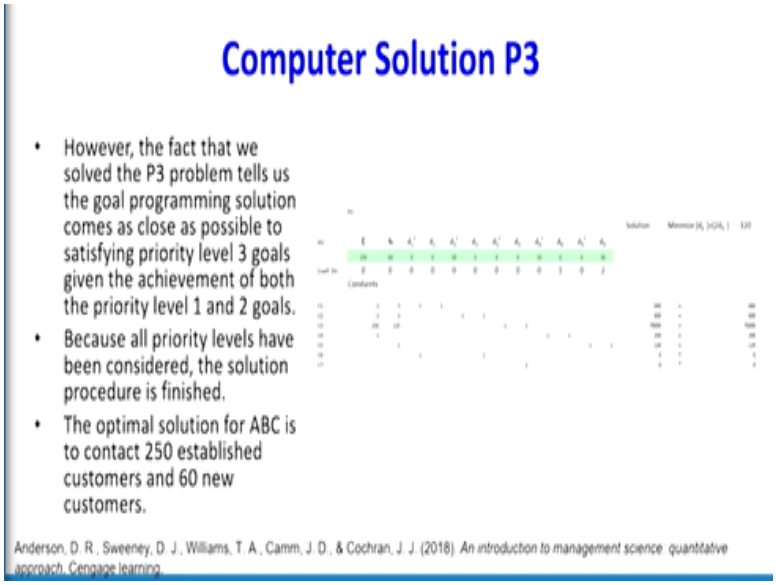
But we are not able to achieve 1 to 0. We have got 120, I will interpret. I will go back to my presentation.



See that this is the result of my objective function. Now, I am going to interpret the solution for the P3 level. Look at the solver output here. The objective function value is 120, but we have to minimize it, which means it has to be 0. We are not able to achieve zero and for other things. We got the value for E= 250 N= 60 and see that we have some positive values for d_2^+, d_4^+, and d_5^-. So, what is the meaning of this one?

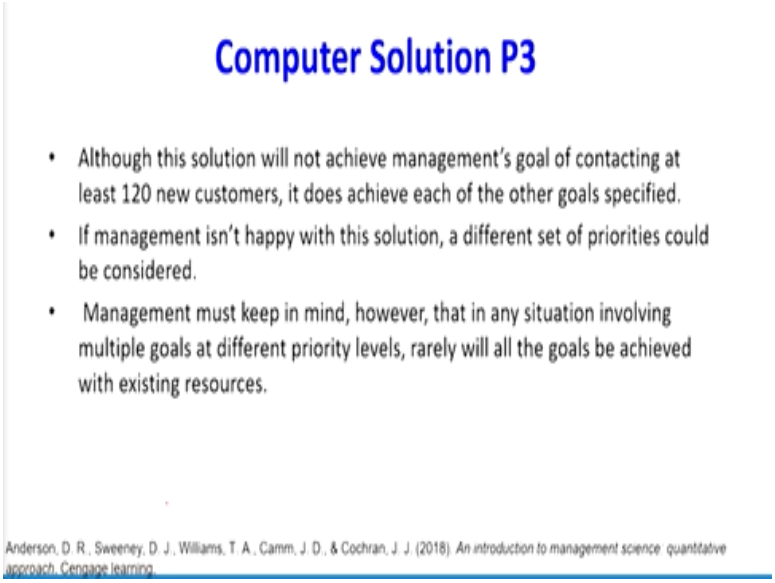


So, referring to the figure, we see that the objective function value of 120 indicates that the priority level of three goals cannot be achieved. Because we got the value of d_5^- = 60, it has to be 0. So, the optimal solution of E = 250, N = 60 results in 60 fewer new customer contacts than desired. So, we have to contact 120 new customers, but we are only able to get 60 customers. So, underachievement is how much? 60. So, that underachievement is nothing but your d_5^-.



However, the fact that we solved the P3 problem tells us the goal programming solution comes as close as possible to satisfying priority level 3 goals given the achievement of both priority levels 1 and 2. So, P3 may not be a perfect solution, but it is very close to our expected solution, but we have already achieved P1 and P2. Because all priority levels have been considered the solution procedure is finished.

So, the final conclusion is that the optimal solution for this company is to contact 250 established customers and 60 new customers. So that they can achieve P1, P2, and P3 level goals. How many goals? There are five goals: goals 1, 2, 3, 4, and 5.



Although this solution will not achieve management's goal of contacting at least 120 new customers, it does achieve the other goals. If management is not happy with this solution a different set of priorities could be considered. So, management must keep in mind, however, that in any situation involving multiple goals at different priority levels, rarely will all the goals be achieved with existing resources.

So, it is difficult to achieve all the goals at a time, but we can achieve the goals as much as possible. Dear students, in this lecture, I have explained how to solve a complex goal programming problem where there are multiple goals in the same priority level. In the next lecture, I will discuss the analytic hierarchical process, which is another type of multi-criteria decision-making technique. Thank you.