SUPPLEMENT TO CHAPTER 16

Preemptive Goal Programming and Its Solution Procedures

Section 16.7 describes how goal programming is one important method for multiple criteria decision analysis when the objective is to strive toward multiple goals simultaneously. It also presents a prototype example to illustrate this approach. The discussion in Section 16.7 focuses on nonpreemptive programming, where the goals are of roughly comparable importance.

Now consider the case of **preemptive goal programming,** where there is a hierarchy of priority levels for the goals. Such a case arises when one or more of the goals clearly are far more important than the others. Thus, the initial focus should be on achieving as closely as possible these *first-priority* goals. The other goals also might naturally divide further into second-priority goals, third-priority goals, and so on. After we find an optimal solution with respect to the first-priority goals, we can break any ties for the optimal solution by considering the second-priority goals. Any ties that remain after this re-optimization can be broken by considering the third-priority goals, and so on.

When we deal with goals on the *same* priority level, our approach is just like the one described for nonpreemptive goal programming. Any of the same three types of goals (lower one-sided, two-sided, upper one-sided) can arise. Different penalty weights for deviations from different goals still can be included, if desired. The same formulation technique of introducing auxiliary variables again is used to reformulate this portion of the problem to fit the linear programming format.

There are two basic methods based on linear programming for solving preemptive goal programming problems. One is called the *sequential procedure,* and the other is the *streamlined procedure.* We shall illustrate these procedures in turn by solving the following example, which is a revision of the prototype example for nonpreemptive goal programming that is presented in Sec. 16.8.

Example. Faced with the unpleasant recommendation to increase the company's workforce by more than 20 percent, the management of the Dewright Company has reconsidered the original formulation of the problem that was summarized in Table 16.8 in Sec. 16.8. This increase in workforce probably would be a rather temporary one, so the very high cost of training 833 new employees would be largely wasted, and the large (undoubtedly well-publicized) layoffs would make it more difficult for the company to attract high-quality employees in the future. Consequently, management has concluded that a very high priority should be placed on avoiding an increase in the workforce. Furthermore, management has learned that raising *more than* \$55 million for capital investment for the new products would be extremely difficult, so a very high priority also should be placed on avoiding capital investment above this level.

Based on these considerations, management has concluded that a *preemptive goal programming* approach now should be used, where the two goals just discussed should be the first-priority goals, and the other two original goals (exceeding \$125 million in long-run profit and avoiding a decrease in the employment level) should be the second- weights still should be the same as those given in the rightmost column of Table 16.8. This reformulation is summarized in Table 1, where a factor of M (representing a huge positive number) has been included in the penalty weights for the first-priority goals to emphasize that these goals preempt the second-priority goals. (The portions of Table 16.8 that are not included in Table 1 are *unchanged.*)

The Sequential Procedure for Preemptive Goal Programming

The *sequential procedure* solves a preemptive goal programming problem by solving a *sequence* of linear programming models.

At the first stage of the sequential procedure, the only goals included in the linear programming model are the first-priority goals, and the simplex method is applied in the usual way. If the resulting optimal solution is *unique,* we adopt it immediately without considering any additional goals.

However, if there are *multiple* optimal solutions with the same optimal value of Z (call it Z^*), we prepare to break the tie among these solutions by moving to the second stage and adding the second-priority goals to the model. If $Z^* = 0$, all the auxiliary variables representing the *deviations from first-priority goals* must equal zero (full achievement of these goals) for the solutions remaining under consideration. Thus, in this case, all these auxiliary variables now can be completely deleted from the model, where the equality constraints that contain these variables are replaced by the mathematical expressions (inequalities or equations) for these first-priority goals, to ensure that they continue to be fully achieved. On the other hand, if $Z^* > 0$, the second-stage model simply adds the second-priority goals to the first-stage model (as if these additional goals actually were first-priority goals), but then it also adds the constraint that the *first-stage objective function* equals Z^* (which enables us again to delete the terms involving first-priority goals from the second-stage objective function). After we apply the simplex method again, if there still are multiple optimal solutions, we repeat the same process for any lower-priority goals.

Example. We now illustrate this procedure by applying it to the example summarized in Table 1.

At the first stage, only the two *first-priority* goals are included in the linear programming model. Therefore, we can drop the common factor M for their penalty weights, shown in Table 1. By proceeding just as for the nonpreemptive model if these were the only goals, the resulting linear programming model is

$$\text{Minimize} \qquad Z = 2y_2^+ + 3y_3^+,$$

subject to

$$5x_1 + 3x_2 + 4x_3 - (y_2^+ - y_2^-) = 40$$
$$5x_1 + 7x_2 + 8x_3 - (y_3^+ - y_3^-) = 55$$

TABLE 1 Revised formulation for the Dewright Co. preemptive goal programming problem

Priority Level	Factor	Goal	Penalty Weight
First priority	Employment level Capital investment	≤40 ≤55	2*M* 3*M*
Second priority	Long-run profit Employment level	≥125 ≥40	5 4

and

$$x_j \geq 0, \qquad y_k^+ \geq 0, \qquad y_k^- \geq 0 \qquad (j = 1, 2, 3;\ k = 2, 3).$$

(For ease of comparison with the nonpreemptive model with all four goals in Sec. 16.8, we have kept the same subscripts on the auxiliary variables.)

By using the simplex method (or inspection), an optimal solution for this linear programming model has $y_2^+ = 0$ and $y_3^+ = 0$, with $Z = 0$ (so $Z^* = 0$), because there are innumerable solutions for (x_1, x_2, x_3) that satisfy the relationships

$$5x_1 + 3x_2 + 4x_3 \leq 40$$
$$5x_1 + 7x_2 + 8x_3 \leq 55$$

as well as the nonnegativity constraints. Therefore, these two first-priority goals should be used as *constraints* hereafter. Using them as constraints will force y_2^+ and y_3^+ to remain zero and thereby disappear from the model automatically.

If we drop y_2^+ and y_3^+ but add the second-priority goals, the second-stage linear programming model becomes

$$\text{Minimize} \qquad Z = 5y_1^- + 4y_2^-,$$

subject to

$$\begin{aligned} 12x_1 + 9x_2 + 15x_3 - (y_1^+ - y_1^-) \qquad\qquad &= 125 \\ 5x_1 + 3x_2 + 4x_3 \qquad + y_2^- \qquad &= 40 \\ 5x_1 + 7x_2 + 8x_3 \qquad\qquad + y_3^- &= 55 \end{aligned}$$

and

$$x_j \geq 0, \qquad y_1^+ \geq 0, \qquad y_k^- \geq 0 \qquad (j = 1, 2, 3;\ k = 1, 2, 3).$$

Applying the simplex method to this model yields the unique optimal solution $x_1 = 5$, $x_2 = 0$, $x_3 = 3\frac{3}{4}$, $y_1^+ = 0$, $y_1^- = 8\frac{3}{4}$, $y_2^- = 0$, and $y_2^- = 0$, with $Z = 43\frac{3}{4}$.

Because this solution is unique (*or* because there are no more priority levels), the procedure can now stop, with $(x_1, x_2, x_3) = (5, 0, 3\frac{3}{4})$ as the optimal solution for the *overall* problem. This solution fully achieves both first-priority goals as well as one of the second-priority goals (no decrease in employment level), and it falls short of the other second-priority goal (long-run profit ≥ 125) by just $8\frac{3}{4}$.

The Streamlined Procedure for Preemptive Goal Programming

Instead of solving a sequence of linear programming models, like the sequential procedure, the *streamlined procedure* finds an optimal solution for a preemptive goal programming problem by solving just *one* linear programming model. Thus, the streamlined procedure is able to duplicate the work of the sequential procedure with just *one run* of the simplex method. This one run *simultaneously* finds optimal solutions based just on first-priority goals and breaks ties among these solutions by considering lower-priority goals. However, this does require a slight modification of the simplex method.

If there are just *two* priority levels, the modification of the simplex method is one you already have seen, namely, the form of the *Big M method* illustrated throughout Sec. 4.7. In this form, instead of replacing M throughout the model by some huge positive number before running the simplex method, we retain the *symbolic* quantity M in the sequence of simplex tableaux. Each coefficient in row 0 (for each iteration) is some linear function $aM + b$, where a is the current *multiplicative factor* and b is the current *additive term.* The usual decisions based on these coefficients (entering basic variable and optimality test) now are based solely on the *multiplicative* factors, except that any ties would be broken by using the *additive* terms. This is how the IOR Tutorial operates when solving interactively by the simplex method (and choosing the Big M method).

The linear programming formulation for the streamlined procedure with two priority levels would include *all* the goals in the model in the usual manner, but with basic penalty weights of M and 1 assigned to deviations from first-priority and second-priority goals, respectively. If different penalty weights are desired within the same priority level, these basic penalty weights then are multiplied by the individual penalty weights assigned within the level. This approach is illustrated by the following example.

Example. For the Dewright Co. preemptive goal programming problem summarized in Table 1, note that (1) different penalty weights are assigned within each of the two priority levels and (2) the individual penalty weights (2 and 3) for the first-priority goals have been multiplied by M. These penalty weights yield the following single linear programming model that incorporates all the goals.

$$\text{Minimize} \quad Z = 5y_1^- + 2My_2^+ + 4y_2^- + 3My_3^+,$$

subject to

$$\begin{aligned} 12x_1 + 9x_2 + 15x_3 - (y_1^+ - y_1^-) &= 125 \\ 5x_1 + 3x_2 + 4x_3 - (y_2^+ - y_2^-) &= 40 \\ 5x_1 + 7x_2 + 8x_3 - (y_3^+ - y_3^-) &= 55 \end{aligned}$$

and

$$x_j \geq 0, \qquad y_k^+ \geq 0, \qquad y_k^- \geq 0 \qquad (j = 1, 2, 3;\ k = 1, 2, 3).$$

Because this model uses M to symbolize a huge positive number, the simplex method can be applied as described and illustrated throughout Sec. 4.7. Alternatively, a very large positive number can be substituted for M in the model and then any software package based on the simplex method can be applied. Doing either naturally yields the same unique optimal solution obtained by the sequential procedure.

More than Two Priority Levels. When there are more than two priority levels (say, p of them), the streamlined procedure generalizes in a straightforward way. The basic penalty weights for the respective levels now are $M_1, M_2, \ldots, M_{p-1}, 1$, where M_1 represents a number that is vastly larger than M_2, M_2 is vastly larger than $M_3, \ldots$, and M_{p-1} is vastly larger than 1. Each coefficient in row 0 of each simplex tableau is now a linear function of all of these quantities, where the multiplicative factor of M_1 is used to make the necessary decisions, with tie breakers beginning with the multiplicative factor of M_2 and ending with the additive term.

PROBLEMS

16S-1. Montega is a developing country which has 15,000,000 acres of publicly controlled agricultural land in active use. Its government currently is planning a way to divide this land among three basic crops (labeled 1, 2, and 3) next year. A certain percentage of each of these crops is exported to obtain badly needed foreign capital (dollars), and the rest of each of these crops is used to feed the populace. Raising these crops also provides employment for a significant proportion of the population. Therefore, the main factors to be considered in allocating the land to these crops are (1) the amount of foreign capital generated, (2) the number of citizens fed, and (3) the number of citizens employed in raising these crops. The following table shows how much each 1,000 acres of each crop contributes toward these factors, and the last column gives the goal established by the government for each of these factors.

	Contribution per 1,000 Acres			
	Crop:			
Factor	1	2	3	Goal
Foreign capital	\$3,000	\$5,000	\$4,000	≥ \$70,000,000
Citizens fed	150	75	100	≥ 1,750,000
Citizens employed	10	15	12	= 200,000

In evaluating the relative seriousness of *not* achieving these goals, the government has concluded that the following deviations from the goals should be considered *equally undesirable:* (1) each \$100 under the foreign-capital goal, (2) each person under the citizens-fed goal, and (3) each deviation of one (in either direction) from the citizens-employed goal.

(a) Formulate a goal programming model for this problem.
(b) Reformulate this model as a linear programming model.
(c) Use the simplex method to solve this model.
(d) Now suppose that the government concludes that the importance of the various goals differs greatly so that a preemptive goal programming approach should be used. In particular, the first-priority goal is citizens fed ≥ 1,750,000, the second-priority goal is foreign capital fm ≥70,000,000, and the third-priority goal is citizens employed = 200,000. Use the goal programming technique to formulate one complete linear programming model for this problem.
(e) Use the streamlined procedure to solve the problem as formulated in part (*d*).
(f) Use the sequential procedure to solve the problem as presented in part (*d*).

16S-2. Consider a *preemptive goal programming* problem with three priority levels, just one goal for each priority level, and just two activities to contribute toward these goals, as summarized in the following table:

	Unit Contribution		
	Activity:		
Priority Level	1	2	Goal
First priority	1	2	≤ 20
Second priority	1	1	= 15
Third priority	2	1	≥ 40

(a) Use the *goal programming technique* to formulate one complete linear programming model for this problem.
(b) Construct the initial simplex tableau for applying the *streamlined procedure.* Identify the *initial BF solution* and the *initial entering basic variable,* but do not proceed further.
(c) Starting from (*b*), use the *streamlined procedure* to solve the problem.
(d) Use the logic of preemptive goal programming to solve the problem graphically by focusing on just the two decision variables. Explain the logic used.
(e) Use the *sequential procedure* to solve this problem. After using the *goal programming technique* to formulate the linear programming model (including auxiliary variables) at each stage, solve the model *graphically* by focusing on just the two decision variables. Identify *all* optimal solutions obtained for each stage.

16S-3. Redo Prob. 16S-2 with the following revised table:

	Unit Contribution		
	Activity:		
Priority Level	1	2	Goal
First priority	1	1	≤ 20
Second priority	1	1	≥ 30
Third priority	1	2	≥ 50

CASES

CASE 16S-1 A Cure for Cuba

Fulgencio Batista led Cuba with a cold heart and iron fist—greedily stealing from poor citizens, capriciously ruling the Cuban population that looked to him for guidance, and violently murdering the innocent critics of his politics. In 1958, tired of watching his fellow Cubans suffer from corruption and tyranny, Fidel Castro led a guerilla attack against the Batista regime and wrested power from Batista in January

1959. Cubans, along with members of the international community, believed that political and economic freedom had finally triumphed on the island. The next two years showed, however, that Castro was leading a Communist dictatorship—killing his political opponents and nationalizing all privately held assets. The United States responded to Castro's leadership in 1961 by invoking a trade embargo against Cuba. The embargo forbade any country from selling Cuban products in the United States and forbade businesses from selling American products to Cuba. Cubans did not feel the true impact of the embargo until 1989 when the Soviet economy collapsed. Prior to the disintegration of the Soviet Union, Cuba had received an average of $5 billion in annual economic assistance from the Soviet Union. With the disappearance of the economy that Cuba had almost exclusively depended upon for trade, Cubans had few avenues from which to purchase food, clothes, and medicine. The avenues narrowed even further when the United States passed the Torricelli Act in 1992 that forbade American subsidiaries in third countries from doing business with Cuba that had been worth a total of $700 million annually.

Since 1989, the Cuban economy has certainly felt the impact from decades of frozen trade. Today poverty continues to be a serious problem on the island of Cuba. Many families do not have sufficient money to purchase bare necessities, such as food, milk, and clothing. Children die from malnutrition or exposure. Disease infects the island because medicine is not sufficiently available. Optical neuritis, tuberculosis, pneumonia, and influenza run rampant among the population.

Relations between the United States and Cuba improved at the end of the Obama administration, but then deteriorated somewhat under the Trump administration. Robert Baker, director of Helping Hand, leads a handful of tender souls on Capitol Hill who cannot bear to see politics destroy so many human lives. His organization distributes humanitarian aid annually to needy countries around the world. Mr. Baker recognizes the dire situation in Cuba, and he wants to allocate aid to Cuba for the coming year.

Mr. Baker wants to send numerous aid packages to Cuban citizens. Three different types of packages are available. The basic package contains only food, such as grain and powdered milk. Each basic package costs $300, weighs 120 pounds, and aids 30 people. The advanced package contains food and clothing, such as blankets and fabrics. Each advanced package costs $350, weighs 180 pounds, and aids 35 people. The supreme package contains food, clothing, and medicine. Each supreme package costs $720, weighs 220 pounds, and aids 54 people.

Mr. Baker has several goals he wants to achieve when deciding upon the number and types of aid packages to allocate to Cuba. First, he wants to aid at least 20 percent of Cuba's 11 million citizens. Second, because disease runs rampant among the Cuban population, he wants at least 3,000 of the aid packages sent to Cuba to be the supreme packages. Third, because he knows many other nations also require humanitarian aid, he wants to keep the cost of aiding Cuba below $20 million.

Mr. Baker places different levels of importance on his three goals. He believes the most important goal is keeping costs down since low costs mean that his organization is able to aid a larger number of needy nations. He decides to penalize his plan by 1 point for every $1 million above his $20 million goal. He believes the second most important goal is ensuring that at least 3,000 of the aid packages sent to Cuba are supreme packages, since he does not want to see an epidemic develop and completely destroy the Cuban population. He decides to penalize his plan by 1 point for every 1,000 packages below his goal of 3,000 packages. Finally, he believes the least important goal is reaching at least 20 percent of the population, since he would rather give a smaller number of individuals all they need to thrive instead of a larger number of individuals only some of what they need to thrive. He therefore decides to penalize his plan by 7 points for every 100,000 people below his 20 percent goal.

Mr. Baker realizes that he has certain limitations on the aid packages that he delivers to Cuba. Each type of package is approximately the same size, and because only a limited number of cargo flights from the United States are allowed into Cuba, he is only able to send a maximum of 40,000 packages. Along with a size limitation, he also encounters a weight restriction. He cannot ship more that 6 million pounds of cargo. Finally, he has a safety restriction. When sending medicine, he needs to ensure that the Cubans know how to use the medicine properly. Therefore, for every 100 supreme packages, Mr. Baker must send one doctor to Cuba at a cost of $33,000 per doctor.

(a) How many basic, advanced, and supreme packages should Mr. Baker send to Cuba?

(b) Mr. Baker reevaluates the levels of importance he places on each of the three goals. To sell his efforts to potential donors, he must show that his program is effective. Donors generally judge the effectiveness of a program on the number of people reached by aid packages. Mr. Baker therefore decides that he must put more importance on the goal of reaching at least 20 percent of the population. He decides to penalize his plan by 10 points for every half a percentage point below his 20 percent goal. The penalties for his other two goals remain the same. Under this scenario, how many basic, advanced, and supreme packages should Mr. Baker send to Cuba? How sensitive is the plan to changes in the penalty weights?

(c) Mr. Baker realizes that sending more doctors along with the supreme packages will improve the proper use and distribution of the packages' contents, which in turn will increase the effectiveness of the program. He therefore decides to send one doctor with every 75 supreme packages. The penalties for the goals remain the same as in part (*b*). Under this scenario, how many basic, advanced, and supreme packages should Mr. Baker send to Cuba?

(d) The aid budget is cut, and Mr. Baker learns that he definitely cannot allocate more than $20 million in aid to Cuba. Due to the budget cut, Mr. Baker decides to stay with his original policy of sending one doctor with every 100 supreme packages. How many basic, advanced, and supreme packages should Mr. Baker send to Cuba assuming that the penalties for not meeting the other two goals remain the same as in part (*a*)?

(e) Now that the aid budget has been cut, Mr. Baker feels that the levels of importance of his three goals differ so much that it is difficult to assign meaningful penalty weights to deviations from these goals. Therefore, he decides that it would be more appropriate to apply a preemptive goal-programming approach (which will ensure that his budget goal is fully met if possible), while retaining his original policy of sending one doctor with every 100 supreme packages. How many basic, advanced, and supreme packages should Mr. Baker send to Cuba according to this approach?

CASE 16S-2 Airport Security

Shortly after the tragic events of September 11, 2001, the United States Congress enacted emergency legislation to give the Department of Transportation primary responsibility for providing security at over 400 major U.S. airports. The Transportation Security Administration was then created within the Department of Transportation to carry out this responsibility. Much progress was made, but calls continued to do even more.

Many years later, a leading OR consultant in the airline industry, Adeline Jonasson, has been hired by the Transportation Security Administration to head up a new task force to further improve airport security. The specific charge to the task force is to investigate what advanced security technology should be developed and used at airport checkpoints to maximize the effectiveness with which passengers can be screened within budget constraints.

Even prior to 2001, airline passengers had become familiar with the two basic types of systems used to check each passenger at a security checkpoint. One is a portal that can detect concealed weapons as the passenger walks through. The other is a screening system that scans the passenger's carry-on luggage. Various proposals have been made for advanced security technology that would improve these two systems. Adeline's task force now needs to make recommendations on which direction to go for the next generation of these systems.

The task force has been told that the functional requirement for the new portal system is that it must be able to detect even one ounce of explosives and hazardous liquids as well as metallic weapons being concealed by a passenger. The technology needed to do this includes quadrupole resonance (closely related to magnetic resonance technology used by the medical industry) and magnetic sensors. There are various ways to design the portal with this technology that would satisfactorily meet the functional requirement. However, the designs would differ greatly in the frequency with which false alarms would occur as well as in the purchase cost and maintenance cost for the portal. The frequency of false alarms is a key consideration since it substantially affects the efficiency with which the passengers can be processed. Even more importantly, a high frequency of false alarms greatly decreases the alertness of the security personnel for detecting the relatively rare terrorists who are actually concealing destructive devices.

The most basic version of the portal system that satisfactorily meets the functional requirement would have an estimated purchase price of $90,000 and, on the average, would incur an annual maintenance cost of $15,000. The drawback of this version is that it would generate a false alarm for approximately 10 percent of the passengers. This false alarm rate can be reduced by using more expensive versions of the system. Each additional $15,000 in the cost of the portal system would lower the false alarm rate 1 percent and also would increase the annual maintenance cost by $1,500. The most expensive version would cost $210,000, so it would have a false alarm rate of only 2 percent of the customers as well as an annual maintenance cost of $27,000.

Regarding the new screening system for carry-on luggage, the functional requirement is that it must clearly reveal suspicious objects as small as the smallest Swiss army knife. The technology needed to do this combines X-ray imaging, a thermal neutron scanner, and computer tomography imaging (which compares the density and other physical properties of any suspicious objects with known high-risk materials). It is estimated that the most basic version that satisfactorily meets this functional requirement would cost $60,000 plus an annual maintenance cost of $9,000. As with the most basic portal system, the drawback of this version is that it isn't sufficiently discriminating between suspicious objects that actually are destructive devices and those that are harmless. Thus, this version would generate false alarms for approximately 6 percent of the customers. In addition to wasting time and delaying passengers, such a high false alarm rate would make it very difficult for the screening operator to pay sufficient attention when the far more unusual true alarms occur. However, more expensive versions of the screening system would be considerably more discriminating. In particular, each additional $30,000 in the cost of the system would enable a reduction of 1 percent in the false alarm rate, while also increasing the annual maintenance cost by $1,200. Thus, the most expensive version, costing $150,000, would decrease the false alarm rate to 3 percent and incur an annual maintenance cost of $12,600.

The task force has been given two budgetary guidelines.

First Budgetary Guideline: Plan on a total expenditure of $250,000 for both the portal system and the screening system for carry-on luggage at each security checkpoint.

Second Budgetary Guideline: Plan on holding down the average total maintenance costs for the two systems at each security checkpoint to no more than $30,000.

These budget guidelines prohibit using the most expensive versions of both the portal system and the screening system for carryon baggage. Therefore, the task force needs to determine which financially feasible combination of versions for the two systems will maximize the effectiveness with which passengers can be screened. Doing this requires first obtaining input from the top management of the Transportation Security Administration regarding what the measure of effectiveness should be and then what management's goals and priorities are for achieving substantial effectiveness and meeting the budgetary guidelines.

Fortunately, Adeline already has had extensive discussions with top management to obtain its guidance on these matters. These discussions led to the adoption of a clear policy that was approved all the way up to the Secretary of Transportation (who also informed the chairmen of the Congressional oversight committees of this action). The policy establishes the following order of priorities.

Priority 1: The functional requirement for each of the two new systems *must* be met. (This is satisfied by all the versions under consideration by the task force.)

Priority 2: The total false alarm rate for both systems should not exceed 0.1 per passenger.

Priority 3: Meet the first budgetary guideline.

Priority 4: Meet the second budgetary guideline.

Now that it has obtained all the needed managerial input, the task force is ready to begin its analysis.

(a) Identify the two decisions to be made, and define a decision variable for each one.

(b) Describe why this problem is a preemptive goal programming problem by giving quantitative expressions for each of the goals in terms of the decision variables defined in part (*a*).

(c) Draw a single two-dimensional graph where the two axes correspond to the decision variables defined in part (*a*). Consider each of the goals in order of priority and use the quantitative expression obtained in part (*b*) for this goal to draw a plot on this graph that graphically displays the values of the decision variables that fully satisfy this goal. After completing this for all the goals, use this graph to determine the optimal solution for this preemptive goal programming problem.

(d) Use a linear programming software package (such as Solver, MPL/Solvers, LINDO, or LINGO) to formulate and solve this preemptive goal programming problem.

(e) If it is possible to fully satisfy all the goals except the lowest-priority goal, one can quickly solve a preemptive goal programming problem by formulating and solving a linear programming model that includes all the goals except the last one as constraints and then uses the objective function to strive toward the lowest-priority goal. Formulate and solve such a linear programming model for this problem on a spreadsheet. What would be the interpretation for the preemptive goal programming problem if this linear programming model had no feasible solutions?

(f) Perform some postoptimality analysis by determining how far the total false alarm rate per passenger can be reduced (perhaps even below the goal) by ignoring the second budgetary guideline but fully meeting the first one.

(g) What additional postoptimality analysis do you feel should be performed in order to provide top management with the information needed to make a sound judgment decision about the best trade-off between (1) the total false alarm rate per passenger, (2) the total expenditure for the two new security systems per security checkpoint, and (3) the total annual maintenance cost for these two systems per security checkpoint.