IIE6120 Linear Programming
Fall 2023 - Term Project

Submission Due: Thursday, December 14, 11:59 pm

Instruction:

- Project is team-based. All the team members are expected to work together.
- Required deliverables must be turned in via the submission link posted in LearnUs by each team.
- Late project submissions will not be accepted unless pre-approved by the instructor with an acceptable reason. Not submitting homework will result in a “0" point.
- Show your work explicitly and clearly following requirements to get full/partial credit for each problem.

Description:

- Carefully read the description of the Golf-Sport case study problem attached to the end of this document, which is from Winston L.W. and Venkataramanan, M. (2003). *Introduction to Mathematical Programming, 4th Edition*. Wiley.

Requirements:

1. Formulate the problem as an LP model and create an AMPL code to solve this model and run it (we call this the basic model). As before you need to turn in four files: a model file, a data file, a script file containing the commands you issue in AMPL to solve the model and display the result, and an output file containing the result of running your script file. These files should be named team-a.mod, team-a.dat, team-a.run, and team-a.out, respectively.

   You will lose points if you do not follow the items below:

   (a) Comments in the code are absolutely necessary. Comments should be such that one could understand the whole problem and model just by reading your code. In particular all sets, parameters, variables, objective function, and constraints should have associated comments clearly defining/explaining them. The comments should be self-contained and not refer to the problem description.

   (b) Use meaningful and short names for all elements of the model consistent with the terminology used in the description.

   (c) Your model file should be completely independent of the data such that any problem with any size can be solved using it just by changing the data in the data file. The data file that you submit is just a particular instance of the problem and corresponds to the example in the description.

   (d) Your script file should contain the necessary commands to display all the parameters and optimal values of variables and objective function in a nice and clean format in the output file along with appropriate labeling messages. In your output labeling messages should clarify what are the values you are displaying. Do not use the log file option of AMPL to create your output file. Instead use the '>' or '»' directives or the 'printf' command in your script file to write the output file (refer to AMPL tutorial document on LearnUs).

   (f) In addition to displaying the results in the output file you need to present the solution in appropriately designed tables in a clean format and submit their printout.

   (g) Your script file should run correctly and generate exactly the output file that you submit.

   (h) Make your best effort to make your files neat, clear and readable. We will not spend time deciphering disorderly files.

2. Answer the "what if" questions asked at the end of the problem description. In each case, work from basic model. Do not combine questions. Also where noted your answer should be based on the basic model solution and its sensitivity analysis output (dual prices/reduced costs/range analysis). Otherwise you can modify the basic model and rerun. Note: For sensitivity analysis refer to the CPLEX-for-AMPL-12.2-Users-Guide (especially chapter 8) to learn how to use appropriate suffixes.

3. Change the problem to an integer programming (IP) problem by requiring that the number of all types products (produced and sold) to be integer.

   (a) Modify your model and solve it and report the solution. Use the appropriate CPLEX option to display the amount of time it took the solver to solve the model. How many branch-and-bound nodes were examined?

   (b) What is the gap between the LP relaxation optimal objective and IP optimal objective?

   (c) Use the appropriate CPLEX option to set a time limit of 0.1 second on the computing time. What is the best integer solution found within this time limit? What percentage of the gap of part 3-(b) is closed within this time?

   (d) Set the appropriate CPLEX option to turn off all MIP cuts and solve the IP problem. Compare the time and number of nodes with the case that cuts were on (part 3-(a)).

Deliverables:

- By the due date submit soft copies of the four files of your basic model via the submission link posted in LearnUs.
- In addition to the aforementioned files, a term project report including the following requirements should also be submitted:
  - The report should have a cover sheet containing the team name and the names of team members.
  - It should contain soft copies of the four files of your basic model. Use a small font (but not too small).
  - The report should have the tables of solution values.
  - The report should contain answers to all parts of questions 2 and 3 (in order). The answers should clearly argue the reasons. But be concise and to the point. Everywhere you refer to your data, model, script, output files or modify a part of them to answer the questions clearly bring a copy of ONLY the referred or modified lines within your text. Overall, based on your report it should be exactly clear how you came up with your answers.

ity. The main barrier to increased use of this technology is cost. A common semiconducting material used in PV cells is single crystal silicon. Single crystal silicon cells are generally the most efficient type of PV cells, converting as much as 23% of incoming solar energy into electricity. The main problem with them is their production cost. Polycrystalline silicon cells are less expensive to manufacture but less efficient than single crystal cells (15% to 17%). Thin films (0.001–0.002 mm thick) of amorphous or uncrystallized silicon are another PV alternative. These thin films are inexpensive and may be easily deposited on materials such as glass and metal, thus lending themselves to mass production. Amorphous silicon thin-film PV cells are widely used in commercial electronics, powering watches and calculators. These cells, however, are not especially efficient—12% in the lab, 7% for commercial cells—and they degrade with time, losing as much as 50% of their efficiency with exposure to sunlight.

Solar power is an intermittent source of electricity. If PV cells are your only source, then the storage of electricity may be necessary. Electricity for a home can be stored in batteries, which can be expensive. Also, to generate sufficient electricity, you need a large area of collectors on your roof or somewhere on your property. The amount of solar energy captured depends on the surface area of the collectors and their conversion efficiency.

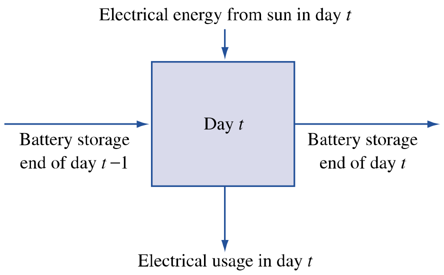
A solar energy system can often be looked at as a conservation system. Figure 1 depicts one way to look at the daily flow of energy.

Your job is to design an active solar system for a home in your area. For the analysis, you will have to collect data on:

- system cost and efficiency,
- daily solar insolation in your area (usually measured in watts/meter^2; this information can be found locally where weather data are stored and collected), and
- typical daily power requirements for a home in your area.

The costs of the system generally include a fixed component and variable components that depend on the total area of the PV collectors, the type of material used in the collector (usually only material is chosen), and the amount of battery storage needed. Your analysis should cover at least 6 months of data (12 months would be better, because you would like your design to be appropriate for the entire year). You should assume that *all* energy requirements for the home will be met by this system (no natural gas will be used for heating or cooking, for example).

FIGURE 1
Daily Energy Flow



Your design should include the following:

- the area of the PV collectors and the amount of battery storage that you need,
- an estimate of the cost of the system (you may include any tax advantages that accrue from the purchase of solar energy systems),
- a profile of the battery storage levels at the end of each day for a six-month period,
- an estimate of cost savings (or loss) over buying your electrical power from the local utility company.

CASE 3

Golf-Sport: Managing Operations

Golf-Sport is a small-sized company that produces high-quality components for people who build their own golf clubs and prebuilt sets of clubs. There are five components—steel shafts, graphite shafts, forged iron heads, metal wood heads, and metal wood heads with titanium inserts—made in three plants—Chandler, Glendale, and Tucson—in the Golf-Sport system. Each plant can produce any of the components, although each plant has a different set of individual constraints and unit costs. These constraints cover labor and packaging machine time (the machine is used by all components); the specific values for each component–plant combination are given in Tables 1–3. Note that even though the components are identical in the three plants, different production processes are used, and therefore the products use different amounts of resources in different plants.

Besides component sales, the company takes the components and manufactures sets of golf clubs. Each set requires 13 shafts, 10 iron heads, and 3 wood

TABLE 1
Product-Resource Constraints: Chandler

Products	Resources		
	Labor (Minutes/Unit)	Packing (Minutes/Unit)	Advertising ($/Unit)
Steel shafts	1	4	1.0
Graphite shafts	1.5	4	1.5
Forged iron heads	1.5	5	1.1
Metal wood heads	3	6	1.5
Titanium insert heads	4	6	1.9
Monthly availability (minutes)	12,000	20,000	—

TABLE 2
Product-Resource Constraints: Glendale

Products	Resources		
	Labor (Minutes/Unit)	Packing (Minutes/Unit)	Advertising ($/Unit)
Steel shafts	3.5	7	1.1
Graphite shafts	3.5	7	1.1
Forged iron heads	4.5	8	1.1
Metal wood heads	4.5	9	1.2
Titanium insert heads	5.0	7	1.9
Monthly availability (minutes)	15,000	40,000	—

TABLE 3
Product-Resource Constraints: Tucson

Products	Resources		
	Labor (Minutes/Unit)	Packing (Minutes/Unit)	Advertising ($/Unit)
Steel shafts	3	7.5	1.3
Graphite shafts	3.5	7.5	1.3
Forged iron heads	4	8.5	1.3
Metal wood heads	4.5	9.5	1.3
Titanium insert heads	5.5	8.0	1.9
Monthly availability (minutes)	22,000	35,000	—

heads. All of the shafts in a set must be the same type (steel or graphite), and all of the wood heads must be the same type (metal or metal with inserts). Assembly times for the sets at each plant are shown in Table 4.

Each plant of Golf-Sport has a retail outlet to sell components and sets, and the specific plant is the only supplier for its retail outlet. The minimum and maximum amounts of demand for each plant–product pair are given in Table 5. Note that, although the minimums must be satisfied, you do not need to satisfy demand up to the maximum amount.

This planning problem is for two months. The costs in Table 6 increase by 12% for the second month, and production times are stationary. Inventory costs are based on end-of-period inventory for each product set and cost out at 8% of the cost values in Table 6. Table 7 lists the revenue generated by each product. Initially, there is no inventory.

The corporation controls the capital available for expenses; the cash requirements for each product are given in the last column of Tables 1–3. There is a total of $20,000 available for advertising for the entire system during each month, and any money not spent in a month is not available the next month. The corporation also controls graphite. Each shaft requires 4 ounces of graphite; a total of 1,000 pounds is available for each of the two months.

TABLE 4

Plant	Time (Minutes per set)	Total Time Available (Minutes)
Chandler	65	5,500
Glendale	60	5,000
Tucson	65	6,000

Your job is to determine a recommendation for the company. A recommendation must include a plan for production and sales. In addition, you should also address the following sensitivity-analysis issues in your recommendation:

- If you could get more graphite or advertising cash, how much would you like, how would you use it, and what would you be willing to pay?
- At what site(s) would you like to add extra packing machine hours, assembly hours, and/or extra labor hours? How much would you be willing to pay per hour and how many extra hours would you like?
- Marketing is trying to get Golf-Sport to consider an advertising program that promises a 50% increase in their maximum demand. Can we handle this with the current system or do we need more resources? How much more is the production going to cost if we take on the additional demand?

TABLE 6
Material, Production, and Assembly Costs ($) per Part or Set

	Plants		
Products	Chandler	Glendale	Tucson
Steel shafts	6	5	7
Graphite shafts	19	18	20
Forged iron heads	4	5	5
Metal wood heads	10	11	12
Titanium insert heads	26	24	27
Set: Steel, metal	178	175	180
Set: Steel, insert	228	220	240
Set: Graphite, metal	350	360	370
Set: Graphite, insert	420	435	450

TABLE 5
Minimum and Maximum Product Demand per Month

	Store (or Plant)		
Products	Chandler	Glendale	Tucson
Steel shafts	[0, 2,000]	[0, 2,000]	[0, 2,000]
Graphite shafts	[100, 2,000]	[100, 2,000]	[50, 2,000]
Forged iron heads	[200, 2,000]	[200, 2,000]	[100, 2,000]
Metal wood heads	[30, 2,000]	[30, 2,000]	[15, 2,000]
Titanium insert heads	[100, 2,000]	[100, 2,000]	[100, 2,000]
Set: Steel, metal	[0, 200]	[0, 200]	[0, 200]
Set: Steel, insert	[0, 100]	[0, 100]	[0, 100]
Set: Graphite, metal	[0, 300]	[0, 300]	[0, 300]
Set: Graphite, insert	[0, 400]	[0, 400]	[0, 400]

TABLE 7
Revenue per Part or Set ($)

Products	Plants: Chandler	Glendale	Tucson
Steel shafts	10	10	12
Graphite shafts	25	25	30
Forged iron heads	8	8	10
Metal wood heads	18	18	22
Titanium insert heads	40	40	45
Set: Steel, metal	290	290	310
Set: Steel, insert	380	380	420
Set: Graphite, metal	560	560	640
Set: Graphite, insert	650	650	720

CASE 4

Vision Corporation: Production Planning and Shipping

Vision is a large company that produces video-capturing devices for military applications such as missiles, long-range cameras, and aerial drones. Four different types of cameras (differing mainly by lens type) are made in the three plants in the system. Each plant can produce any of the four camera types, although each plant has its own individual constraints and unit costs. These constraints cover labor and machining restrictions, and the specific values are given in Tables 8–10. Note that even though the products are identical in the three plants, different production processes are used and thus the products use different amounts of resources in different plants. The corporation controls the material that goes into the lenses; the material requirements for each product are given in the last column of Tables 8–10. A total of 3,500 pounds of material is available for the entire system during the planning period.

TABLE 8
Product-Resource Constraints: Plant 1

Products	Resources: Labor (Hours/Unit)	Machine (Hours/Unit)	Material (Lb./Unit)
Small	3	8	1.0
Medium	3	8.5	1.1
Large	4	9	1.2
Precision	4	9	1.3
Total available	6,000	10,000	—

TABLE 9
Product-Resource Constraints: Plant 2

Products	Resources: Labor (Hours/Unit)	Machine (Hours/Unit)	Material (Lb./Unit)
Small	3.5	7	1.1
Medium	3.5	7	1.0
Large	4.5	8	1.1
Precision	4.5	9	1.4
Total available	5,000	12,500	—

TABLE 10
Product-Resource Constraints: Plant 3

Products	Resources: Labor (Hours/Unit)	Machine (Hours/Unit)	Material (Lb./Unit)
Small	3	7.5	1.1
Medium	3.5	7.5	1.1
Large	4	8.5	1.3
Precision	4.5	8.5	1.3
Total available	3,000	6,000	—

Transport has 3 major customers (RAYco, HONco, and MMco) for its products. The maximum sales for each customer–product pair is given in Table 11. Product sales prices are given in Table 12, and the shipping costs from each plant to each customer are detailed in Table 13. Table 14 contains the production costs for each product–plant pair.

All shipping from plants 1 and 2 that goes to RAYco or HONco must go through a special inspection. These units are sent to a central site, inspected, and then sent to their destination. The capacity of this special inspection site is 1,500 pieces.

Your job is to determine a recommendation for the company. A recommendation must include a plan for production and shipping as well as the cost and revenue generated from each plant. In addition, you should address the following potential issues in your recommendation:

- If you could get more material, how much would you like? How would you use it? What would you be willing to pay?
- If you could get more inspection capacity, how much would you like? How would you use it? What would you be willing to pay?