INTEGRATING SUSTAINABILITY INTO A GOAL PROGRAMMING EXERCISE

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ABSTRACT

This paper discusses a sustainability exercise for use in a management science course. Specifically, we discuss an exercise using goal programming and Excel Solver for making supplier selection decisions incorporating a triple bottom line approach (economic, environmental and social performance objectives). The multiple, conflicting objectives and the qualitative nature of the social performance objective require the use of multi-criteria decision-making. Our goal programming exercise requires only Excel and could be expanded to include additional triple bottom line criteria.

JEL: C6, M11

KEYWORDS: Sustainability, Management Science, Curriculum, Triple Bottom Line, Goal Programming

INTRODUCTION

Our Supply Chain Management (SCM) program at UW Oshkosh started integrating sustainability into our major in the Fall Semester of 2006 and continues to integrate sustainability into all of our SCM courses. The first widespread definition of sustainability was presented in *Our Common Future* (World Commission on Economic Development, 1987, p. 8) in which sustainable development was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Other researchers (e.g., Elkington (1994, 1998)) expanded the definition of sustainability to include the triple bottom line criteria of economic, environmental, and social performance. The least understood and under-researched of the three bottom lines is social performance. Mass and Bouma (as cited in Castro & Chousa, 2006) divided the social performance criteria into two broad categories: internal measures (education, training, safety, health care, employee retention, and job satisfaction) and external measures (sponsoring, volunteer work, investment in society, and stakeholder involvement). Norman and MacDonald (2004) argued that it is impossible to calculate a social performance bottom line in the same way that an income statement is created. Summing a company's performance on various social performance measures into a single bottom line is problematic due to: (a) the question of what units to use to express social performance, and (b) the manner in which social performance often is expressed—using percentages, which cannot be added or subtracted into a single meaningful measure. However, even though managers cannot calculate a bottom line for social performance, we argue that managers still could make value judgments and comparisons concerning which social performance criteria are more important. Multi-criteria decision-making (MCDM) methods, and in particular, goal programming, work well for making these value judgments and comparisons.

Goal programming is an extension of linear programming in which the objective function measures the minimization of unwanted deviations from goals (targets). As discussed by Romero (2004), two of the most common types of objective functions for goal programming models are lexicographic and weighted. The lexicographic type of achievement function, used later in our paper, leads to preemptive, or prioritized, goals. As described by Anderson, Sweeney, Williams, Camm, and Martin (2012), goal programming problems with preemptive priorities are solved by finding the solutions for a sequence of linear programming models with different objective functions: Priority Level 1 goals are considered first, Priority Level 2 goals second, etc. At each step of the solution procedure, a revision in the solution is allowed only if it causes no reduction in the achievement of higher priority goals previously minimized. Anderson et al. (2012) discussed two types of constraints in a goal programming model: hard constraints, which are typical linear programming constraints that cannot be violated, and soft constraints, which correspond to goal equations and can be violated but with a penalty for doing so (the penalty is represented by deviation variables).

Our paper discusses the continued integration of sustainability concepts in our supply chain management curriculum. We already have added several sustainability exercises in our Manufacturing Planning & Control, Supply Chain Management, Supply Chain Strategy, and Advanced Quality Management courses. In the current paper, we outline the use of goal programming for supplier selection decisions based on triple bottom line criteria. First, we present literature with applications of goal programming for sustainability type of multi-criteria decisions. Second, we present the in-class exercise using goal programming and Excel Solver. Third, we conclude with a summary of the goal programming exercise and possible extensions to this exercise.

LITERATURE REVIEW

Goal programming, with its ability to handle multiple, conflicting criteria, has been used to model sustainability decisions in many contexts, e.g., agricultural planning, utility planning, and supply chain planning. Examples of sustainability decisions in each of these areas are discussed below.

Darradi et al. (2012) discussed the use of goal programming to optimize environmental performance (nitrogen, sediments, and water yields) of agricultural activities in a case study in France. Acosta-Alba et al. (2012) applied goal programming to optimize economic, environmental, and social performance criteria in a study of dairy farms in France. Cisneros et al. (2011) created a goal programming model to analyze the tradeoffs between economic, environmental, and social performance criteria when studying land uses, crops, pastures, and conservation practices in a case study in Argentina.

San Cristobal (2012) developed a goal programming model to determine the mix and location of renewable energy plants in Spain and included economic, environmental, and social performance criteria in that model. Papandreou and Shang (2008) proposed a goal programming model for designing utility systems while considering economic and environmental (emissions) goals. Liner and deMonsabert (2011) considered economic, environmental, and social performance criteria in their goal programming model for selecting water management alternatives using publicly available data from a California utility. Cowan, Daim, and Anderson (2010) combined the analytic hierarchy process (AHP) with goal programming to select an optimal mix of hydroelectric power and storage technologies to achieve triple bottom line objectives. They used AHP to assign weights to the deviational variables within the objective function of their goal programming model.

Oglethorpe (2010) illustrated a goal programming approach using a real case study to create a food supply chain that considers triple bottom line objectives: economic (return on sales); environmental (GHG emissions and water use), and social (health impacts from fat content of products and number of jobs). Buyukozkan and Berkol (2011) also studied designing a sustainable supply chain by combining goal programming with quality function deployment (QFD) and the analytic network process (ANP).

IN-CLASS EXERCISE USING GOAL PROGRAMMING AND EXCEL SOLVER FOR SUPPLIER SELECTION

The exercise described below analyzes the selection of new suppliers to replace a current hazardous material used in the manufacture of a company’s product. The buying company must purchase 2,000 units per year of a similar material that performs the same function as the current material. Each supplier has limits on its capacity—Supplier 1 can provide at most 1,500 units; Supplier 2 can provide at most 1,200 units; Supplier 3 can provide at most 2,500 units.

An explanation of the supplier selection criteria follows.

1. Economic Criterion: Purchase cost savings per unit compared to the current supplier.
2. Environmental Criterion: Hazardous waste per unit generated by the supplier's process (stated in pounds).
3. Social Performance Criterion: Hours of employment per unit generated in an economically disadvantaged area.

As shown in Table 1, these criteria focus on economic, environmental, and social performance objectives.

Table 1: Estimated Supplier Performance on the Criteria

Criterion		Supplier 1	Supplier 2	Supplier 3
1)	Purchase Cost Savings per Unit	\$10	\$25	\$8
2)	Hazardous Waste per Unit (lbs.)	1.5	1.2	2.2
3)	Hours of Employment per Unit	0.8	0.9	1.0

This table shows estimated supplier performance for all three suppliers on the criteria considered. The first criterion lists the purchase cost savings per unit from changing from the current supplier to each of the new suppliers. The second criterion lists the amount of hazardous waste per unit generated by each supplier's manufacturing process. The third criterion lists the hours of employment per unit generated in an economically disadvantaged area by each of the supplier's processes.

Step 1 of the exercise is to prioritize goals and to set targets for each goal:
Priority 1 Goal: The desired annual purchase costs savings must equal <u>at least</u> \$32,000.
Priority 2 Goal: The total amount of hazardous waste generated annually by the suppliers should be <u>at most</u> 1,800 pounds.
Priority 3 Goal: The hours of employment per year generated in economically disadvantaged areas should be <u>at least</u> 2,200.

Step 2 is to define the decision variables, the deviation variables, the goal constraints (in order of priority), and the hard constraints:

Decision Variables:
X_1 = units purchased from Supplier 1.
X_2 = units purchased from Supplier 2.
X_3 = units purchased from Supplier 3.

Goal 1 Constraint: $$10X_1 + 25X_2 + 8X_3 - d_1^+ + d_1^- = 32{,}000 \quad (1)$$
Deviation Variables:
d_1^+ = the amount greater than the goal of \$32,000.
d_1^- = the amount less than the goal of \$32,000.
We wish to minimize the amount less than \$32,000 (represented by d_1^-).

Goal 2 Constraint: $$1.5X_1 + 1.2X_2 + 2.2X_3 - d_2^+ + d_2^- = 1{,}800 \quad (2)$$
Deviation Variables:
d_2^+ = the amount greater than the goal of 1,800 pounds of hazardous waste.
d_2^- = the amount less than the goal of 1,800 pounds of hazardous waste.
We wish to minimize the amount greater than 1,800 pounds (represented by d_2^+).
Goal 3 Constraint: $$0.8X_1 + 0.9X_2 + 1.0X_3 - d_3^+ + d_3^- = 2{,}200 \quad (3)$$
Deviation Variables:

d_3^+ = the amount greater than the goal of 2,200 hours.
d_3^- = the amount less than the goal of 2,200 hours.
We wish to minimize the amount less than 2,200 hours (represented by d_3^-).

Hard Constraints:

Supplier 1 Capacity:	$X_1 \leq 1{,}500$	(4)
Supplier 2 Capacity:	$X_2 \leq 1{,}200$	(5)
Supplier 3 Capacity:	$X_3 \leq 2{,}500$	(6)
Total Demand:	$X_1 + X_2 + X_3 = 2{,}000$	(7)

Step 3 is to define the objective function. Here, we use the lexicographic approach demonstrated by Anderson et al. (2012):

Objective Function: $Min\ P_1(d_1^-) + P_2(d_2^+) + P_3(d_3^-)$ (8)

P_1, P_2, and P_3 are only labels—they remind us of the priority of each goal.

Step 4 is to write the complete goal programming model:

Objective Function:	$Min\ P_1(d_1^-) + P_2(d_2^+) + P_3(d_3^-)$	(9)
Subject to:		
Goal 1 Constraint:	$10X_1 + 25X_2 + 8X_3 - d_1^+ + d_1^- = 32{,}000$	(10)
Goal 2 Constraint:	$1.5X_1 + 1.2X_2 + 2.2X_3 - d_2^+ + d_2^- = 1{,}800$	(11)
Goal 3 Constraint:	$0.8X_1 + 0.9X_2 + 1.0X_3 - d_3^+ + d_3^- = 2{,}200$	(12)
Supplier 1 Capacity:	$X_1 \leq 1{,}500$	(13)
Supplier 2 Capacity:	$X_2 \leq 1{,}200$	(14)
Supplier 3 Capacity:	$X_3 \leq 2{,}500$	(15)
Total Demand:	$X_1 + X_2 + X_3 = 2{,}000$	(16)
Non-negativity:	$X_1, X_2, X_3, d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^- \geq 0$	(17)

Step 5 is to solve the model using Excel. To do this, first we modify the objective function to include only the P_1 priority goals (called the P_1 Problem):

P_1 Problem:

Objective Function:	$Min\ d_1^-$	(18)
Subject to:		
Goal 1 Constraint:	$10X_1 + 25X_2 + 8X_3 - d_1^+ + d_1^- = 32{,}000$	(19)
Goal 2 Constraint:	$1.5X_1 + 1.2X_2 + 2.2X_3 - d_2^+ + d_2^- = 1{,}800$	(20)
Goal 3 Constraint:	$0.8X_1 + 0.9X_2 + 1.0X_3 - d_3^+ + d_3^- = 2{,}200$	(21)
Supplier 1 Capacity:	$X_1 \leq 1{,}500$	(22)
Supplier 2 Capacity:	$X_2 \leq 1{,}200$	(23)
Supplier 3 Capacity:	$X_3 \leq 2{,}500$	(24)
Total Demand:	$X_1 + X_2 + X_3 = 2{,}000$	(25)
Non-negativity:	$X_1, X_2, X_3, d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^- \geq 0$	(26)

The Excel spreadsheet is shown in Figure 1. The Changing Variable Cells are shaded in Cells B4:J4. You would leave them blank initially, although now in Figure 1, they show the results of the first solution from running Solver. The Set Objective Cell is shaded in Cell B7. The coefficients and right-hand-side values for constraints are listed in Rows 10 to 16. We simplify the entering of constraints as shown in Rows 18 to 24.

Figure 1: Solver Model for P_1 Problem Classroom Use

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**Figure 1**												
2	***P*$_1$ Problem**												
3	Variables:	X1	X2	X3	d1+	d1-	d2+	d2-	d3+	d3-			
4		1,200	800	0	0	0	960	0	0	520			
5		**Min**											
6	Objective	**d1-**											
7	Function:	0	=F4										
8													
9	Subject to:	**Enter coefficients and right-hand-side values for constraints here.**											
10	Goal 1:	10	25	8	-1	1						=	32,000
11	Goal 2:	1.5	1.2	2.2			-1	1				=	1,800
12	Goal 3:	0.8	0.9	1					-1	1		=	2,200
13	S1 Capacity:	1										≤	1,500
14	S2 Capacity:		1									≤	1,200
15	S3 Capacity:			1								≤	2,500
16	Demand	1	1	1								=	2,000
17		**Simplification of constraints using SUMPRODUCT function.**											
18	Goal 1:	32,000	=SUMPRODUCT(B$4:J$4,B10:J10)									=	32,000
19	Goal 2:	1,800	=SUMPRODUCT(B$4:J$4,B11:J11)									=	1,800
20	Goal 3:	2,200	=SUMPRODUCT(B$4:J$4,B12:J12)									=	2,200
21	S1 Capacity:	1,200	=SUMPRODUCT(B$4:J$4,B13:J13)									≤	1,500
22	S2 Capacity:	800	=SUMPRODUCT(B$4:J$4,B14:J14)									≤	1,200
23	S3 Capacity:	0	=SUMPRODUCT(B$4:J$4,B15:J15)									≤	2,500
24	Demand	2,000	=SUMPRODUCT(B$4:J$4,B16:J16)									=	2,000

This figure shows the Excel spreadsheet created to run the Solver model for the P_1 problem. Cells B4:J4 are used for the Changing Variable Cells. Cell B7 is used for the Set Objective Cell. The formula for Cell B7 is listed in Cell C7. Cells B10:M16 are used to enter the coefficients and right-hand-side values for constraints. Rows 18 to 24 are used for entering the left-hand-side and right-hand values of each constraint. The formulas used for the left-hand-side of each constraint are shown in Cells C18:C24.

To run Solver, we specify the following:

1. For Set Objective Cell, enter: B7
2. Select "Min"
3. For Changing Variables Cells, enter: B4:J4
4. Select "Add" to enter the following constraint: B18:B20=M18:M20
5. Select "Add" to enter the following constraint: B21:B23≤M21:M23
6. Select "Add" to enter the following constraint: B24=M24
7. After entering the last constraint, select "OK"
8. Ensure that the following is checked to ensure non-negativity: "Make Unconstrained Variables Non-Negative"
9. For Solving Method, select "Simplex LP"
10. Select "Solve"

After running Solver, we have the following values for the variables:

$X_1 = 1{,}200$; $X_2 = 800$; $X_3 = 0$; $d_1^+ = 0$; $d_1^- = 0$; $d_2^+ = 960$; $d_2^- = 0$; $d_3^+ = 0$; $d_3^- = 520$.
We can tell that we achieved our Priority 1 Goal fully because $d_1^- = 0$.
Note that there are multiple solutions possible for this P_1 problem. As long as your solution has $d_1^- = 0$, it is correct. When we solve the P_2 and P_3 problems, the solutions will converge.

P_2 Problem

Next, we modify the objective function to include only the P_2 priority goals (called the P_2 Problem). We also must add a constraint to ensure that the solution from the P_1 Problem is not degraded. These changes

Figure 2: Solver Model for P_2 Problem Classroom Use

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**Figure 2**												
2	***P*₂ Problem**												
3	Variables:	X1	X2	X3	d1+	d1-	d2+	d2-	d3+	d3-			
4		800	1,200	0	6,000	0	840	0	0	480			
5		**Min**											
6	Objective	**d2+**											
7	Function:	840	=G4										
8													
9	Subject to:	**Enter coefficients and right-hand-side values for constraints here.**											
10	Goal 1:	10	25	8	-1	1						=	32,000
11	Goal 2:	1.5	1.2	2.2			-1	1				=	1,800
12	Goal 3:	0.8	0.9	1					-1	1		=	2,200
13	S1 Capacity:	1										≤	1,500
14	S2 Capacity:		1									≤	1,200
15	S3 Capacity:			1								≤	2,500
16	Demand	1	1	1								=	2,000
17		Simplification of constraints using SUMPRODUCT function.											
18	Goal 1:	32,000	=SUMPRODUCT(B$4:J$4,B10:J10)									=	32,000
19	Goal 2:	1,800	=SUMPRODUCT(B$4:J$4,B11:J11)									=	1,800
20	Goal 3:	2,200	=SUMPRODUCT(B$4:J$4,B12:J12)									=	2,200
21	S1 Capacity:	800	=SUMPRODUCT(B$4:J$4,B13:J13)									≤	1,500
22	S2 Capacity:	1,200	=SUMPRODUCT(B$4:J$4,B14:J14)									≤	1,200
23	S3 Capacity:	0	=SUMPRODUCT(B$4:J$4,B15:J15)									≤	2,500
24	Demand	2,000	=SUMPRODUCT(B$4:J$4,B16:J16)									=	2,000
25	*P*₁ Problem Solution	0	=F4									=	0

This figure shows the Excel spreadsheet created to run the Solver model for the P_2 problem. Cells B4:J4 are used for the Changing Variable Cells. Cell B7 is used for the Set Objective Cell. The formula for Cell B7 is listed in Cell C7. Cells B10:M16 are used to enter the coefficients and right-hand-side values for constraints. Rows 18 to 25 are used for entering the left-hand-side and right-hand values of each constraint. The formulas used for the left-hand-side of each constraint are shown in Cells C18:C25.

are shown in Figure 2. We need to change the formula in Cell B7 as follows: =G4. This change allows us to minimize d_2^+. Next, we must add a constraint to ensure that the Priority 1 Goal is not degraded, i.e., ensure that $d_1^- = 0$. We make this change as shown in Row 25 and then enter another constraint in Solver: B25=M25.

After running Solver, we have the following values for the variables:
$X_1 = 800$; $X_2 = 1{,}200$; $X_3 = 0$; $d_1^+ = 6{,}000$; $d_1^- = 0$; $d_2^+ = 840$; $d_2^- = 0$; $d_3^+ = 0$; $d_3^- = 480$.
We maintained the achievement of the Priority 1 goal ($d_1^- = 0$). As for the Priority 2 goal, we can see that we were not able to meet this goal fully because $d_2^+ = 840$.

P_3 Problem

Next, we modify the objective function to include only the P_3 priority goals (called the P_3 Problem). We also add a constraint to ensure that the solution from the P_2 Problem is not degraded. These changes are shown in Figure 3. Then, we change the formula in Cell B7 as follows: =J4. This change allows us to minimize d_3^-. Next, we add a constraint to ensure that the Priority 2 Goal is not degraded, i.e., ensure that $d_2^+ = 840$. We make this change as shown in Row 26 and then enter another constraint in Solver: B26=M26.

Notice that when solving the P_3 problem, we were unable to improve the solution from the P_2 problem. This means any improvement of the P_3 problem would degrade either the P_1 or P_2 solutions. Therefore, we have found our best solution above.

SUMMARY & POSSIBLE EXTENSIONS

The goal of this paper was to demonstrate an in-class exercise using goal programming and Excel Solver. We presented triple bottom line objectives along with performance metrics for each objective. We could modify the Excel Solver model in future exercises in the following ways (a) to include more objectives (goal constraints) and (b) to consider multiple objectives at the same priority level. Another possible follow-up exercise involves asking students to ponder which triple bottom objectives are important to a supplier selection decision and how to prioritize those objectives. Kearins and Springett (2003) described this type of thinking as “reflexivity.” Reflexivity requires students to think about both personal and societal values. For example, is the production of CO_2 desirable or undesirable? Other questions include the following: (a) What other triple bottom line objectives would you include in the supplier selection decision and how would you prioritize those objectives if you were a purchasing manager at a company? (b) Now, revisit the previous questions and pretend now that you are the owner of the company. This type of follow-up question may lead students to place greater emphasis on economic objectives when they are spending their own money, rather than the company’s money.

Figure 3: Solver Model for P_3 Problem Classroom Use

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	**Figure 3**												
2	**P_3 Problem**												
3	Variables:	X1	X2	X3	d1+	d1-	d2+	d2-	d3+	d3-			
4		800	1,200	0	6,000	0	840	0	0	480			
5		**Min**											
6	Objective	**d3-**											
7	Function:	0	=J4										
8													
9	Subject to:	**Enter coefficients and right-hand-side values for constraints here.**											
10	Goal 1:	10	25	8	-1	1						=	32,000
11	Goal 2:	1.5	1.2	2.2			-1	1				=	1,800
12	Goal 3:	0.8	0.9	1					-1	1		=	2,200
13	S1 Capacity:	1										≤	1,500
14	S2 Capacity:		1									≤	1,200
15	S3 Capacity:			1								≤	2,500
16	Demand	1	1	1								=	2,000
17		Simplification of constraints using SUMPRODUCT function.											
18	Goal 1:	32,000	=SUMPRODUCT(B$4:J$4,B10:J10)									=	32,000
19	Goal 2:	1,800	=SUMPRODUCT(B$4:J$4,B11:J11)									=	1,800
20	Goal 3:	2,200	=SUMPRODUCT(B$4:J$4,B12:J12)									=	2,200
21	S1 Capacity:	800	=SUMPRODUCT(B$4:J$4,B13:J13)									≤	1,500
22	S2 Capacity:	1,200	=SUMPRODUCT(B$4:J$4,B14:J14)									≤	1,200
23	S3 Capacity:	0	=SUMPRODUCT(B$4:J$4,B15:J15)									≤	2,500
24	Demand	2,000	=SUMPRODUCT(B$4:J$4,B16:J16)									=	2,000
25	P_1 Problem Solution	0	=F4									=	0
26	P_2 Problem Solution	840	=G4									=	840

This figure shows the Excel spreadsheet created to run the Solver model for the P_3 problem. Cells B4:J4 are used for the Changing Variable Cells. Cell B7 is used for the Set Objective Cell. The formula for Cell B7 is listed in Cell C7. Cells B10:M16 are used to enter the coefficients and right-hand-side values for constraints. Rows 18 to 26 are used for entering the left-hand-side and right-hand values of each constraint. The formulas used for the left-hand-side of each constraint are shown in Cells C18:C26.

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