The Coastal Business Journal

Volume 15 | Number 1 Article 3

May 2016

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The Coastal Business Journal

ISSN: 2163-9280 Spring 2016
Volume 15, Number 1

AN ACTIVE LEARNING EXERCISE TO HELP STUDENTS DISCOVER HOW TO MODEL A THIRD DECISION

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ABSTRACT

In this paper, we describe an active learning exercise for a fictitious business producing sea turtle bamboo beach towels. The students are asked to assume the role of a junior analyst at a company as they are led through a series of business memos, directed questions, nutshell summaries, and class discussions. In this role, students have the opportunity to discover how to review business communications to identify a new third decision, what additional data will be needed, and what changes will be required to reformulate the existing product mix model for sea turtle bamboo beach towels.

INTRODUCTION

In an undergraduate introduction to management science class, students are first introduced to modeling two-decision word problems and solving the problems using the graphical solution method. In an examination of six introductory management science textbooks, we identified how various authors introduced a third decision variable to a linear programming problem. All six textbooks opened with an introductory chapter on management science followed by a chapter demonstrating the graphical solution technique for only two-decision variables. The approach to introduce a third decision variable existed on a continuum. At one end of the continuum, Taylor (2013) included three or more decision variable problems at the end of the third chapter without discussion or examples. Balakrishnan, Bender, and Stair (2013) briefly related at the end of the second chapter that the problems at the end of the chapter provide an opportunity to formulate larger problems, since they required more than two variables and could not be solved graphically. Hillier and Hillier (2015) introduced a new problem with three-decision variables in the text of their third chapter. Likewise, Ragsdale (2015) introduced a new problem with three-decision variables in the text of his third chapter. Asllani (2015) also introduced a new problem but with 48 decision variables in the text of his third chapter. However, there were no specific discussions of transitioning from modeling with two variables versus three or more variables in

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the five textbooks cited. On the other end of the continuum, Anderson, et al. (2016) introduced a third variable in their third chapter on sensitivity analysis by extending a two-decision variable problem that had been solved using the graphical technique. They introduced the additional decision variable via a paragraph that gave the objective function coefficient costs and constraint coefficient manufacturing times for each of the resources used. The revised formulation with the third decision variable incorporated into the objective function and four manufacturing time constraints were then presented and used as the basis for sensitivity analysis.

In this paper, we combine the Anderson, et al. (2016) extension approach with the active learning approach. Serva and Fuller (2004) found that active learning can be predictive of performance and recommended that faculty consider it for teaching concepts such as decision making. Page and Mukherjee (2000) reported the application of active learning to a management science course using the seven principles in action from Chickering and Gamson (1987). Riddle (2010) described an active learning class exercise to encourage students to discover how to build a two-decision linear programming model as well as discover feasible solutions.

Furthermore, we integrate writing about quantitative business decisions through business memos and nutshell summaries. Kuh (2008) identified writing across the curriculum in areas such as quantitative reasoning as a high impact educational practice. Carrithers and Bean (2008) and Williams and Reid (2010) required students to write a memo about a problem, the solution technique(s), and the recommended course of action. Carrithers, Ling, and Bean (2008) required students to prepare a nutshell slide to identify the main points of their analysis. We provide students with a nutshell template to guide them in outlining a brief summary.

In this paper, we describe an imbedded business scenario with associated business communications to introduce a third business decision in an active learning exercise. By asking the students to assume the role of a junior analyst, they perform an initial two-decision analysis and prepare business memos with their recommendations for a product mix in a homework assignment. Next they fill in a nutshell summary template in class for the two-decision analysis. Then they are led through a series of class discussions to discover how to review follow-up business communications to identify the third decision, identify the additional data, and then formulate the associated mathematical model with three-decision variables. The exercise concludes with a revised nutshell summary template to summarize the three-decision product mix.

TEACHING INSTRUMENT

In Figure 1, a series of four business memos from four different managers are used to define the first homework assignment for a two-decision product mix problem. In the assignment, students take on the role of a junior business analyst tasked with developing a production plan for regular and deluxe bamboo beach towels. From the first memo, the students must identify the two-decisions, the objective, and sources for further information. In the second memo from the procurement manager, the students must identify the organic bamboo fabric requirements, the

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organic bamboo material costs, and the organic bamboo fabric supplies for two types of bamboo beach towels. The second memo also requires the students to identify the deluxe organic bamboo material depletion requirement. In the third memo from the operations manager, the students must identify the operations data for assembly times, the assembly time available, and the assembly time costs for the two types of bamboo beach towels. In the fourth memo from the marketing manager, the students must identify the product prices and demand forecasts for the two types of bamboo beach towels.

MEMO
TO: Junior business analyst
FROM: Ed Green, manager
RE: Product mix for sea turtle bamboo beach towels for the coastal market

How many regular sea turtle bamboo beach towels and deluxe sea turtle bamboo beach towels for the coastal market should we produce next week in order to maximize profit? Please confer with the procurement, operations, and marketing managers for appropriate data and constraints.

MEMO
TO: Junior business analyst
FROM: Bill Spender, procurement manager
RE: Procurement information for sea turtle bamboo beach towels for the coastal market

Each regular sea turtle bamboo beach towel requires one meter of regular organic bamboo fabric which can be procured at $6/meter. Each deluxe sea turtle bamboo beach towel requires 1.2 meters of deluxe organic bamboo fabric which can be procured at $8/meter. We can procure up to 350 meters of regular organic bamboo fabric. To deplete the current deluxe organic bamboo fabric in stock, use exactly 360 meters of deluxe organic bamboo fabric for the production plan.

MEMO
TO: Junior business analyst
FROM: Ollie Efficiency, operations manager
RE: Operations data for sea turtle bamboo beach towels for the coastal market

Each regular sea turtle bamboo beach towel requires four minutes of assembly time while each deluxe sea turtle bamboo beach towel requires five minutes of assembly time. There are 40 hours of assembly time available. Assembly labor costs $12/hour.

MEMO
TO: Junior business analyst
FROM: Melanie Show, marketing manager
RE: Marketing insights for sea turtle bamboo beach towels for the coastal market

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Produce the regular towels with the regular organic bamboo fabric and produce the deluxe towels with the deluxe organic bamboo fabric. The regular sea turtle bamboo beach towel will sell for $10.80 while the deluxe sea turtle bamboo beach towel will sell for $13.60. Since our advertising has included sustainability characteristics for bamboo, such as regeneration, fast growth rate, and low pesticide use, anticipate strong coastal market demand for both types of sea turtle bamboo beach towels.

Figure 1. Original two-decision product mix homework assignment composed of 4 memos

The students are required to use the information in the four memos to write a business memo and to formulate a linear programming model as shown in Figure 2. Figure 2 shows the solution key memo that was distributed to the students. This memo example demonstrates clearly restating the problem, assumptions, and solution technique as well as provides the recommended solution and its impact on the objective. At the end of the memo, there is a reference to an attachment (provided in Appendix A of this paper) that shows the mathematical model and solution techniques used to calculate the optimal solution for the two-decision problem.

MEMO
TO: Ed Green, manager
FROM: Junior business analyst
CC: Bill Spender, procurement manager
Ollie Efficiency, operations manager
Melanie Show, marketing manager
RE: Product mix for sea turtle bamboo beach towels for the coastal market

In response to your request to determine the number of regular and deluxe sea turtle bamboo beach towels to produce and sell next week in order to maximize profit, I gathered information from procurement, operations, and marketing. Procurement provided the organic bamboo fabric costs per towel and the regular and deluxe organic bamboo fabric available and requested that all of the deluxe organic bamboo fabric be utilized. Operations provided the assembly time per towel, the assembly time available, and the cost of assembly labor. I assumed no backorders. Assuming that each towel produced is sold, I recommend the following product mix:

225 Regular sea turtle bamboo beach towels
300 Deluxe sea turtle bamboo beach towels

Producing and selling this mix of regular and deluxe towels will generate $1800 in profit. I based my recommendation on a linear programming model that is defined in attachment 1 (included in the Appendix A to this paper). I solved my model using the graphical solution method as well as by using the solver in the Excel software. If you have any questions, please contact me.

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Figure 2. Response memo for the two-decision product mix homework assignment in Figure 1

After students turn in the assignment to build the two-decision model, solve it, and write a memo describing the problem and their recommended production plan, the business scenario for the homework problem is used for additional class periods to introduce new concepts. One important activity promoted by Carrithers, et al. (2008) is to ask students to "nutshell" their recommendation and its implications on a single presentation slide. An example of a nutshell summary template for the two-decision product mix problem that the students just completed in homework 1 is shown in Figure 3 with the lines filled in. Asking the students to fill in a "nutshell" summary template helps them to recall the problem by identifying the solution, its impact on the profit objective, and its relationship to the assembly time and fabric supply constraints.

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Create a "Nutshell" summary by filling in the lines.

Brief problem description: **Product Mix for Two Types of Bamboo beach towels**

Recommended production schedule:
225____ Regular sea turtle bamboo beach towels
300____ Deluxe sea turtle bamboo beach towels
Anticipated profit: **$1800**

Notes: Uses **all 40**_____ hours of assembly time
Uses **225**____ meters of the 350 meters of regular organic bamboo fabric available
Uses **all of the 360**_____ meters of the deluxe organic bamboo fabric as required

Figure 3. "Nutshell" summary for the two-decision product mix

After filling in the nutshell summary, a new follow-up business memo is distributed from the manager. Figure 4 shows the handout that asks the students to continue their role play as a junior business analyst by reading the follow-up memo. The follow-up memo from the manager describes a new extra-large bamboo beach towel design that must be considered.

MEMO
TO: Junior business analyst
FROM: Ed Green, manager
RE: Product mix for sea turtle bamboo beach towels for the coastal market

We have a new extra-large bamboo beach towel design. How many regular, deluxe, and extra-large sea turtle bamboo beach towels for the coastal market should we produce next week in order to maximize profit? Please confer with the procurement, operations, and marketing managers for appropriate data and constraints.

Figure 4. Follow-up memo to introduce class to a third decision for the homework assignment in Figure 1

Students are also given a series of directed questions to answer as a class as shown in Figure 5. Students are asked to identify how the original problem has changed with the introduction of the new design. Then they are asked to identify what additional information they will need from the procurement, operations, and marketing managers to extend their product mix model to include the new extra-large bamboo beach towel design. Examples of answers to the questions are shown in Figure 5.

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What has changed with the new extra-large bamboo beach towel design?
We have a new decision, which means we have a new decision variable.

Given the new extra-large bamboo beach towel design, what information do you need to gather from the procurement manager to determine the product mix?
We need the number of meters of organic bamboo fabric per extra-large towel and its costs per meter.

Given the new extra-large bamboo beach towel design, what information do you need to gather from the operations manager to determine the product mix?
We need the labor requirements per extra-large towel and whether any special skill is required that might increase the labor cost.

Given the new extra-large bamboo beach towel design, what information do you need to gather from the marketing manager to determine the product mix?
We need the price of an extra-large towel and the demand forecast for extra-large towels.

Figure 5. Questions about information required for the third decision

Once the students have outlined the information needs in class, they are given more information in the form of three additional memos as shown in Figure 6. In each of the four memos, the students must identify information for three types of bamboo beach towels. For example, the new memo from the procurement manager requires students to identify the organic bamboo materials required, the organic bamboo material costs, and the organic bamboo material supplies for all three types of bamboo beach towels as well as the deluxe organic bamboo material depletion requirement. The new memo from the operations manager requires students to identify the assembly times, assembly labor cost per hour, and the assembly time available for all three types of bamboo beach towels. Finally, the new memo from the marketing manager requires students to identify the selling price of each of the three bamboo beach towels and that the demand for each type of bamboo beach towel is anticipated to be strong.

MEMO
TO: Junior business analyst
FROM: Bill Spender, procurement manager
RE: Procurement information for sea turtle bamboo beach towels for the coastal market

Each regular sea turtle bamboo beach towel requires one meter of regular organic bamboo fabric while each extra-large sea turtle bamboo beach towel requires 1.4 meters of regular organic bamboo fabric. Up to 350 meters of regular organic bamboo fabric can be procured at $6/meter. Each deluxe sea turtle bamboo beach towel requires 1.2 meters of deluxe organic bamboo fabric which costs $8/meter. To deplete the current deluxe organic bamboo fabric in stock, use exactly 360 meters of deluxe organic bamboo fabric for the production plan.

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MEMO
TO: Junior business analyst
FROM: Ollie Efficiency, operations manager
RE: Operations data for sea turtle bamboo beach towels for the coastal market

Each regular, deluxe, and extra-large sea turtle bamboo beach towel requires four, five, and six minutes of assembly time, respectively. There are 40 hours of assembly time available. Assembly labor costs $12/hour.

MEMO
TO: Junior business analyst
FROM: Melanie Show, marketing manager
RE: Marketing insights for sea turtle bamboo beach towels for the coastal market

Produce the regular and extra-large towels with the regular organic bamboo fabric and produce the deluxe towels with the deluxe organic bamboo fabric. Each regular, deluxe, and extra-large sea turtle bamboo beach towel will sell for $10.80, $13.60, and $16.20, respectively. Since our advertising will continue to include bamboo sustainability characteristics such as regeneration, fast growth rate, and low pesticide use, anticipate strong coastal market demand for all three types of sea turtle bamboo beach towels.

Figure 6. Additional follow-up memos with the data needed for a three-decision product mix

After discussing the memos with new information, the students are given a handout with the original model with extra space for the modifications as shown in Figure 7. The class discussion continues with the students identifying the new third variable for the number of extra-large bamboo beach towels to produce and sell. Then they describe how to modify the objective function by calculating the profit coefficient for the new extra-large bamboo beach towel.

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Original Linear Programming Model

Legend: X1 = number of regular sea turtle bamboo beach towels produced and sold
X2 = number of deluxe sea turtle bamboo beach towels produced and sold

Objective Function: MAX 4X1+3X2 Maximize profit

Constraints

1) $4X1+5X2 \leq 2400$ Assembly time available (minutes)
2) $1X1 \leq 350$ Regular organic bamboo fabric available (meters)
3) $1.2X2 = 360$ Deluxe organic bamboo fabric depletion (meters)
4) $1X1, 1X2 \geq 0$ Non-negativity constraint

Revised Linear Programming Model

Does the legend change? **Yes** If so, how? **Add X_3.**
Does the objective function change? **Yes** If so, how? **Add X_3 and its profit coefficient $6.6.**
Does the assembly time available constraint change? **Yes** If so, how? **Add X_3 and its assembly time coefficient 6 minutes.**
Does the regular fabric available constraint change? **Yes** If so, how? **Add X_3 and its regular organic bamboo fabric coefficient 1.4 meters.**
Does the deluxe fabric depletion requirement change? **No** If so, how? _____
Do the non-negativity constraints change? **Yes** If so, how? **Add X_3.**

MARK on the original model below the changes.

Legend: X1 = number of regular sea turtle bamboo beach towels produced and sold
X2 = number of deluxe sea turtle bamboo beach towels produced and sold
X3 = number of extra-large sea turtle bamboo beach towels produced and sold

Objective Function: MAX 4X1+3X2**+6.6X3** Maximize profit

Constraints:

1) 4X1+5X2**+6X3** ≤ 2400 Assembly time available (minutes)
2) 1X1**+1.4X3** ≤ 350 Regular organic bamboo fabric supply (m)
3) 1.2X2 $= 360$ Deluxe organic bamboo fabric depletion (m)
4) 1X1, 1X2, **X3** ≥ 0 Non-negativity constraint

Figure 7. Modifying the original model for a third decision

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As Figure 7 indicates, class discussion includes explaining which constraints are impacted and how. For example, the students must identify that they must add the new decision variable X3 with the six-minute coefficient to the assembly time available constraint. In addition, the students must identify that they must add the new decision variable X3 to the regular organic bamboo fabric available constraint. The students must also determine that they do not need to modify the deluxe organic bamboo fabric depletion requirement since the extra-large bamboo beach towel does not require any deluxe organic bamboo fabric. Finally, the students determine that they must add the new decision variable X3 to the non-negativity constraints. By the end of the class discussion the students have discovered how to model their first three-decision variable problem.

Then the students are shown the Excel solution approach that includes the new third variable. The revised Excel model is shown in Appendix B. Next the students are asked to fill in a "Nutshell" summary for the three-decision problem statement with the revised recommendation, revised impact on the objective function value, and revised impacts on the assembly time and fabric constraints. An example of a nutshell summary template for the three-decision product mix problem is shown in Figure 8 with the lines filled in.

Create a "Nutshell" summary by filling in the lines.

Brief problem description: **Product Mix for Three Types of Bamboo beach towels**

Recommended production schedule:
0_____ Regular sea turtle bamboo beach towels
300____ Deluxe sea turtle bamboo beach towels
150____ Extra-large sea turtle bamboo beach towels
Anticipated profit: **$1890**

Notes: Uses **all 40**_____ hours of assembly time
Uses **210**____ meters of the 350 meters of regular organic bamboo fabric available
Uses **all of the 360**_____ meters of the deluxe organic bamboo fabric as required

Figure 8. "Nutshell" summary for the three-decision product mix

DISCUSSION

Since Palocsay & Markham (2014) reported that product mix problems were covered in all the management science courses included in their recent survey, the active learning exercise presented in this paper can be readily integrated into such courses. The method presented in this paper may also be used to develop additional scenarios. Such development requires instructor planning to create the business scenario, the associated business memos, directed questions, and nutshell summary templates. The integration of modeling extensions, active learning, directed

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questions, and writing about models may be used in other quantitative business classes or even other disciplines.

Larger class sizes, whether face-to-face or online, present a challenge in providing an opportunity for every student to speak in the class discussion. However, the nutshell templates and questions provide an opportunity for every student to write out responses regardless of whether they have a chance to verbalize them with the class.

In conclusion, using the high impact practice of introducing modeling complexity through role playing a business scenario with professional writing can help students become more engaged in learning about business modeling. As students read through the business memos, they assumed the role of a junior business analyst. In this role, students had the opportunity to identify what changed with the introduction of a new decision, to build the revised model, and to summarize the recommendation and its impact on the objective and resources available.

ACKNOWLEDGMENTS

We thank the anonymous reviewers and the editor for their helpful suggestions. Support for this paper was provided by the College of Business and the Quality Enhancement Program at the University of West Florida.

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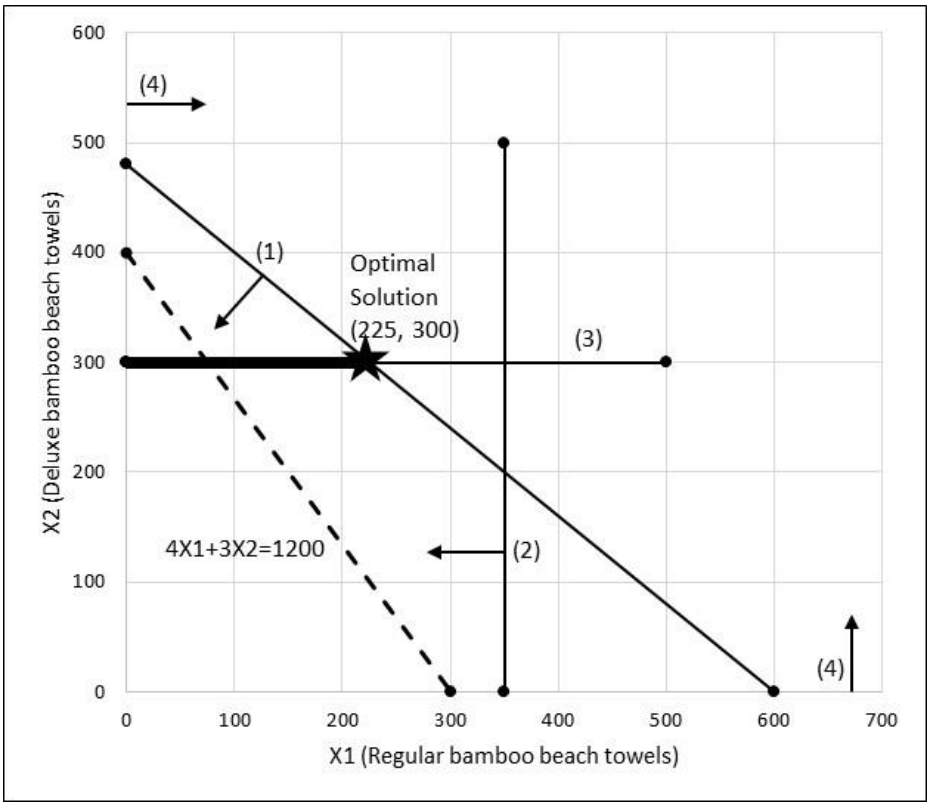
Appendix A
Attachment to Figure 2: Response memo for two-decision product mix homework assignment

The linear programming (LP) model to solve the two-decision product mix problem follows.

Legend: X1 = number of regular sea turtle bamboo beach towels produced and sold
X2 = number of deluxe sea turtle bamboo beach towels produced and sold

Objective Function: MAX 4X1+3X2	Maximize profit
Constraints	
1) $4X1+5X2 \leq 2400$	Assembly time available (minutes)
2) $1X1 \leq 350$	Regular organic bamboo fabric available (meters)
3) $1.2X2 = 360$	Deluxe organic bamboo fabric depletion (meters)
4) $1X1, 1X2 \geq 0$	Non-negativity constraint

The graphical solution procedure to solve the two-decision LP follows. The feasible region is the bold line segment from (0,300) to (225, 300).



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Appendix A (continued)

The Excel solution procedure to solve the two-decision LP follows.

	A	B	C	D	E	F
1	**Production Planning for Sea Turtle Bamboo Beach Towels for the Coastal Market**					
2						
3		**Regular X1**	**Deluxe X2**			
4	**Unit Profit**	4	3			
5						Minutes
6		**Minutes of assembly used per unit produced**		**Minutes used**		Available
7	**Time**	4	5	2400	≤	2400
8						
9						Meters Regular
10		**Meters of regular fabric used per unit produced**		**Meters regular fabric used**		Available
11	**Fabric**	1		225	≤	350
12						
13						Meters Deluxe
14		**Meters of deluxe fabric used per unit produced**		**Meters deluxe fabric used**		Available
15	**Requirement**		1.2	360	=	360
16						
17		**Regular X1**	**Deluxe X2**	**Total Profit**		
18	**Units Produced**	225	300	1800		
19						
20						
21	**Labor Cost**	0.2	0.2	$/min		
22	**Fabric Cost**	6	8	$/m		
23	**Towel Price**	9.8	13.6	$/towel		

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Appendix B

The linear programming (LP) model to solve the three-decision product mix problem follows.

Legend: X1 = number of regular sea turtle bamboo beach towels produced and sold
X2 = number of deluxe sea turtle bamboo beach towels produced and sold
X3 = number of extra-large sea turtle bamboo beach towels produced and sold

Objective Function: MAX 4X1+3X2+6.6X3 Maximize profit

Constraints:

1) 4X1+5X2+6X3 ≤ 2400 Assembly time available (minutes)
2) 1X1+1.4X3 ≤ 350 Regular organic bamboo fabric supply (m)
3) 1.2X2 = 360 Deluxe organic bamboo fabric depletion (m)
4) 1X1, 1X2, X3 ≥ 0 Non-negativity constraint

The Excel solution procedure to solve the three-decision LP follows.

	A	B	C	D	E	F	G
1	**Production Planning for Sea Turtle Bamboo Beach Towels for the Coastal Market**						
2							
3		**Regular X1**	**Deluxe X2**	**Extra-large X3**			
4	**Unit Profit**	4	3	6.6			
5							Minutes
6		**Minutes of assembly used per unit produced**			**Minutes used**		Available
7	**Time**	4	5	6	2400	≤	2400
8							
9							Meters Regular
10		**Meters of regular fabric used per unit produced**			**Meters regular fabric used**		Available
11	**Fabric**	1		1.4	210	≤	350
12							
13							Meters Deluxe
14		**Meters of deluxe fabric used per unit produced**			**Meters deluxe fabric used**		Available
15	**Requirement**		1.2		360	=	360
16							
17		**Regular X1**	**Deluxe X2**	**Extra-large X3**	**Total Profit**		
18	**Units Produced**	0	300	150	1890		
19							
20							
21	**Labor Cost**	0.2	0.2	0.2	$/min		
22	**Fabric Cost**	6	8	6	$/m		
23	**Towel Price**	10.8	13.6	16.2	$/towel		