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Introducing Integer Modeling with Excel Solver

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Abstract

This article suggests ideas for introducing integer modeling of fixed (entry) costs with Excel Solver to business students. The presented example uses concepts from accounting, such as assessing distribution channel profitability, and blends them with management science techniques. The effectiveness of the software use is in integrating it successfully into a comprehensive discussion about assumptions, modeling, limitations, software pitfalls, validation, and implications for managerial decision making.

1. Introduction

The widespread use of spreadsheet add-in software has undoubtedly changed the way we teach operations research and management science to business students (Erkut, 1998). Complex operations research concepts such as integer programming that required specialized software and mathematical modeling background can now be introduced and demonstrated in a single lecture, in a context with which students can identify and which they can easily follow. While spreadsheet add-ins have made operations research more tangible, they have also presented instructors with important questions that need to be addressed.

First, how much emphasis should be put on teaching actual optimization modeling concepts? For example, integer programming models frequently involve tricky ways of expressing problem constraints, and are difficult for students with little mathematical background. The evolutionary solver in Premium Solver accommodates Excel functions such as IF, INDEX, and COUNTIF that business students are tempted to use, and find more intuitive. Excel Solver, the optimization add-in that is part of the standard Excel package, cannot handle such Excel functions, and requires a more classical approach to modeling optimization problems. This has implications for how optimization modeling is actually taught, and changes student understanding of "difficult" versus "easy" optimization problems. These inherently different philosophies of using optimization software in the classroom are the subject of an interesting study by Baker and Camm (2005). Surprisingly, the results are not clear-cut, and the classical

approaches to teaching integer modeling still appear to have some distinct advantages.

Second, how much discussion do optimization algorithms and software pitfalls merit in a core business class? Optimization should be seen as a tool to help business students - future managers - make decisions, not an end in itself. This appears to be an argument for using a relatively superficial approach to optimization modeling in business courses, so that students can handle a particular business situation without spending too much time on mathematical formulations and understanding the algorithms behind the solvers. Paradoxically, this can be actually viewed as an argument for spending more time on the intuition behind the algorithms that solvers use. It is much more important for business students to learn about the *limitations* of the models and the software than it is for them to learn *ad-hoc* approaches for getting answers that then do not make sense from a business perspective. Students should know how much they can expect from (and trust) optimization formulations and solvers. This is particularly true in the case of the standard Excel Solver that can produce misleading results on complex optimization problems, and on integer programming models in particular. Troxell (2002) discusses teaching about Excel software pitfalls in the context of undergraduate business education. Other than her study, surprisingly little can be found in the literature on raising student awareness of this important issue.

Finally, as Trick (2004) points out, finding examples of integer programming problems that appeal to business students can be difficult, and to most students the concept of integer programming applications ends

with problems in which the variables are restricted to be integer, e.g., the number of widgets to be produced by a factory. However, it is important that students obtain an idea of the power of integer modeling, as this power has become apparent in the success of many integer optimization modeling applications that have been recently presented at the INFORMS Edelman Prize competition or published in *Interfaces* (see, for example, Bertsimas et al., 1999; Apte et al., 2004; Lee and Chen, 2002; Gendron 2005; Chao et al., 2005 and Van den Briel et al., 2005). It is also important to motivate the discussion by introducing the concepts in an application context that does not take too much time to set up and understand.

This article explains how integer programming modeling is introduced in the MBA core curriculum at Babson College in the context of selecting appropriate distribution channels for a small business. The full-time MBA program at Babson has an integrated core curriculum in which decision support tools are taught in the context of cases presented by operations, accounting, and finance faculty. All MBA students complete the core curriculum during their first year, and can take elective courses to deepen their knowledge in a particular area in their second year. Integrated teaching has a number of advantages for the operations research area, the biggest one of which perhaps is that integrated applications lend credibility to decision support systems. However, integrated teaching also presents a unique challenge to operations research faculty, who do not have a stand-alone course in which they can focus on the modeling techniques themselves. There are only a couple of workshop-style lectures, and not enough time to introduce a substantial amount of new software. Since MBA students frequently do not have access to specialized software during their internships in the summer following their first year anyway, it is preferable that the operations research software tools taught in the core curriculum be standard Excel add-ins, such as Excel Solver. More advanced tools are covered in the second-year electives.

The integer programming class is a joint teaching session with the accounting faculty, and the particular application described in this article allows us to address several of the questions mentioned earlier:

- Integer programming is introduced in a business context that the students have had time to understand thoroughly through the accounting part of

the lecture, thus enabling operations research instructors to focus on teaching what they know best: the actual optimization modeling techniques;

- The classical mathematical modeling of integer programming problems is presented, and *ad-hoc* modeling with Excel functions such as IF, COUNT, etc., is avoided;
- Students complete an exercise to understand first-hand the ideas behind binary integer programming modeling;
- The problem provides an opportunity to discuss optimization algorithms, difficult versus easy optimization problems, and Excel Solver pitfalls when it comes to integer programming problems.

While an integrated teaching environment is helpful for making this business application appear realistic, the model can be used as a stand-alone example as well. An operations research instructor can set up the case by explaining how the inputs to the optimization problem are obtained at an intuitive level. This article will provide some basic information about the accounting concepts used in the case.

2. The Case Setup

The background for the session is the Even'Star Organic Farm case (Shanks et al., 2006), a case with a relatively simple background so that students can be introduced to the concept of pricing channel profitability in accounting. The basic premise is as follows: Brett Grohsgal, a former chef from Washington, DC, has started an organic farm in southern Maryland after creating a network of contacts in restaurants and observing the demand for organic vegetables grow over the years. The vegetables for this year (large tomatoes, small tomatoes, watermelon, okra, basil, cucumbers, sweet potatoes and winter squash) have already been planted, and he has a choice of three channels to distribute the produce: restaurants (R), community supported agriculture (CSA), and two farmers' markets (FM). The price of each type of produce is different in the different channels. In addition, entering each channel is associated with an *entry cost* (we avoid the term *fixed cost* because of its specific meaning in accounting), as well as with variable costs that scale with the amounts sold through each channel. Brett needs to figure out which channels to use, and how much of each produce to sell in each channel. Brett is an actual

entrepreneur whom we helped with the analysis, and the story resonates with students, who can easily understand the context and focus on the lessons from the case.

The accounting and the decision support systems faculty jointly emphasize the importance of a systematic approach for analyzing the situation. The three stages of the analysis are as follows:

- Learn about the situation and issues, compute costs and benefits of each type of produce and channel;
- Employ modeling techniques to come up with the optimal distribution of produce;
- Verify that the solution makes sense intuitively, and discuss the implications for Brett's business.

In the first stage, students work through the computation of costs with the accounting faculty. Students have information on the cost of seedlings, fertilizer, labor, mulch, and irrigation per acre, as well as the average yield per acre Brett has obtained historically for each type of produce. Based on these data, they can determine the cost of a case of each type of produce (later, the operations research instructor can refer back to these assumptions, and discuss the implications of using average historical estimates). The computation of the cost for each distribution channel is not trivial. Moreover, it is not unique - there are different ways to approach the cost accounting, and therefore different estimates of the variable and entry costs. For example, one possibility for computing the entry cost for the restaurants channel is as follows: Brett has a certain cost (e.g., truck mileage, time) associated with driving from his farm in southern Maryland to DC in order to deliver to DC restaurants. He will incur this cost independently of whether he delivers to one or to ten restaurants. Therefore, he can treat this cost as an "entry" cost, and count the cost associated with delivering to each additional restaurant customer after the first restaurant in DC as the variable cost of delivery per customer. For further details on the accounting solution, the interested reader is referred to Shanks et al. (2006).

Depending on how the entry versus variable costs are computed, students may obtain different inputs for

the second stage of the analysis, which involves creating an optimization model, and solving for the optimal allocation of produce to channels. This in turn provides for an interesting conversation in the third stage of the analysis, which is a joint accounting/decision support systems discussion of the insights Brett could gain from the first two stages.

A summary of one possible set of the accounting computation results from the first stage is provided in the worksheet Data in the file⁽¹⁾. The optimization models from the second stage are presented in the worksheets Assignment Solution and IP Model in the same file.

3. The Optimization Model

At this point in the course, students have been introduced to linear programming problem formulations and Excel Solver. They know that there are three parts to every optimization problem: (1) decision variables (changing cells for Solver); (2) objective function (target cell for Solver), and (3) constraints. It is not difficult for them to come up with the decision variables in this problem as the number of cases of each type of produce Brett should sell in each channel, and with the objective function as the overall channel margin (the expression for the channel margin is (total revenues - total costs)). However, this is the first time students in the course encounter a two-step optimization model. In order to maximize the overall channel margin, they need to keep track of the channel selected and the variable costs and revenues associated with selling in that channel. Students with little modeling background are inevitably tempted to use IF statements in Excel to represent the cost computation. For example, in order to compute the cost of entering the Restaurants channel, they use a statement of the kind "If the total number of cases of produce sold in the Restaurants channel is greater than zero, add the entry cost for the Restaurants channel to overall costs," which would be entered in cell E54 in the spreadsheet model⁽²⁾ (worksheets Assignment Solution and IP Model), and would read "=IF(D11>0,Data!D25,0)". Excel Solver cannot handle IF statements. What is more troubling, however, is that Solver sometimes does not return an intelligible error message, so students are not aware that the IF statements are causing a problem.

(1) <http://ite.pubs.informs.org/Vol7No1/Pachamanova/EvenStarSolution.xls>

(2) <http://ite.pubs.informs.org/Vol7No1/Pachamanova/EvenStarSolution.xls>

In order to guide the students through the model, I distribute a model template⁽³⁾ and a handout with an assignment, which students complete before class. The handout is enclosed in Appendix 1, and snapshots of the spreadsheets are available in Appendix 2. As students work through the handout, they learn that one can think of entering a channel as a binary decision that can be represented by 0 or 1 in dedicated cells in the spreadsheet (cells D12:F12). This eliminates the need to use IF statements. For example, the entry cost for the Restaurants channel in cell E54 can be computed as " $=D12*Data!D25$ ". Once the students have specified a combination of channels they think Brett should use, they can solve a linear optimization problem to determine the optimal number of cases of each type of produce that Brett should sell in the selected channels (at this point, it is assumed that the number of cases does not have to be integer. I come back to that discussion later in class). The file template contains constraints on the binary variables (cells L24:N26), but they are deliberately hidden in the right-hand side of the worksheet, and students are told not to worry about them at this stage. There are eight possible combinations of channels; however, one of them ($\{0,0,0\}$) is not useful in practice, so students need to solve seven linear optimization problems. Solving linear problems of this size with Excel Solver is easy and fast, and the optimal solutions can be trusted, so students can identify the true optimal combination of channels as well as the optimal distribution for the produce. It is then only a natural step forward to discuss automating the process in class, and introduce students to the concept of binary integer modeling. In fact, students raise the issue of using binary decision variables themselves.

Extending the linear programming model to an integer programming model happens as follows: cells D12:F12 are specified as "bin" (binary) in the constraints part of the Solver dialog box, and added to the changing cells part in the Solver dialog box. At the beginning, I leave the option "Assume Linear Model" unchecked.

When called, Excel Solver may behave erratically - it may produce suboptimal or unintuitive solutions, and may sometimes declare an optimal solution that is worse than the starting point. For example, if all initial

values for all decision variables are set to 0, Excel Solver returns the suboptimal solution in Fig. 1.

Decision Variables:					Total cases sold
	Restaurants	CSA	FM		
Tomatoes (large)	295	111	0		407
Tomatoes (small)	0	465	143		608
Watermelon	0	0	167		167
Okra	0	37	39		76
Basil	0	72	0		72
Cucumbers	0	0	251		251
Sweet Potatoes	107	0	0		107
Winter Squash	133	0	0		133
Total	917	902	0		1820
Channel used?	1	1	1		
Objective Function:					
Channel Margin	\$ 49,223.31				

Figure 1: A suboptimal solution returned by Excel Solver when the starting values for all decision variables are zero, and the 'Assume Linear Model' option is unchecked.

This stage of the modeling process allows for an extensive discussion of the limitations of integer programming in Excel Solver. The standard version of Excel Solver cannot handle integer programs well. This is particularly true if the model involves both integrality constraints and nonlinearities, and students ought to know they cannot use Excel Solver in such cases. It should be pointed out that the limitations with regard to nonlinear integer problems are not unique to Excel Solver - such problems are inherently very difficult to solve. However, the standard Excel Solver is more susceptible to problems than solvers that use more sophisticated algorithms for integer programming. One could argue that this makes the standard Excel Solver better suited for teaching purposes, as it demonstrates more dramatically that one should not accept the computer output without critical inspection. It is important for students to realize that obtaining a solution in some situations is not as easy as the click of a button. The instructor may want to emphasize also that a number of optimization solvers, such as CPLEX and MOSEK, can handle efficiently large mixed-integer linear programs. In addition, Premium Solver and Premium Solver Platform for Excel have better solver engines and more reliable integer programming code for linear problems. The educational version of Premium Solver may be a good resource for students, as its interface is the same as the standard Excel Solver, but it has more solver options, and is available at no additional cost with the purchase of a number of operations research textbooks, e.g., Rags-

(3) <http://ite.pubs.informs.org/Vol7No1/Pachamanova/EvenStarAssignment.xls>

dale (2006), or Powell and Baker (2003) (a comprehensive list of such textbooks is available from Frontline Systems, Inc.'s website⁽⁴⁾). Instructors who have sufficient time to spend on integer modeling can use the example in this lecture as a motivation to use more advanced software for the remainder of their courses.

Students, having identified the optimal solution manually as part of their preparation for the class, can see the potential for problems with the EvenStar Organic Farm integer programming model. For example, one of the constraints in the problem requires that the monetary value for the number of cases of large tomatoes sold to CSA customers should be at least 16.78% of the overall monetary value of produce sent to CSA customers (see Appendix 1). Most students without modeling background tend to formulate this constraint as nonlinear, e.g. (referring to spreadsheet⁽⁵⁾, worksheet IP Model): $(E3*Data!G2)/(SUMPRODUCT(E3:E10,Data!G2:G9)) \geq Data!G12$. I explain that by multiplying both sides of the inequality by $SUMPRODUCT(E3:E10,Data!G2:G9)$, students can convert this nonlinear constraint into a linear constraint, thus making the problem easier for Solver. The latter algebraic manipulation, of course, works only when the expression in the denominator is nonnegative, but in practice this condition is frequently satisfied in business applications. In the context of the Excel Solver solution errors the students have just observed, this example of converting a nonlinear constraint into a linear one reinforces the notion of the importance of recognizing the type of optimization problem for solving the problem effectively.

Having reviewed linear versus nonlinear problems, I check the "Assume Linear Model" option. When this option is checked, Solver starts out by solving the linear relaxation of the problem, and, at least in the case when the initial values of all decision variables are set to 0, it finds the optimal solution that students have discovered through their assignment. This gives me the opportunity to discuss briefly the integer programming algorithm (branch-and-bound) Solver uses to come up with an optimal solution. The meaning of the options available to the user under Options in the Excel Solver dialog box (e.g., Tolerance, Max Iterations, and Max Seconds) then becomes more intuitive to the stu-

dents. For example, the Tolerance option allows users to specify an acceptable percentage difference between the best bound from the branch-and-bound method and the integer solution Solver reports. The default value in Excel Solver is 5%, as the integer programming algorithm frequently finds a near-optimal solution quickly, and then spends a large amount of time checking if this is the best possible integer solution. I change the value to 0% for illustration purposes, set the values of the decision variables to 0, and run Solver again. The optimal solution does not change. When the tolerance is set to 0, the option "Assume Linear Model" is checked, and Excel Solver reports it has found a solution, it is generally expected that the solution is indeed optimal (see, for example, Frontline Systems' online help⁽⁶⁾). However, in practice the standard Excel Solver performance is not robust even in the latter case. For example, Excel Solver may not be able to find a feasible solution or may return a very bad solution when started at the optimal integer solution, or at a slightly infeasible solution. Excel Solver does not check properly whether the "Assume Linear Model" conditions are indeed satisfied. However, it may declare that the "The conditions for Assume Linear Model are not satisfied," which is the same error message one would obtain if the problem is poorly scaled. Trying out different starting values for the decision variables, and checking the "Automatic Scaling" option in the Solver dialog box helps stabilize Excel Solver's behavior in this particular problem, but does not always work. Thus, in practice the Excel Solver output when it comes to integer or mixed-integer programming problems should not be taken at face value and should be analyzed thoroughly.

After reviewing the Excel Solver options and error messages, I discuss integer (as opposed to binary) variables in general, e.g., when modeling the number of cases of each produce. This is a counterintuitive issue for many students who believe that problems with integer variables are easier to solve. I talk about enumeration versus smart searches for optimal solutions, and about alternative optimization methods such as evolutionary algorithms (available with Premium Solver) that present their own limitations (Baker and Camm, 2005). I conclude with a discussion of further applications of the modeling technique described in

(4) <http://www.solver.com/>

(5) <http://ite.pubs.informs.org/Vol7No1/Pachamanova/EvenStarSolution.xls>

(6) <http://www.solver.com/suppstdmsgresult2.htm>

the class. Financial applications of integer modeling (e.g., modeling complex transaction cost functions and limits on the number of trades in optimal portfolio rebalancing with thousands of securities, as in Bertsimas et al., 1999) are frequently very interesting to the students. Extending the discussion to large scale applications validates, in an important way, the integer modeling technique the students have just seen.

I return to a discussion of the optimal solution to Brett's problem, presented in Fig. 2. It turns out that it is optimal not to use the farmers' markets channel.

Decision Variables:					
	Restaurants	CSA	FM	Total cases sold	
Tomatoes (large)	258	148	0	406	
Tomatoes (small)	0	608	0	608	
Watermelon	167	0	0	167	
Okra	0	76	0	76	
Basil	0	72	0	72	
Cucumbers	251	0	0	251	
Sweet Potatoes	107	0	0	107	
Winter Squash	133	0	0	133	
Total	916	904	0	1820	
Channel used?	1	1	0		
Objective Function:					
Channel Margin	\$ 53,620.50				

Figure 2: Optimal solution for the Even' Star channel distribution optimization problem.

I ask the students why Solver did not set all binary variables to zero in the optimal solution. After all, this would result in a higher channel margin, because the entry costs would not be subtracted from the channel margin. Students are puzzled at first, and we discuss the constraints that have so far been hidden in the right hand-side of the spreadsheet (cells L24:N26). These constraints make sure that if the total number of cases sold in a channel is greater than zero, the integer variable for that channel is set to 1, and consequently the cost of entering that channel is subtracted from the overall channel margin.

After the mathematical issues in finding the optimal solution are explained, the accounting faculty joins in a discussion of whether the optimal solution makes sense from a business strategy perspective. We review the assumptions made both on the accounting and the modeling side, and note that all input parameters in the optimization model have been obtained by averaging values from previous years. Is it then a good idea to abandon the farmers' markets channel altogether? Farmers' markets may be a good way to dispose of extra produce if the yield in this particular year is high.

We talk about the sensitivity analysis that needs to be done to establish that the solution in Fig. 2 is indeed a robust solution. In this context, I mention that in integer programming, there is no equivalent to the sensitivity analysis output in linear programming. However, one can figure out by re-solving the problem if a certain percentage of change in yields will change the optimal solution. This is a good place to talk also about methods for making an optimization problem robust with respect to uncertainty in the input data, such as optimization over scenarios using stochastic programming, robust optimization, as well as other modeling techniques for evaluating the impact of changes in initial conditions, such as simulation. This wrap-up discussion is very helpful for validating the presence of operations research in the business core curriculum.

4. Conclusions

This article presented ideas for introducing integer programming modeling with Excel Solver to business students, while making students aware of software limitations and pitfalls, and validating the rigorous approach to business decisions. Albeit simple, the model of the business situation allows for a discussion of a number of important issues, both on the optimization and the management side, and in my experience is well-received by students. It also reflects priorities which, I believe, are important for the education of business students: the optimization software is not the focus, but is there so that it can enable the issues of making assumptions, modeling, validation, and business decision-making to be discussed.

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Appendix

Appendix I - Even' Star Organic Farm Student Assignment(To Be Completed Before Lecture)

As part of the joint accounting/decision support systems Even' Star case assignment, you need to figure out which channels (Restaurants, CSA or Farmers' Markets) Brett should use, and what is the optimal number of cases of each produce Brett should sell in the channels he uses. Note that using a channel is associated with incurring entry costs (those you should compute as part of the accounting assignment). Therefore, if the entry costs for a channel are too high, it may be optimal not to use that channel at all.

1. Problem Setup

The optimization model is complex, and the spreadsheet⁽⁷⁾ is set up to provide you with helpful hints in building it. You should fill out all cells with red borders. Look for comments in the spreadsheet as you formulate the optimization problem (Note: If you select View > Comments from the top menu in Excel, you will be able to see all comments at once.).

Start out by defining the **decision variables** (the **light green cells D3:F10**). They represent the total number of cases of each product Brett should sell through each channel during the whole year. The **dark green cells D12:F12** are **toggle cells** whose values can be only 0 or 1 - set their value equal to 1 if you think Brett should use the corresponding channel, and 0 if you think Brett should not use the corresponding channel. The objective is to maximize the channel margin (the bright yellow cell **D17**), and the formula that has been set up for that cell computes the cost of using the particular combination of channels you choose.

Brett has to deal with multiple constraints, but we will simplify the problem in order to make it manageable for the purposes of this assignment. Use the following constraints in your formulation:

Constraint 1 (Rows 25-32 in the spreadsheet): Total cases sold of each type of produce cannot be more than the total number of available cases of that produce for the season (**D25:D32** <= **F25:F32**).

Constraint 2 (Row 34 in the spreadsheet): Due to limitations in truck capacity, the total number of cases sold in the farmers' market cannot be more than 600.

Constraint 3 (Row 35 in the spreadsheet): Brett cannot find more than 20 restaurant customers at this point, so this is the maximum number of restaurants he would be able to sell to. Write a formula in cell **D35** that computes the number of restaurant customers he can afford to have if Solver finds that the optimal number of cases he can sell to restaurants is the total in cell **D11**. The number of cases Brett sells to each restaurant should have been found as part of your accounting assignment (it is provided in cell **B12** of the **Data** worksheet).

Constraint 4 (Row 36 in the spreadsheet): Brett cannot find more than 90 CSA customers. In cell **D36**, write a formula to compute the optimal number of CSA customers Brett can have if the total number of cases he needs to sell through the CSA channel is the number Solver computes in cell **E11**. Be careful: the number of CSA customers is linked to the optimal number of cases in cell **E11** through the dollar amount (\$400 from cell **B14** in the **Data** worksheet) that should be allocated per CSA customer.

Constraint 5 (Row 38 in the spreadsheet): Brett believes that each CSA box should contain a variety of produce. CSA customers value particularly highly his tomatoes, so we will require that the dollar amount for cases of large tomatoes sent to CSA customers should be at least 16.78% of the overall CSA market value (the number

⁽⁷⁾ <http://ite.pubs.informs.org/Vol7No1/Pachamanova/EvenStarAssignment.xls>

is provided in cell G12 of the **Data** worksheet). The overall CSA market value can be computed as the number of cases of each produce sent to CSA customers in cells **E3:E10** multiplied by the corresponding CSA price for a case of that produce (the prices are provided in cells **G2:G9** of the **Data** worksheet). Hint: The SUMPRODUCT function in Excel will save you a lot of typing. One can impose additional constraints on the contents of a typical CSA box (the data for a typical composition of a CSA box for past years is provided in cells **K2:K9** of the **Data** worksheet). However, we suggest that you do not impose more constraints unless you have some extra time to play with the assumptions, because they significantly restrict the options available to Brett.

Constraints 6 (Cells **L24:N26**): These constraints have already been set, so please do not make any changes to them. They ensure that if you enter 0 for a particular channel in the dark green cells **D12:F12**, that channel does not get used.

Rows 42-61 break up the calculation of the overall channel margin in pieces that should not be too hard for you to fill out. Hints for what should be entered in each cell are in the spreadsheet. Please note: since the entry costs for a channel are only incurred if a channel is used, cells **E54:E56** should contain the formulas "**=D12***(entry cost for Restaurants)", "**=E12***(entry cost for CSA)" and "**=F12***(entry cost for FM)". These entry costs should be computed as part of your accounting assignment (the numbers are provided in cells **D25:F25** in the **Data** worksheet).

2. Solving the Problem

The Solver dialog box has been already set up. Please make sure you understand the set up of the problem.

Change the numbers in cells **D12:F12** from 1 to 0 and from 0 to 1 to specify what combination of channels should be used, then run Solver. Note: there are 7 possible useful combinations for cells **D12:F12**: (1,1,1), (1,0,1), (0,1,1), (1,1,0), (1,0,0), (0,1,0), and (0,0,1). You will need to run Solver for each of these combinations, and make a note of the optimal Channel Margin you get by using that combination of channels. Make a note also of the strategy Brett should pursue, i.e., how many cases of each type of produce he should sell if he goes with that combination of channels. Is the optimization problem linear?

Important! Remark 1: Please make sure you read the Solver results message box carefully. Because of the constraints in the problem, some of the combinations of channels may be *infeasible*, in which case Solver will populate the cells in the spreadsheet with numbers that do not make sense, and report "*Solver could not find a feasible solution.*" Make a note of Solver's message, and do not save that solution - it will not make sense.

Remark 2: By specifying "0" in one of the cells **D12:F12**, you will make sure that the particular channel does not get used. However, the spreadsheet is set up in such a way that channels for which you have entered "1" will **not** necessarily be used. This is Ok.

3. Assignment

Prepare a brief summary with your results:

- Which combination of channels resulted in the highest channel margin?
- How many cases of each type of produce should Brett sell through each channel?
- Do these recommendations make sense given his overall business objectives?

Appendix II - Spreadsheet Model Snapshots

Worksheet **Data** in EvenStarAssignment.xls and EvenStarSolution.xls.

	A	B	C	D	E	F	G	H	I	J	K
1		Expected available cases			Prices	Restaurants	CSA	Farmers Markets			Approximate Percentages of Standard CSA Case/lot
2	Tomatoes (large)	406		Tomatoes (large)	\$ 40.00	\$ 36.00	\$ 38.25	Tomatoes (large)	12.50%		
3	Tomatoes (small)	608		Tomatoes (small)	\$ 26.00	\$ 36.00	\$ 34.00	Tomatoes (small)	8.25%		
4	Watermelon	167		Watermelon	\$ 20.00	\$ 20.00	\$ 20.25	Watermelon	10.00%		
5	Okra	76		Okra	\$ 24.00	\$ 36.00	\$ 34.00	Okra	5.00%		
6	Basil	72		Basil	\$ 18.00	\$ 24.00	\$ 21.25	Basil	5.00%		
7	Cucumbers	251		Cucumbers	\$ 24.00	\$ 24.00	\$ 25.20	Cucumbers	16.67%		
8	Sweet Potatoes	107		Sweet Potatoes	\$ 36.00	\$ 36.00	\$ 36.00	Sweet Potatoes	10.00%		
9	Winter Squash	133		Winter Squash	\$ 36.00	\$ 36.00	\$ 36.00	Winter Squash	18.75%		
11	Total number of cases sold to one restaurant over the season					Historical average percentage of large tomatoes in CSA box					
12		119				16.78%					
13	Total dollar amount sold to a CSA customer over the season										
14		\$ 400.00									
15	Total number of cases possible to ship to the farmers markets in a season										
16		600									
18	Maximum possible number of restaurant clients										
19		20									
20	Maximum possible number of CSA customers										
21		90									
23				Restaurants		CSA		Farmers Markets			
24	Variable costs per client per season			\$ 214.40	\$ 31.68	\$ 0					
25	Entry cost per season			\$ 1,495.50	\$ 730.50	\$ 5,833.50					

Worksheet **IP Model** in EvenStarSolution.xls.

	A	B	C	D	E	F	G	H	I	J	K
1	Decision Variables:										
2				Restaurants	CSA	FM	Total cases sold				
3	Tomatoes (large)	258	148	0	406						
4	Tomatoes (small)	0	608	0	608						
5	Watermelon	167	0	0	167						
6	Okra	0	76	0	76						
7	Basil	0	72	0	72						
8	Cucumbers	251	0	0	251						
9	Sweet Potatoes	107	0	0	107						
10	Winter Squash	133	0	0	133						
11	Total	916	904	0	1820						
12	Channel used?	1	1	0							
15	Objective Function:										
16											
17	Channel Margin	\$ 53,620.50									
20	Constraints:										
21											
22		LHS	sign	RHS	units						

Worksheet **IP Model** in EvenStarSolution.xls (continued).

	LHS	sign	RHS	units	integer
Constraints:					
Total available cases	Cases sold	<=	Available cases		
Tomatoes (large)	406	<=	406	cases	Rest ent
Tomatoes (small)	608	<=	608	cases	CSA ent
Watermelon	167	<=	167	cases	FM entry
Okra	76	<=	76	cases	
Basil	72	<=	72	cases	
Cucumbers	251	<=	251	cases	
Sweet Potatoes	107	<=	107	cases	
Winter Squash	133	<=	133	cases	
Farm Market Capacity Ceiling	0	<=	600	cases	
Max number restaurants	8	<=	20	restaurants	
Max CSA subscribers	79	<=	90	customers	
CSA Mix requirement	\$ 5,313.47	>=	\$ 5,313.47		
Restaurant mix requirement	cases %	=	exhibit 1 %		
Income Statement:					
Revenues					

Worksheet **IP Model** in EvenStarSolution.xls (continued).

Income Statement:					
Revenues					
Restaurants	\$ 28,340.15				
CSA	\$ 31,665.47				
Farmers markets	\$ -				
Total revenues	\$ 60,005.61				
Costs					
Variable					
Restaurants	\$ 1,651.07				
CSA	\$ 2,508.05				
Farmers markets	\$ -				
Entry					
Restaurants	\$ 1,495.50				
CSA	\$ 730.50				
Farmers markets	\$ -				
Total costs	\$ 6,385.12				
Channel margin	\$ 53,620.50				