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Using spreadsheet optimisation facilities as a decision aid within the theory of constraints framework

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Errata
In Table 3, Table 4, and on page 10, the figures 1950 and 450 for Resource A should read 1800 and 600 respectively.

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USING SPREADSHEET OPTIMISATION FACILITIES AS A DECISION AID WITHIN THE THEORY OF CONSTRAINTS FRAMEWORK

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Abstract

This paper seeks to bridge the gap between managers and management science (MS) models by demonstrating how to use a computer spreadsheet to explore common managerial issues such as product mix and resource allocation.

In the past, managers may have been put off by the complexity and user-unfriendliness of many MS models. However the advent of spreadsheets has opened up access to these models in a user-friendly way.

This paper demonstrates how to set up a spreadsheet to explore issues such as how to make the most effective use of scarce resources. Using the optimisation capabilities of spreadsheets, this question can be answered in minutes. Sensitivity and answer reports are generated automatically, which give the user much information about the quality of the solution. While Excel will be used for this demonstration, the general approach is similar for other spreadsheet packages such as Quattro Pro.

The paper also shows how the use of MS models can be embedded in the wider Theory of Constraints (Goldratt), for fuller benefits and understanding. This approach has been applied to a local company who have gained fresh insights into their operations.

INTRODUCTION

Resource Allocation and Product Mix Problems

Resource allocation is a problem faced everywhere by all managers, unless they are very lucky and have too many resources. In most cases, the total resource to be allocated needs to be shared among many activities. Often this is done on an ad hoc basis, rarely planned explicitly. However in many cases, a more planned use of resources would achieve a better return. For example, the product mix problem has long been solved by Management Scientists using a technique called Linear Programming (LP), noting that the common rule of favouring products with the highest profit margins often leads to sub-optimal profits. More recently Goldratt (1990a) has used a simple P and Q product mix example to demonstrate this same phenomenon, and to introduce the Theory of Constraints (TOC) see Goldratt (1990b) as a method superior to the cost accounting method, for making product mix and resource use decisions.

Several authors have used and built on his ideas and drawn parallels between LP and TOC, eg Mabin (1988) and Patterson (1992). More recently, Lee and Plenert (1993) have sought to demonstrate the superiority of LP over TOC, by providing a numerical example involving the addition of optional new products to the P and Q product mix problem. However, as Maday (1994) and Posnack (1994) have both argued, Lee and Plenert have portrayed TOC in a less than generous light. If TOC had been applied as Goldratt intended, then again TOC would give the same results as LP.

This present paper takes the argument several steps further. First it is this author's contention that LP or other optimisation models should be used within the TOC framework. Indeed, this paper shows how LP can be used within the TOC framework as a useful decision aid. LP on its own produces only a fraction of the benefits that its use within the TOC framework can bring. Similarly it is argued that TOC benefits from the quantitative strengths of techniques such as LP, for example a solution will be found quickly if one exists, and "what if" information is available.

Secondly, the previous papers by Patterson (1992) and Lee and Plenert (1993) have used specialist LP packages to which most managers will not have access. However, current spreadsheets have optimisation facilities available that can be used to perform such calculations. Given the widespread use of spreadsheets, it appears worthwhile to use them in preference to specialist packages, to encourage wider adoption of such powerful everyday tools. This paper demonstrates and discusses such use.

This paper shows how a product mix problem can be laid out on a spreadsheet and readily solved using Excel Solver. The managerial relevance of even simple problems like this has been demonstrated in Patterson (1992), who showed how a complex product mix problem was successfully simplified, with useful results. We have had further endorsement of using TOC and LP through a teaching case based on a local company (Mabin 1994). The company involved has benefited already and expects to continue to do so, from the insights such an analysis has provided.

Linear programming and Optimisation on Spreadsheets

Linear Programming (LP) is a well-established Management Science (MS) technique that has up till now been largely the domain of the MS specialist. However, with the advancement of spreadsheet packages such as Excel which now incorporate optimisation and problem solving capabilities, LPs can now be modelled and solved by the general computer user. Using spreadsheets as a medium for modelling and solving LPs brings obvious advantages such as ease of access and universality. Other advantages include easier user understanding, through the minimal use of technical jargon. Spreadsheets are a valuable tool for developing pilot models, and for communicating decision models and concepts to non-MS people, especially those such as clients and students who are familiar with spreadsheets. However as with all spreadsheet models, careful spreadsheet design is imperative, and from our experience we have learnt that some spreadsheet formulations are better than others. This paper provides recommendations based on this experience.

Optimisation using the Excel Spreadsheet Package

Spreadsheets are a universal tool used widely in organisations (Cavana (1989), Cragg and King (1993)), and most now provide optimisation facilities. According to the Excel manual, "Microsoft Excel Solver utilizes non linear optimization code developed by Leon Lasdon and Allan Ware. Linear and integer problems utilize the Simplex Method with bounds on the variables and the branch and bound method ..." These features enable the solution of Linear Programming and other optimisation problems on either Macintosh or PC platforms, thus making Solver an extremely accessible and versatile means of solution, for people both within and outside the MS community.

This paper is based on experience gained while using the Solver software in our teaching of LP to MBA students, for whom we believe it is an advantage to be able to use the spreadsheet tool with which they are familiar, rather than use a specialist OR package (like QSB or QAM which we have used in previous years) which bears little similarity to packages they use or have available in their work-places. With this greater familiarity, we are hopeful that the power of LP will be invoked more often.

While the demonstration problem in this paper is small, Solver can handle 200 decision variables, with upper or lower bounds, and up to 100 additional constraints including integer constraints, so reasonably large problems could conceivably be tackled.

However the use of spreadsheets and the Solver optimisation routines does require care to avoid several traps. This paper aims to alert users to some pitfalls and provide some pointers to overcome these. Large models are particularly hard to check for errors and specialist LP packages would be recommended for large problems. However, spreadsheets do provide a useful tool for pilot or demonstration models.

Structure of the paper

A simple product mix problem is described which will be used to demonstrate how LP can be used within the TOC framework. First the problem is described, then an outline of the integration of LP into TOC, and this will be illustrated using a spreadsheet package, Excel, for solving optimisation problems, in particular, linear programs (LPs).

Linear Programming within a TOC Framework

Optimisation techniques such as LP and evaluative (non-optimisation) techniques such as simulation, can be used within the TOC framework, providing a synergy between both. TOC becomes more definite through the increased quantification, and the quantitative techniques benefit from the broader, less quantitative frame of TOC.

The demonstration problem is a two-product product mix decision problem taken from Goldratt (1990a): a plant makes two products, P and Q, which sell for $90 and $100 respectively and have raw material costs of $45 and $40 respectively. Thus gross profit margins are $45 and $60 respectively. Demands are 100 and 50 units per week, respectively. The plant's operating expenses (labour and overheads) amount to $6000 per week which, under TOC, is treated as a fixed expense. The products pass through 4 processes, A to D, each of which is available for 40 hours per week, ie 2400 minutes per week. The process times in minutes per unit are set out in Table 1.

The objective is to find the quantities of P and Q to make to maximise the weekly profit.

Table 1: Process times (minutes per unit)

		Process				
		A	B	C	D	Total Time
Product	**P**	15	15	15	10	55
	Q	10	30	5	5	50

The paper will demonstrate how LP can be used as part of a TOC approach, in addressing this problem.

The TOC 5 Step Focussing Method of Goldratt (1990b) is used to outline this.

Step 1: Identify the Constraint(s):

The spreadsheet itself is often able to help the decision maker identify the constraint(s) by calculating gross usage requirements and comparing them with availabilities.

Step 2: Exploit the Constraint(s):

Using LP then provides the user with an "optimal solution", ie the best possible outcome, given the constraints. In the case here, the solution specifies how many of each of P and Q should be produced to maximise profit, and what this maximum weekly profit will be. For the user to do this step by trial and error is time consuming and not guaranteed to find the "right" answer. As evidenced by Lee and Plenert's paper (1994), Goldratt/Fox's method (Fox, 1987) is open to interpretation, and thus is not guaranteed to find the solution either. In contrast, LP guarantees to find the solution, or to state definitely that one does not exist.

Step 3: Subordinate other activities to the Constraint(s):

The LP solution states how much of each resource will be used by this profit maximising product mix. It states also how much of each resource will be "slack" or spare capacity left over. In this current (static) portrayal of the problem, using more of a resource with spare capacity will not improve the profit: it will only provide a build up of inventory in the system. However, when it is acknowledged that times and capacities are only averages, and some variation is inevitable, then some of this spare resource can be used to provide buffers, as part of a planned "Drum-Buffer-Rope" system as advocated by Goldratt and Fox (1986). The overall plan must seek to ensure the flow of product, and in this context, batch sizes, both process and transfer batches, must be considered. Such considerations are not a normal part of an LP study, but come directly from the TOC framework, and are an essential step in operationalising the LP model.

Step 4: Elevate the Constraint:

The LP model provides the decision maker with three types of "what if?" information:

(1) an estimate of the value of more of the scarce resource;

(2) ranges within which the profit margins of the products can change before the solution will change;

(3) ranges within which individual resource availabilities can vary before the product mix strategy will change.

Thus the LP provides plenty of information about the robustness of the current optimal solution, that would not be available by other means such as a trial and error model. This information can be used to decide whether to elevate the constraint, and, if so, how far, and by what means.

Step 5: Go back to step 1:

If anything has changed go back: the LP model can be amended with the changes to resource availabilities, or profit margins or whatever, and re-run. It is simpler than starting from scratch.

This final step of TOC makes a real difference: and provides a valuable formal addition to the LP solution methodology, which can be seen as reactive and one-off, in contrast to TOC's continuous improvement approach.

Using a Spreadsheet Package for Solving LP's

There are three stages to solving optimisation problems such as LPs on a spreadsheet: setting up the spreadsheet, solving the problem, and producing reports. The following description relates specifically to solving linear optimisation problems (LPs) using Excel 4.0, though other types of problem can be solved with Solver and other spreadsheets have similar facilities.

Setting up the spreadsheet

The problem described earlier can be set out in a spreadsheet as in Table 2, with input data shown in shaded boxes.[1]

The user must then specify the following:

• *Changing Cells:* A range of cells that can be varied. These are the quantities we wish to find: namely, how much of each of P and Q we should make. These cells [in this case, C10 and D10] are the "changing cells" in Excel terminology, and "decision variables" in LP terminology.

Input some sample values. Note that we have supplied some initial guesses for the values in cells C10 and D10. In this case we have simply input the market demands for P and Q.

• *Target Cell:* A single cell to optimise (maximise, minimise or a specified value to be met).

[1]Note only the input data in shaded cells and changing cells in cells C10 and D10 should be input as numbers. All other cells should be formulae or cell references based (directly or indirectly) on these input data and/or changing cells.
For example, cell F4 should contain a formula such as "=C5 - C6",
C15 is "= C10 * F4"
E11 is "=C10*C11 + D10 * D11"
and E19 "=C10" ; F19 "= C4".
Some further elaboration is given later; for further details, contact the author.

In this case we wish to maximise net profit [ie cell E17] Gross profit could have been used equally well, since operating expenses are fixed.

In this cell, enter a formula for the objective function, based on input data and the decision variables (in this case, E17 would be defined as E15 - E16, and E15 is defined as C15 + D15. The cell display will be the value of this formula for E17 for the current settings of the changing cells.

Table 2: Spreadsheet for Product Mix Problem

	A	B	C	D	E	F	G
1	*P's & Q's Product Mix Problem*						
2			Product				
3	*Input Data*		P	Q	*Derived Data*		
4	Demand	(units/wk)	100	50	Profit	45	60
5	Price	($/unit)	90	100	($/unit)		
6	RM Cost	($/unit)	45	40			
7	Fixed Expenses ($/wk)		6000				
8					Resource Use		
9	*Production Plan*		P	Q	Totals	Available	Slack
10	Quantity to Make		100	50	150		
11	Resource	A	15	10	2000	2400	400
12		B	15	30	3000	2400	-600
13		C	15	5	1750	2400	650
14		D	10	5	1250	2400	1150
15	Gross Profit		4500	3000	7500		
16	*Less Expenses*				*6000*		
17	Net Profit				1500		
18					Produced	Required	Shortfal
19	Demand for P				100	100	0
20	Demand for Q				50	50	0

• *One or more Constraints*:[2] A set of cells to be compared, representing the underlying constraints to be obeyed. Each constraint consists of 2 cells to be compared and a relational operator. Solver tests the satisfaction of a constraint by comparing two cells only.

In this case, there is a column showing total resource usage (cells E11:E14) at the current production levels specified in the changing cells. This is specified using formulae based on the changing cells and input data, for example E11 = C10*C11 + D10*D11. Available resource is specified in F11:F14. The resource constraints are then of the form E11 <= F11, which tests that Total Resource A used is less than or equal to resource A available.

[2]Note there is a difference between Goldratt's definition of a constraint, and the present usage. Excel follows the LP convention of defining constraints as anything that **could** limit a system's performance. Thus potential and actual constraints are all constraints. Goldratt's definition of a "Constraint" is anything that is currently limiting the system from performing better. In LP terms, this is equivalent to Binding Constraints.

While the user could simply insert zeros in the changing cells, using non-zero values allows the user/modeller to check the resource usage formulae. Inserting a number of different values allows some user experimentation, not possible with a normal LP model. Such experimentation prior to solution is invaluable to ensure the spreadsheet model is working as expected.

In particular, cells E11 through G14 indicate that resources are overcommitted: the full market demand of P and Q cannot be made because there is not enough of Resource B. Thus B has been identified as the major constraint. (Step 1 of TOC)

Solving the LP Problem: How to exploit the constraint(s)

Solving the LP will tell us the best possible combination of P and Q to make the highest profit, taking the constraints as given, thus exploiting the constraints. The Appendix explains how Solver is used within the Excel package to solve the LP.

Reports

After the LP is solved, the user can select any or all of three standard reports, detailing the answer, sensitivity analysis information and a limits report. Examples of the answer and sensitivity reports follow in Tables 3 and 4.[3]

Answer reports

The answer report for this problem is shown in Table 3.

The optimal values of the target cell [E17] and changing cells [C10, D10] are shown in the right hand column in the top two segments of the table. These indicate that the optimal product mix is 100 of P and 30 of Q, with a total net profit of $300. In other words, the optimal strategy is to make as much of P as the market will take, and then make Q until Resource B is used fully.

The optimal solution of the LP model thus directs us how to exploit the constraint (Step 2 of TOC).

As Goldratt (1990a) shows, the cost accounting method would recommend giving preference to Q, and making 50 of Q as per market demand, because of its higher profit margin. However this strategy makes a $300 loss, as the spreadsheet model can confirm. Goldratt/Fox's rule is to rank products in order of decreasing ratios of profit margin/constraint minutes, and produce each in turn till the constrained resource is

[3] Note that when creating reports, Solver names the cells automatically by searching for the first text to the left and then the first text above each changing cell, combines the text into a cell label for the report.

exhausted. In this case, P has a profit of $45 and takes 15 minutes on Resource B, ie. P gives a $3 profit for every minute of Resource B. In comparison, Q returns only $2/minute of B.

The constraints are shown in the Formula column of the Constraints section. The status of the constraints indicates whether which constraints are Binding and which are not. Binding constraints have no slack, ie are used entirely which means they are currently limiting the system from doing better ie these are constraints in Goldratt's definition. This indicates that Resource B and Demand for P are currently determining the product mix.

Table 3: Solver Answer Report

Microsoft Excel 4.0 Answer Report
Worksheet: P&Qfull.xls
Report Created: 6/23/94 13:34

Target Cell (Max)

Cell	Name	Original Value	Final Value
$E$17	Net Profit Totals	1500	300

Adjustable Cells

Cell	Name	Original Value	Final Value
$C$10	Quantity to Make: P	100	100
$D$10	Quantity to Make: Q	50	30

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$E$11	A Totals	1950	$E$11<=$F$11	Not Binding	450
$E$12	B Totals	2400	$E$12<=$F$12	Binding	0
$E$13	C Totals	1650	$E$13<=$F$13	Not Binding	750
$E$14	D Totals	1150	$E$14<=$F$14	Not Binding	1250
$E$19	Demand for P Produced	100	$E$19<=$F$19	Binding	0
$E$20	Demand for Q Produced	30	$E$20<=$F$20	Not Binding	20
$C$10	Quantity to Make: P	100	$C$10>=0	Not Binding	100
$D$10	Quantity to Make: Q	30	$D$10>=0	Not Binding	30

Resources A, C and D and Market Demand for Q are all "Non Binding" constraints, which means there is slack of resources A, C and D, and unfilled market demand for Q. Because of the optimality of the present product mix, any deviation from the present resource use would imply a reduction in profit, ie. to attempt to produce more of Q would reduce the profit, and using more of Resource A, C or D would not increase profit.

Hence the LP's advice on Step 3: "Subordinate other activities to this decision" is that 20 units of Q market should be left unfilled, and resources A, C and D should be used only as indicated.

However this recommendation is derived by assuming no variability in demand, process times or profit margins. Some variability in all these is inevitable, and TOC can improve on this by using the Drum-Buffer-Rope system to ensure flow through the system, and by appropriate transfer and process batch sizes (Goldratt and Fox).

Sensitivity reports

The sensitivity report shown in Table 4 provides the "what if" information, which gives advice on elevating the constraint (Step 4 of TOC).

In particular, the LP model provides the decision maker with three types of "what if?" information:

(1) an estimate of the value of more of the scarce resource, given by the "Shadow Price": in this case, if the **Demand for P** could be expanded, extra units of P would give a profit of $15 per extra unit of P sold, with up to 60 more units (allowable increase column) still providing this return. Note that this return is $15, not $45, because given Resource B still only has 2400 minutes per week, every extra unit of P takes 15 minutes of B, so the amount of Q made will be 1/2 of a unit less, with a net result of $15 extra profit.

Table 4: Solver Sensitivity Report

Microsoft Excel 4.0 Sensitivity Report
Worksheet: P&Qfull.xls
Report Created: 6/23/94 21:17

Changing Cells

Cell	Name	Final Value	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
$C$10	Quantity to Make: P	100	0	45	1E+30	15
$D$10	Quantity to Make: Q	30	0	60	30	60

Constraints

Cell	Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
$E$11	A Totals	1950	0	2400	1E+30	450
$E$12	B Totals	2400	2	2400	600	900
$E$13	C Totals	1650	0	2400	1E+30	750
$E$14	D Totals	1150	0	2400	1E+30	1250
$E$19	Demand for P Produced	100	15	100	60	40
$E$20	Demand for Q Produced	30	0	50	1E+30	20

The worth of an extra minute of **Resource B** is $2: this is because extra time on B will be spent making Q, assuming that the Demand for P remains at 100, and each extra minute makes 1/30 of a Q which is worth $2. This is the very same $2/constraint minute from Goldratt/Fox's rule mentioned earlier.

For all other resources, we had slack, so extra of those is worthless. This corresponds to a shadow price in the LP report of 0.

(2) ranges within which the profit margins of the products can change before the solution will change.[4] The Allowable Increase and Allowable Decrease columns of the Changing Cells section of the Sensitivity report indicate that the profit margin of P could decrease by 15 ie. fall to $30, before this would affect the product mix. An increase in P's profit margin would not affect the product mix. Clearly any change in either direction would directly affect profit, though. Product Q's profit margin would have to increase above $90 before the product mix would change.

(3) ranges within which individual resource availabilities can vary before the product mix **strategy** will change.

As an example, Resource A could be reduced by 450 (see Allowable Decrease column) minutes before it would affect the product mix. In contrast, any change in Resource B availability will affect the product mix and profit. However the product mix strategy will stay the same within the range specified in the allowable increase/decrease columns. eg. if Resource B increased by up to 600 units ie. up to 3000 minutes, the optimal strategy would still be to make all of P, then as much Q as possible to use up Resource B. Beyond this, the strategy may change. Within the range specified, each extra minute will still be worth the amount indicated by the shadow price.

Thus the LP provides plenty of information about the robustness of the current optimal solution, that would not be available by other means such as a trial and error model. This information can be used to decide whether to *elevate the constraint* (Step 4 of TOC), and, if so, how far, and by what means.

The final step of TOC is if anything has changed go back: the LP model can be amended with the changes to resource availabilities, or profit margins or whatever, and re-run. It is simpler than starting from scratch.

This final step of TOC makes a real difference: and provides a valuable formal addition to the LP solution methodology, which can be seen as reactive and one-off, rather than a continuous improvement approach, as advocated by TOC. Too often with traditional

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[4] 1E+30 is infinity, ie. there is no limit to this Increase/Decrease.

models, users and decision makers treat their constraints as givens, whereas TOC urges the decision maker to never stop looking for improvements. Most managers would want to know how to satisfy all market demand, rather than which demand to leave unfilled.

TOC also contributes greatly in questioning the assumptions of LP, particularly the assumption of all data being known and constant. In reality this is never true. While it is frequently assumed that fluctuations will average out, Goldratt and Cox (1986) have demonstrated through the Dice Game that they usually do not - rather delays accumulate. The Dice Game is a simple simulation model, and the use of more sophisticated simulation models can help investigate and predict system performance, particularly the effects of batch sizes, queues, variable process times and the like. Simulation is another MS standard technique that can thus be seen to fit well in the TOC framework.

Discussion

Often managers claim that their problems are not linear, and hence LP would be inappropriate. However, many would be happy with the type of argument embodied in the formula for resource use, such as Cells E11 through E14. This is in fact a linear relationship, and is the simplest type to choose and thus a sensible one to start with.

Many managers would be comfortable with setting up a spreadsheet as in Table 2 and searching by trial and error for a reasonable solution. Once on a spreadsheet, the step to LP merely automates this search process and guarantees an optimum solution will be found, if one exists. It introduces *no new assumptions* about the problem. Linearity has already been assumed by the use of linear formulae (for cells E11 through E14) when setting up the spreadsheet. This is a strong point in favour of using LP, particularly in a spreadsheet environment. Solver can also be used to find solutions to LPs, non-linear problems, and integer problems, without having to change much. For example, non-linear resource use formulae could be used in place of the linear ones.

Pitfalls to be avoided when using Excel Solver

• As mentioned above, in Solver reports, cells are named automatically by searching for and combining column and row labels. Hence data needs to be in appropriately labelled rows and columns, which it should be anyway, but this is sometimes problematic. However, it is worth noting that reports can be freely edited, which has advantages in that reports can be annotated and rearranged, but could create problems with authenticity.

• If a constraint is specified in terms of the Changing Cell, then it is treated as a bound and no shadow price will be given, even if it should have one. For example it would have been simpler to input the *production* <= *demand* constraints as [C10:D10 <=

C4:D4]. However by doing so, Solver would treat these constraints as bounds, and will not include them in the constraints section of the sensitivity report. No shadow prices will be given, even if it turns out these constraints are binding. In many cases, as in our example, it is advantageous to increase the demand for product P if possible.

We have also observed occasions where the incorrect sensitivity information is given in these circumstances: Solver sometimes shows non-zero reduced costs where these should be zero, and incorrect ranges for objective coefficients. However these problems can be avoided by specifying constraints as described above, using an intermediate cell, not changing cells.

• Non-negativity conditions must be specified as constraints, or RHS ranges will be overstated.

• While the Excel manual states that the RHS ranges are the allowable range within which the optimal values of the changing cells hold, for binding constraints this is not true. As is usual, RHS ranges for all constraints (including binding constraints) give the range over which the **shadow price** does not vary.

• As with all spreadsheets, care is required to ensure that a cell really does contain the desired formula or value, as the display is not necessarily the same as the contents. Similarly, displayed accuracy is not necessarily the same as that of the contents. When interpreting sensitivity information, shadow prices in particular, it pays to check the precision by clicking on the cell and checking its contents. Formats can be adjusted if needed.

Pointers for trouble-free Solving

• Create your spreadsheet with care, with separate areas for input data, and derived data. Base all other cells on the input data (directly or indirectly) and changing cells.

• Insert an extra column, and decision variable values, and check the worksheet is behaving in the way expected by experimenting using a trial and error approach, adjusting the decision variables and observing the changes to the rest of the spreadsheet.

Check that objective function cell and constraints depend on cells being varied, via cell references and/or formulae: don't believe what you see on the spreadsheet display, check the cell contents.

• Check that you have included all necessary constraints, including bounds and non-negativity conditions, and that your units are correct.

Conclusions

Spreadsheets are now capable of solving LPs, thus providing quick answers to common problems such as product mix problems. The benefits of using spreadsheets include ease of access, universality, and the ability to experiment with relationships prior to actually solving the LP. All of these are powerful reasons to choose this medium. Managers not familiar with MS are more likely to be comfortable with this spreadsheet LP approach than specialist MS packages, because they are more familiar with the trial and error experimentation with a spreadsheet such as in Table 2, and yet the linearity assumptions have already been made. Hence using LP is a quicker, more efficient, guaranteed way of finding the best solution in a spreadsheet environment.

This paper also provided pointers and noted pitfalls to be avoided, relating to setting up and interpreting the information to obtain true and full information. As with any spreadsheets, great care is needed, and for this reason I would recommend spreadsheets for exploratory LPs only.

The most important contribution of this paper has been to show how LP can and should be used within the wider TOC framework for mutual benefit. Product mix problems are usually only part of a larger, less defined problem, which TOC can handle more easily.

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APPENDIX:

The Appendix explains how Solver is used within the Excel package, to solve the LP model specified in this paper. Cell references relating to the above example appear in brackets [ ].

Select 'Solver' under Format menu in Excel

a. Enter target cell reference in the box

Set Cell [ ] [eg enter E17]

Select max, min or value

In this case we wish to maximise profit, so "max" should be chosen.

b. Click on box:

By changing cells:

[ ]

and enter cells to be varied (decision variables) [eg enter C10:D10]

Note C10:D10 signifies a range of cells, C10 through to D10, including both end cells.

c. Click on [Add] to input constraints :

Each constraint comprises two cell references and a "relational operator"

The relational operator ie <=, >=, = to show the required relation between the 2 cells is entered within Solver.

eg in this problem there are three groups of constraints:

resource constraints, demand constraints and non-negativity conditions.

Resource constraints:

Usage cannot exceed available resource

[E11:E14] <= [F11:F14]....Click on [Add]

"Production should not exceed Demand" constraints:

(If production exceeds demand, profit margins would no longer be as stated)

[E19:E20] <= [F19:F20] Click on [Add]

Non-negativity conditions:

[C10:D10] >= [0] Click on [OK]

(As in many optimisation problems, it does not make sense to make negative quantities.)

d. Now choose [Options]

Click on [ ] Assume linear model box

(This will cause the Simplex Method of Linear Programming to be used to solve the problem)

Click on [OK]

e. Click on [Solve] and wait!

f. Check answer in [C10:D10 and E17]

In this case, it states the optimal solution has been found: making 100 of P and 30 of Q will result in the highest profit, namely $300 per week.
If necessary amend model.

To do this, pull down [Solver] , Click on [Add] , [Change] , or [Delete] as appropriate

Check model displayed, if OK then click on [Solve]

ABOUT THE AUTHOR

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