Reframing the Product Mix Problem using the Theory of Constraints

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Abstract

This paper builds on prior work examining pedagogical strategies for the teaching of OR/MS. In particular, the authors focus on the use of framing as a pedagogical meta-framework and extend the repertoire of frames in use presented elsewhere. The purpose of framing and reframing is to improve the understanding of problems and problematic situations by providing a means of developing and synthesising multiple perspectives. Reframing also facilitates recognition and understanding of the potential biases inherent in any particular frame. This paper extends discussion of a product-mix case for which the authors had previously outlined several frames commonly used in traditional OR/MS analysis. The paper presents five further frames that draw on Goldratt's Theory of Constraints methodology and on lessons learnt from use of the case study. The paper concludes with a discussion of the effects of the different frames, the strengths and weaknesses of each, and the advantages of multiple frames.

1 Introduction

> '*Pedagogical advances follow naturally epistemological and methodological advances - and perhaps, premature pedagogical expressions are as natural. We are ever-learning and there is a compulsion to communicate to others that which we learn.*' [30]

The early development of OR/MS was characterised by the deliberate use of multi-disciplinary project teams, whose composite strengths, creativity and problem-solving abilities were enhanced by the complementarity of the different approaches and perspectives that were brought to bear on a problem. Simon, Dantzig et al [28] have stated that 'the OR/MS community has, as its common mission, the development of tools and procedures to improve problem solving and decision making'. Indeed, we may reflect that this view has pervaded the academic community since the introduction of OR/MS to management education in the early/mid sixties.

However, we may also reflect that our OR/MS education programmes have provided, in the main, a 'traditional' hard-systems emphasis on technical analytical skill and the generation of optimal solutions, rather than the development of 'softer' problem identification and problem structuring skills. The hard systems approach deals with how to solve the problem; the soft systems approach seeks to ask what the problem is. It was as if, as Daellenbach [5] contends, our educators assumed that problems had been or could be readily identified, and/or such problems would be amenable to our familiar hard-systems analytical approaches.

Such assumptions do not fit comfortably with Ackoff's view [1] that 'managers do not solve problems in well-ordered mathematical worlds as much as manage messes' which have to be understood. Such assumptions have been similarly critiqued by Grinyer [13], who has stated that whilst effective operational researchers have long recognised the use of models as a means of assisting managers to reframe their understanding of the world, the typical frames-in-use have been mathematical in structure and content, with a prime purpose of specifying a 'best' solution to the problem as 'captured' in its mathematical form, regardless, oftentimes of the ill-match between model and reality, or of the uncertainty surrounding the problem. Fortunately, such assumptions are less likely to be typical of mid-nineties educational practice, given the many initiatives gaining momentum in OR/MS undergraduate and graduate education [4].

Recent focus on aspects of pedagogy, especially as they relate to the teaching of OR/MS / decision making, and especially as they relate to the phenomenon of post-experience management students, have been most evident in recent major conferences. Whole streams have been devoted to aspects of innovative education, teaching and learning, addressing amongst other things, experiential and collaborative learning, making learning fun through role-play, and the use of information and allied interactive computing techologies. See, for example, the work of Savage [26], McKenna [21], Elder [7], Powell [25], Sniedovich [30] at IFORS, DSI, EURO-InfOR/MS etc.

Throughout the eighties and nineties, the notions of framing, and framing methodology, have gained credence, increasing use and acceptance, particularly in the analysis of organisational structures and organisational effectiveness (eg Pondy [24], and Morgan [22]). More generally, (re)framing can be seen as an aid to problem identification and problem structuring that values and encourages the development of multiple problem representations and multiple perspectives.

In a previous paper [19], the authors provided a contribution to pedagogy by showing how framing can be used as a meta-framework in teaching OR/MS: a range of frames was applied to a classic OR/MS problem - the product-mix problem - with frames being drawn from the traditional OR/MS repertoire. The present paper illustrates how frames drawn from the more recent Theory of Constraints (TOC) (see for example [4], [6], [8-12], [14], [18]]) can also be applied to the same product mix problem. While the traditional OR/MS frames typify the 'hard' approaches, the TOC frames are 'softer' in nature.

The product mix problem used for illustration is the Goulds Fine Foods case which has been described elsewhere [16, 19, 20]. It involves the production of two product lines (Manufacturing Hams and Sausages) using limited resources, and trying to meet demand that exceeds capacity. The main data is summarised in the spreadsheet below (which was one of the frames employed in [19]). The case itself was initially presented as a narrative, while other frames presented in [19] included flowchart, tabular, graphical and LP frames.

	A	B	C	D	E	F
1	**Spreadsheet Model of Goulds' Production Problem**					
2			**Hams**	**Sausage**		
3	**Decision Variables:**	**No. Produced**	8.0	20.0		
4	**Constraints:**				**Required**	**Available**
5	**Production**	Mixing (Ham)	5.0	0.0	40.0	40.0
6		Mixing (Saus)	0.0	0.5	10.0	40.0
7		Filling	8.0	1.0	84.0	40.0
8		Cooking	8.0	1.0	84.0	160.0
9		Chilling	10.0	2.0	120.0	200.0
10		Pack & Despatch	1.0	7.0	148.0	160.0
11					**Sold**	**Demand**
12	**Demands**	Hams/wk			8.0	8.0
13		Sausage/wk			20.0	20.0
14					**Total**	
15	**Objective function:**	**Profit**	6.0	1.0	68.0	

Figure 1: The Spreadsheet Frame

2 The Theory of Constraints Frames

2.1 The TOC Product Mix Algorithm

The TOC methodology provides an alternative series of frames with which to seek and filter information. For example, production decisions can be linked to or guided by a focus on the constraining resources or activities, and especially the most profitable use of those otherwise constraining resources or activities.

In order to establish production priorities between the products, Goldratt [11] provides an algorithm, sometimes referred to as the TOC product mix algorithm, which in simple cases produces the best product mix. The algorithmic decision rule is based on the ratio of profit to constraint-use for each product, and can be determined as follows:

First, determine the most constrained resource (called the constraint). Then, the ratio of "gross profit per constraint hour" (GP/CH) is calculated for each product. Since the filler is the resource constraint, GP/CH for Hams is 0.75 (= 6 units of profit per batch /8 hours of filling per batch) and for Sausages is 1.0 (=1/1). Then rank these products in decreasing order of the GP/CH ratio (for example, Sausages, then Hams) to determine priorities. This ranking is used, together with resource availabilities and other constraints such as market demand, to determine the actual production quantities of each product.

	Hams	**Sausages**
Gross Profit	6	1
Time on constraint (Filler hrs/batch)	8	1
Gross Profit per Constraint Hour	6/8 = **0.75**	**1**

Figure 2: The TOC Product Mix Algorithm Frame

The product mix algorithm therefore says "make Sausages (S) first, up until the quantity of Sausages being demanded, and then make Hams (H)". For average demand, Goulds would make 20 batches of S and 2.5 batches of H – the same result as the LP.

The TOC frame has advantages in that it is quicker and more intuitive to apply if there are few constraints (though there are versions which cater for multiple resource constraints, or you can use LP.) It also allows us to cope better with variable demand, which is a feature of the Goulds' case. Demand for S ranges from 0 – 40 batches per week, while demand for H ranges from 5 - 11 batches, so on a week where demand for S is 30 batches, say, the product mix algorithm would direct Goulds to make 30 batches of S, and then the 10 hours remaining on the filler would be used to make 1.25 batches of Hams (if non-integer batches are possible).

2.2 TOC Frame II - the Five Focusing Steps (5FS)

A second TOC framework, the TOC Five Focusing Steps in the process of On-going Improvement (5FS), also develops a perspective on constraints - but does so without artificially limiting the view to constraining resources or activities. Indeed, the 5FS process allows further development of alternative perspectives for this case. A brief summary of the 5FS is provided below; for more details, see [6], [10], [11], or [23]. Note that when using the 5 Step process we assume that the goal of the organisation has already been determined, although this is part of the first question addressed by TOC, namely "What to change?" as discussed for example in [10], [3], [18] and [27].

Five Focusing Steps in the Process of On-Going Improvement
Step 1: IDENTIFY the system constraint(s)
Identify the constraint(s) that is/are preventing the system from achieving its goal. What part of the system constitutes the weakest link?
Step 2: Decide how to EXPLOIT the constraint
Decide how to use the constraint to wring every bit of capability out of it. Query what we can do to get the most out of this constraint without committing to potentially expensive changes or upgrades
Step 3: SUBORDINATE other activities to the decisions made in Step 2
Do not let other activities stop the constrained activities from actually producing their best. We may need to de-tune some parts, and rev up other parts to make the system as a whole as productive as possible. Is the constraint still a constraint? If so, continue; if not, this constraint has been eliminated, and we skip to Step 5.
Step 4: ELEVATE the constraint(s)
Remove the constraint or make it less constraining by adding or upgrading capacity
Step 5: If anything has changed … GO BACK to Step 1
Do not let inertia become a system constraint!

Applying the 5FS process to this case, we are encouraged to do all we possibly can to exploit the latent profitability of the over-riding or dominant constraint, seeking if necessary to subordinate other actions to these exploitative decisions made in "Step 2". We seek to do this before adding further capacity.

This approach/perspective can be contrasted with the myopic view implicitly adopted by users of the LP frame. Using the LP lens, one is led to identify the constraints; next to choose the right product mix; and then to move immediately to add further capacity (which is the 5FS "Step 4: Elevate"). We note that using the TOC framework and principles can often lead to considerable improvement without adding new capacity - for example, seeking to reduce set-up times and process times on the constraints as much as possible; and seeking to ensure the filler is never idle, by rescheduling tea and lunch breaks will often resolve the problem without additional capacity.

Sometimes we can proceed through these 5 Steps without difficulty acting at an operational level, but sometimes the constraint is a policy - sometimes explicit, sometimes implicit and unstated, and sometimes all we can see is a number of seemingly unrelated symptoms or problems. In such cases the use of logic trees (such as TOC's Thinking Process tools) is appropriate, as will be discussed later.

2.3 TOC Framework III - Combining LP with a TOC Framework

Using the two frameworks in combination, we can view the LP model results within the TOC 5FS framework. This approach is described by Mabin and Gibson [20], which in turn built on Luebbe and Finch [15] and Mabin [17]. Such a combination leads to the following interpretation:

Step1: IDENTIFY the constraint(s)
The first step in using TOC would be to identify the major constraint(s) which are preventing Goulds from reaching their goal.
In this case, we note that the goal would be to maximise profit. If we try to make the most profit possible, by filling market demand, we note that the constraint is the filling process - we need 84 hours of filling to meet market demands, but only 40 hours are available per week.

In this type of so-called "product mix" problem, formulated as an LP, there will usually be more than one constraint. In the Goulds case, market demand for sausages is also a constraint. Goldratt [10] would generally argue that one of these is more critical than the others, and that we should focus actions on the most critical constraint. In LP also, this is possible, and the LP approach may also lead to this view. Note, Goldratt's definition of the term "constraint" is more specific than the LP definition: "constraints" in TOC equate to "binding constraints" in LP.

Step 2: Decide how to EXPLOIT the constraint
Choose best product mix. In order to establish priorities between the products, one can use the product mix algorithm as before, or an LP. Goulds had been giving priority to Hams because Hams have a higher profit margin. Using the TOC product mix algorithm or LP leads one to conclude it is better to give priority to Sausages.
Make sure every minute of filling is used to advantage. This includes choosing the best product mix as determined above, avoiding idle time through breakdowns, scheduled breaks, or time waiting for materials to work on. Make sure all sausage demand is satisfied.
Using this step Goulds found that Filler time was not being used to the absolute maximum. They discovered that by changing personnel on the filler line they could increase the production rate. They also reduced set-up times on the constraint.

Step 3: SUBORDINATE other activities to the decisions made in Step 2
Make only 2.5 batches Ham, ie subordinate demand for Hams to Sausage demand. Subordinate other operations to serve the Filler machine. For example, mix only as required to keep the Filler fully utilised. The TOC scheduling system called Drum-Buffer-Rope [12] provides a good method for this 'subordinate' step.

Step 4: ELEVATE the constraint(s)
If previous steps have not removed the problem, add more Filler Capacity. The LP can be adjusted to reflect any changes that have been made, and as long as the constraint has not changed, the shadow prices and RHS ranges can be used if desired to guide capacity decisions.
In fact, Goulds installed a double nozzle to fill Hams. This action cost a fraction of the cost of adding more Filling capacity, but had the effect of doubling the filling rate for Hams.

Step 5: If anything has changed … GO BACK to Step 1
If anything has changed, go back.
Indeed, in the case of Goulds, the bottleneck had now been substantially relieved due to the changes and improvements in Filling rates for Hams.
We should go back through Steps 1-5. The LP could now be revised and re-solved. Or the TOC product mix rule could be used. This would probably suggest that Hams should be made first, **then** Sausages!

This frame emphasises a stepwise process of problem solution, fostering a pro-active way of dealing with the constraints, and focuses on continuous improvement, requiring repeated application of the 5FS to continually improve and move further towards the goal.

The frame minimises the "given-ness" of constraints. For example, whereas an LP approach would be geared to "maximise profit subject to constraints" and would thus provide justification for more resources, the 5FS approach encourages one to develop a perspective to manage and modify the constraints, thus avoiding any unnecessary addition of new or extra resources as a first recourse of action. In LP terms, the 5FS approach leads to a management focus on resource usage and technical efficiencies, that is, contemplation of changes in the LHS 'input-output' coefficients before consideration of changes to the RHS capacity or resource constraints!

It involves working around/with the constraints rather than 'living' with or accepting them. The 5FS approach gives priority to organisational goals, whereas the LP 'Product Mix' frame tends to implicitly or unwittingly treat constraint coefficients as givens.

2.4 TOC Frame IV - The Conflict Frame

Underlying the Product Mix problem is a dilemma: "Which product should be given priority?" The perspective developed by using Goldratt's exotically-named Evaporating Cloud framework [9], is one that draws attention towards the assumptions that underpin or give life to the dilemma. Goldratt's frame is constructed by filling a schematic depiction of the dilemma. The purpose for which the constructed frame is used is perhaps better reflected in the alternative title given by Dettmer [6] - the Conflict Resolution Diagram.

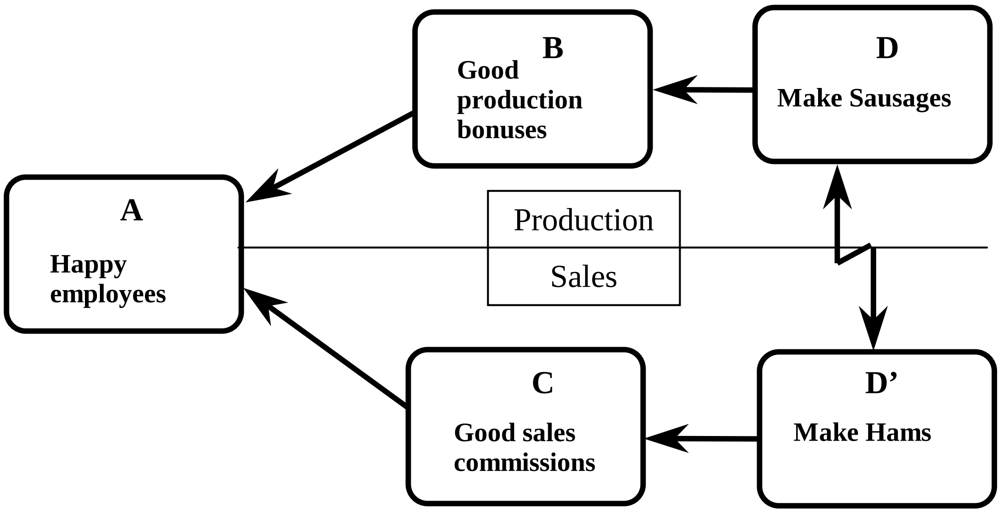

Figure 3 - The Conflict Frame

Here, in illustration, we have framed an underlying conflict that often exists between different departments such as Production and Sales:

The view of "Production" may be that:
In order to be happy employees
we must get good production bonuses
… and …
in order to get good production bonuses
we must make Sausages.
On the other hand, the view of Sales is likely to be that:
In order to be happy employees
we must get good sales commissions
… and …
in order to get good sales commissions
we must make Hams.
Hence the conflict!

The reason for the conflict can be explored by examining the assumptions that underlie the relationships depicted by arrows connecting the boxes in the diagram. We need to elicit these assumptions, or reasons why the relationships are thought to hold. In this case, the assumptions can be shown as annotations on the diagram. For example, production think that **in orde**r for their staff to be happy, **they must** get good production bonuses, … **because** production bonuses are a significant part of their pay. Similarly, **in order** for staff to get good bonuses **they must** therefore produce Sausages, … **because** production bonuses are paid according to volume produced, … and **because** it's quicker to produce Sausages rather than Hams.

The rest of the "**because**" assumptions can be stated in the same way, and can be listed/annotated as below or on the Conflict Cloud diagram.

Assumptions:
A - Happy employees are what we want
AB - Production bonuses are a big part of wages
Employees motivated by $
BD - Production bonuses are paid on quantity produced
We can make more Sausages than Hams in the time available
AC - Sales commission are a significant part of wages
Employees are motivated by $
CD' - Sales commission are based on sales revenue
Hams earn higher revenue
DD' - Can't produce all of both products

Then ways of challenging or "breaking" the assumptions should be found for each assumption, as the list below illustrates:

Ideas for Solutions (ways of breaking assumptions)
A - Get good work some other way
AB - Remove bonuses
BD - Change bonus scheme
AC - Remove commissions
CD' - Change commission scheme
DD' - Change your operations to make both!

If we could find a way of meeting demand for both Hams and Sausages, then our dilemma or conflict between D and D' would be removed. This may seem an impossible task at first, but as documented in [20] and sketched in section 2.4, it can indeed be achieved through applying the 5FS process. 'Breaking the arrow', denoted here by the lightning bolt at the right of the conflict diagram between D & D', that is challenging the fundamental assumption at the most evident point of conflict, is often the most effective place to break the conflict.

Alternatively we could resolve the conflict by breaking arrows/challenging assumptions further to the left of the diagram, which would likely involve challenging some deep-seated beliefs - political, emotional and financial –surrounding, in this case, the bonus system. For example, we could change the bonus systems in a way which could impact on arrows between A & B, A & C, B & D or C & D'.

Generally speaking, the further to the left of the conflict diagram that one attacks a conflict, the more fundamental will be the nature of the issues that are being addressed. Whichever arrow is broken, it should produce a breakthrough or 'win-win' solution. We have found that using the cloud often leads to solutions that appear simple in hindsight, and that both sides feel they've benefited or won. If the conflict is of a chronic nature, then additional steps may be necessary and TOC provides further guidance for this. However, this lies outside the scope of this paper. It is worth noting, however, that the conflict frame can prove just as useful in the examination of multi-party conflict as it is for any personal or internal conflict or dilemma.

2.5 TOC Frame V - The Logic Tree Frame

Goldratt [9] has also developed a set of cause and effect diagrams, also known as Reality Trees, the use of which signals the acceptance that wider, broader, deeper issues are involved in or impact on the problem that we currently have to address. That is, there is an acknowledgement of other systemic influences that bear upon our decision making and that need to be understood.

An initial step promoted by use of this frame might be to map out all the symptoms (perhaps only a subset of the effects) that currently indicate all is not well in the organisation. Such symptoms may be manifest as ongoing friction, overstated sales projections (especially for Hams, in the Goulds Case), the sales force feeling powerless and frustrated at not being able to satisfy customer demands, and so on. Our frame then dictates that for each symptom we explore possible cause-effect relationships responsible for their manifestation. Using cause-effect analysis with a rigorously defined protocol (see Dettmer [6], Kendall [14], Noreen et al [25, Appendix],or Scheinkopf [27]), we then attempt to trace these symptoms back to the root cause of the problem, seeking to identify whether a single core problem exists that needs addressing.

Framing the problem situation in this way emphasises the acceptance of a systems perspective, and the likely systemic nature of relationships and links between key variables and entities. The frame emphasises the view that there is no point fire-fighting symptoms - it is better to address and eradicate the cause.

A possible TOC Current Reality Tree (CRT) for a problem of this nature is given by Cox and Spencer [4, Ch 10]. A CRT analysis should lead to the identification of the core problem underlying all (or most of) the symptoms, that is the things we normally complain about. If the core problem were to be dealt with properly, these symptoms would disappear. Frequently the core problems are (at least in hindsight) well known to the organisation, but have been avoided or ignored for some time because they are deemed to be too hard to deal with. Kendall [14] asserts that measurements, policies and training are the three pillars of an organisation and that weaknesses in one or more of these areas are often identified as core problems in a CRT analysis. A core problem in the Goulds case might include measurements misaligned with the organisation's goal or with other parts of the system. For example, each department might be assessed/measured according to its own goals, with Production trying to maximise production and Sales trying to maximise sales revenue. Other core problems might relate to outdated or erroneous policies involving the bonus system; to priorities used in the scheduling of jobs; or to the lack of, or inappropriate, training, with, for example, staff being unaware of the importance of the filling machine, or not trained to achieve the best production flow.

3. Conclusions

The foregoing case provides an illustration of the way in which framing and reframing can be effectively employed to improve the quality of understanding of problems we face, and of the decision making processes in which we can engage.

In the previous paper, we illustrated some of the 'hard' frames that are employed routinely by OR/MS practitioners and educators for 'modelling' purposes; while in the present paper we illustrated some 'softer' frames that guide the problem identification and problem structuring process as much as the solution process. The chosen 'hard' frames are, however, not always explicitly recognised as problem structuring devices that operate from and reflect different perspectives; or as devices that 'promote' the gathering, filtering and structuring of information in often deliberate and distinct ways, thereby leading to different insights about problems and how to tackle them.

The traditional 'hard' OR/MS frames most often used are graphical, flowchart, tabular, mathematical or LP frames. An extension of this repertoire of frames to include those from TOC, has been provided, illustrating the additional insights that can be derived from such use. TOC offers other frames such as the product mix algorithm, the focussing process, the conflict diagram, and the reality tree.

All of these frames require the modeller to precisely define the problem using the language or concepts of the frame, and require the modeller to make assumptions in order to represent the relationships. The way in which these assumptions are treated appears to be one major difference between the traditional methods and TOC: the traditional approaches generally require a statement of assumptions, while the TOC frames require not merely a statement of assumptions, but also a questioning of their validity. The latter frames thus tend to be demanding of the decision maker in different ways, often presenting a challenge to preconceived views. They induce analysts to question assumptions more, and to dig below the stated problem to surface the core issues. Indeed, TOC solutions arise in the main from the breaking of assumptions.

The purpose of this paper and its predecessor has been to show the practicalities and benefits of using a variety of frames to tackle any given problem. The series of 'hard' frames used with this case are amongst those most often used by OR/MS practitioners. They have been employed here because they tend to emphasise different aspects of the case situation, and because they provide different insights, shadowing some features, and revealing others that may remain unseen if only one frame were used.

One of the main differences between the OR/MS and TOC frames is that the former ask, "What is the best product mix?" whereas the TOC frames ask, "How can we improve the performance of the system?" The TOC frames suggest the usual "product mix" frame is addressing the wrong question! They seem to accept that a tradeoff has to be made, and in doing so yield an inferior answer to that found using the TOC frames. Other OR/MS tradeoff models may be similarly flawed; see for example Goldratt's discussion of the EOQ (Goldratt [10, p 43 ff].

The case has highlighted how our perceptions, analyses and choices are guided by, and often limited by, the frame-in-use. Indeed, we note that the effect of framing can be such that choices that become transparent and clearcut in one frame, may be not be seen at all in another. In as much as each frame is partial and that potential biases exist in each frame, the multiple framing exercise performed here, demonstrates the value of using a variety of disparate frames to reduce such bias.

Our experience shows where the value of multiple frames is recognised, the positive impact on the subsequent behaviour of decision makers is that they are more likely to be tolerant of other perspectives; to seek other possible interpretations of the problem; to search for and examine unstated, implicit objectives, prevailing criteria, existing value judgements etc; and therefore to improve their understanding of problem.

We conclude that additional positive effects of the use of framing as a meta-framework in the pedagogical setting can be the greater recognition of the implicit frames that we already use, how we make use of them, and how we can extend their use from the analytical setting to problem identification and to the problem structuring domain. As such we state that the development of an integrative meta-framework to provide appropriate guidance to students in the development of problem identification and problem structuring skills, is worthwhile.

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