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Rethinking tradeoffs and OR/MS methodology

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The purpose of this paper is to explore the role of a process known as the 'evaporating cloud' (EC) as a way of enhancing OR/MS modelling. While other authors have described the use of the EC process to explore the tradeoffs in a traditional Economic Order Quantity model, this paper demonstrates the use of the EC with a facilities location problem, which was originally solved via mixed integer programming. We relate our findings to OR/MS modelling in general, and argue that the EC could contribute effectively to different phases of the problem-solving process, for example, aiding the problem-structuring phase and helping to find better solutions in many OR/MS modelling situations. We demonstrate that the EC is a valuable tool to use in modelling practice as a problem-structuring tool, as a way of dealing specifically with tradeoffs, and that it can therefore be a useful complement to OR/MS methodology, and contribute to OR/MS practice and teaching.

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1. Introduction

Tradeoffs are ubiquitous in the real world, so it is hardly surprising that they are a central theme/subject of OR/MS approaches where the aim is to provide practical ways of resolving the compromises that tradeoffs often represent. Traditionally, the decision to trade off one objective against another implies an acceptance that it is impossible to simultaneously optimize across these multiple objectives, and thus compromise is seen to be unavoidable. Thus, OR/MS methods have been developed to provide practical ways of working with such accepted compromises. Indeed, the need to find the best solution in these tradeoff situations is arguably the primary justification for the development and use of methods such as mathematical programming for constrained optimization, multi-criteria methods, simulation, decision trees, and heuristic methods.

A well-trodden problematic situation in management text books is the economic order quantity (EOQ) decision that is faced by firms wishing to minimize their inventory-related costs. In such situations, for example, the firm may want to purchase materials required to produce a product with minimum cost. In order to minimize inventory-related costs, the firm would like to have low holding costs and low ordering costs, but the firm faces a conflict in that it cannot have both simultaneously. What should the firm do? The traditional OR/MS formulation and approach facilitates an EOQ solution derived using calculus, which 'minimizes' the sum of the two.

However, Goldratt (1990a) and others (eg, Jackson *et al*, 1994) have challenged the underlying assumptions surrounding the EOQ model and its variants, portraying the EOQ as a false optimum. It may be argued that the plausibility of the accepted tradeoffs disguises the nature of the implicit assumptions that may or may not justify such tradeoffs. Such writers have used a schematic approach to conflict resolution known as the evaporating cloud (EC) (Goldratt, 1994; Scheinkopf, 1999) and also known as the Conflict Resolution Diagram (Dettmer, 1997, 1999, 2007), with which they surface and challenge the basic assumptions underlying the EOQ. By so doing, 'evaporating' apparent conflicts, dilemmas or tradeoffs, 'win-win' solutions can often be identified in which holding costs and order cost are minimized simultaneously. Such solutions are now commonplace in inventory management practice.

The question then arises as to whether a parallel situation might exist in other traditional OR modelling domains. OR/MS models are primarily directed at finding the best solution under some constraints or in the face of multiple conflicting objectives where the best solution successfully 'trades off' these objectives against each other. Hence it would appear that a parallel situation may exist more generally with other OR/MS models, in that the EC process may yield better solutions, and in particular, win-win solutions that avoid the need to trade off competing objectives.

This paper shows, via a two-stage facilities location problem originally formulated and solved as a mixed integer program (MIP), how the implicit tradeoff can be represented

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and addressed via the EC to generate better solutions, and argues as a corollary that most OR/MS modelling efforts would be enhanced by using the EC process to explore the assumptions underlying and surrounding the OR/MS models. In doing so, we argue that by incorporating the EC into the OR/MS modelling process, better solutions will be more routinely identified, and that this broader-based OR/MS practice will be better placed to realize its vision of the 'Science of Better'.

The remainder of the paper first outlines the facilities location problem and how it was/may be addressed, before providing a directed comparison of the approaches, not only in terms of processes, but also in terms of assumptions and solutions. We then discuss how the EC process may be applied to other OR/MS models, and beneficially used to enhance OR/MS modelling.

2. The retailer's facilities location problem and its re-appraisal using the EC process

Let us now re-examine a problem that is faced by retail firms wishing to optimize their inventory and distribution systems. In this example, based on a real electrical appliances retail chain in north-west England, the firm provides goods (domestic appliances/consumer electronics) to customers that are 'sold' to end customers through its retail stores, but are delivered from the firm's warehouses/depots to the customers' premises where they are installed by specialist delivery personnel. The question is how many warehouses/depots should they have, where should they be located, and which delivery areas should each warehouse/depot serve? This typical centralization/decentralization tradeoff can be modelled as a facilities location problem, with attention paid to the inventory costs that would be incurred at the facilities (warehouses or depots) and that depend on the size of the inventory held, plus the distribution/transport costs for the delivery to the customer and installation at the customers' premises.

2.1. The traditional OR approach—optimization

With such tradeoffs, the firm would consider it ideal if they could minimize both warehouse costs and transport costs simultaneously. However, the former would require one central warehouse and the latter would require many warehouses. Traditionally, such problems have been modelled and solved using mixed integer programming to identify the best number of warehouses, their locations, and the allocation of demand regions to those warehouses.

This problem, used as the basis of a research project, was modelled and solved as a MIP formulation of a two-stage facilities location problem, as follows:

$$\text{Minimize } z = \sum_i f_i y_i + \sum_j f'_j y'_j + \sum_i \sum_k (c_{ik} + v_i) x_{ik} + \sum_i \sum_j (c'_{ij} + v_i) x'_{ij} + \sum_j \sum_k (c''_{jk} + v'_j) x''_{jk}$$

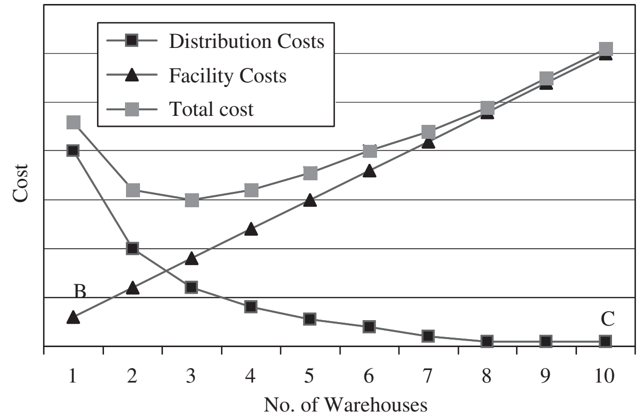

Figure 1 Facility cost/distribution cost tradeoff.

subject to

$$\sum_i x_{ik} + \sum_j x''_{jk} \geqslant d_k, \quad k = 1, \; N_k$$

$$\sum_i x'_{ij} - \sum_k x''_{jk} = 0, \quad j = 1, \; N_j$$

$$M_i y_i - \left(\sum_j x'_{ij} + \sum_k x_{ik} \right) \geqslant 0, \quad i = 1, \; N_i$$

$$M'_j y'_j - \sum_k x''_{jk} \geqslant 0, \quad j = 1, \; N_j$$

$$y_i, \; y'_j = 0, 1; \; x_{ik}, \; x'_{ij}, \; x''_{jk} \geqslant 0$$

where $y_i = 1$ if warehouse i is 'open'; 0 if 'closed', $y'_j = 1$ if depot j is 'open'; 0 if 'closed', x_{ik} quantity supplied from warehouse i for demand zone k (in demand units per annum), x'_{ij} quantity supplied from warehouse i to depot j (in demand units per annum), x''_{jk} quantity supplied from depot j to demand zone k (in demand units per annum), f_i fixed cost per annum incurred if and only if warehouse i is opened, f'_j fixed cost per annum incurred if and only if depot j is opened, v_i, v'_j variable cost per unit of demand throughput incurred at warehouse i, depot j, respectively, c_{ik} delivery cost per unit of delivering from warehouse i to demand zone k, c'_{ij} delivery cost per unit shipped between warehouse i and depot j (bulk shipment), c''_{jk} delivery cost per unit of delivering from depot j to demand zone k (local delivery), d_k demand of zone k (in demand units per annum), M_i, M'_j arbitrary large numbers for independent demand constraints (Note aggregate demand constraints may also be used but are omitted here for simplicity) (Mabin, 1981).

The model was solved for various scenarios representing different demand patterns, service levels, and other factors (Mabin, 1981). The results for a given scenario were plotted (see Figure 1 as an example) to reveal a typical tradeoff situation. The MIP 'optimization' approach was deemed to be appropriate, given the implicit assumption that minimizing both costs cannot happen simultaneously. It assumes there is a satisfactory compromise, and this is found where the total cost curve is at its minimum value.

The conclusion for the scenario shown is that three warehouses produce the minimum total cost solution. The three chosen warehouse locations were specified by the MIP solution, together with the allocation of depots and delivery zones to the three warehouses, in order to meet the required service levels for the demand pattern specified.

We now examine how the EC process of the multimethodology known as the Theory of Constraints (TOC), may contribute to the problem-solving process in this case.

2.2. *The TOC approach using the EC process to develop a 'Win-Win' solution*

As Dettmer (1999) suggests, conflict is often subtle or unspoken, and frequently goes unrecognized, with no one aware that an underlying conflict is affecting the situation. As a result, the problem may be difficult or even impossible to solve or resolve effectively (Ackoff, 1978). The problem situation described above would not generally be regarded as a conflict. It may not even be viewed as a dilemma. However, there are a few clues as to its presence: we are attempting to minimize a sum of two factors that move in opposite directions; Figure 1 bears a striking similarity to the traditional EOQ cost minimization graph and we have treated the situation as a constrained optimization.

By analogy to the EOQ problem, the retailer's tradeoff would appear to be a candidate for applying the EC process. We will represent the retailer's tradeoff via the EC process and explain how a solution might be developed using the EC and, later, other TOC methods.

2.2.1. Representing the tradeoff as a dilemma using an EC diagram The EC process starts from the premise that a compromise is not the best we can do, and that a win-win solution can be found. To frame the retailer's tradeoff as an EC diagram, first we identify the two opposing actions, D & D′:—having *one* central warehouse, *versus* having *multiple* warehouses—which are shown on the EC diagram, on the one side to minimize facility costs, and on the other side to minimize delivery costs, shown as boxes B and C, respectively. Finally, we identify the common objective, placed in box A, to minimize total costs. B and C are required if A is to be achieved. D and D′ are the prerequisites of B and C, respectively. Using this method, we may derive the following cloud diagram shown in Figure 2.

We read this EC diagram (from left to right) as: *in order for* Retailers to Minimize total costs, they *must* Minimize facility costs. *In order to* do this, they *must* have One central warehouse. On the other hand, *in order for* Retailers to

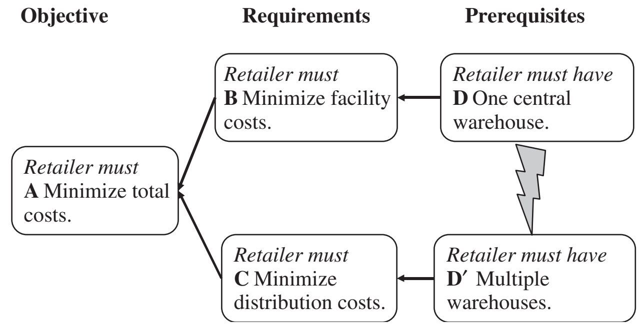

Figure 2 The retailer's tradeoff reframed as an EC.

Minimize total costs, they *must* Minimize delivery costs, and *in order to* do this, they *must* have Multiple warehouses. Hence the conflict! (denoted by the lightning bolt arrow).

2.2.2. Resolving the dilemma Now that we have framed the conflict or dilemma as an EC diagram, and to deepen our understanding of the supposed conflict, we seek to determine whether it can be 'evaporated'. We do so by using one of two common ways of breaking the conflict—firstly a quick, direct way where one looks for ways of having B without D, and/or C without D′.
For example, we would ask,

> 'How could we minimise facility costs (B) not with a central warehouse (D)
> ... but, instead with multiple warehouses (D′)?'

One answer might be

> If the multiple warehouses were small and low-budget,
> ... they may be cheaper than one fancy central warehouse.

Then we would ask:

> 'How could we minimise delivery costs (C) not with multiple warehouses (D′)
> ... but with a central warehouse (D)?

which might lead to productive ideas prompted by thinking along the lines of:

> 'Maybe the central warehouse was connected to delivery areas by an extremely efficient delivery system that flows like a pipeline ...'

Alternatively, we can generate ideas for solutions by methodically surfacing assumptions that underlie the dilemma, which assumptions are then expected to be challenged and perhaps invalidated. The assumptions can be surfaced by completing the sentence: . . . *In order to* . . . *we must* . . . *because* . . . and recognizing that the 'because' clause(s) encapsulate one or more assumptions.

For example:

BD *In order to* minimize facility costs B, the retailer *must have* one central warehouse D *because* . . . .

*BD*1: Each facility incurs costs.
*BD*2: Total inventories increase with the number of warehouses.
*BD*3: One central warehouse has lower facility costs than a multiple warehouse system, due to economies of scale in warehousing.

Other similarly surfaced assumptions are shown in Table 1 (not necessarily a complete or comprehensive list, but they will provide an indication of how we proceed).

Now, we demonstrate how we may explore ways of resolving the conflict or dilemma by challenging the assumptions with breakthrough ideas, which (Goldratt 1990a, 1994) terms 'injections'. For example:

- *Breaking BD*:
  - Several small facilities may be cheaper than one large one.
  - All facilities need not be the same: we can have small depots or even just transfer locations on roadside lay-bys.
  - Smart holding of stock can reduce stock requirements in a multiple warehouse system, while maintaining service levels.
- *Breaking AC*:
  - We could get customers to bear some of the delivery costs. For example, get customers to uplift goods from a regional depot rather than offer free delivery.
- *Breaking CD'*
  - We could make the product simpler and also provide clear instructions so customers can do installation themselves. This could be offered as an option for customers not wanting to wait for delivery.
- *Breaking DD'*:
  - We could have one main warehouse to minimize stock holding/warehousing costs while also using several low-cost depots or transhipment sites to minimize delivery costs.
    These would be equivalent to multiple warehouses as far as delivery costs are concerned, but as they would hold no stock there would be no need for a proper warehouse and so would be very cheap to operate, especially if they were just transhipment points.
  - This would allow the retailer in effect to operate at points B and C in Figure 2 simultaneously, the sum of which is far lower than the minimum of the total cost curve.

For more difficult problems, we would usually attempt to construct a full set of injections for these assumptions such as in Table 2.

A strategic win-win solution for this problem can then be formed by selecting a combination of the injections, and is seen to be akin to the TOC solutions for supply chains, in general. The final test is whether the conflict or dilemma has been resolved.

The recommendations obtained by our analysis are consistent with the general TOC solution for supply chains (see Box 1).

Box 1 The related supply chain scenario

For supply chains in particular, a generic solution has been developed using TOC methods. While in the case analysed here, products were shipped according to actual customer orders, in many supply chains products are shipped to retailers according to forecast, resulting in the wrong stock in the wrong places/wrong quantities, with resulting overstock for some products and lost sales for others. In contrast, the TOC solution is a pull system, sending products out to retailers to replace products consumed (Goldratt *et al*, 2000; Schragenheim and Dettmer, 2001; Schragenheim, 2007; Goldratt, 2008). The TOC solution is basically to have one central plant or warehouse and to have pipeline stock sufficient to meet short-term demand at retailers, with strategically sized buffers. Demand is communicated direct to the central warehouse, and stock is replenished as quickly and frequently as possible to match demand. This avoids the Bullwhip effects observed in the classic 'Beer Game' (Sterman, 1989; Lee *et al*, 1997).

2.2.3. Further development of the solution using other TOC methods TOC protocols would then guide us to critique and develop these injections further, as needed, until a full workable solution is devised for the particular situation, and an implementation plan developed. The suite of TOC methods available can support all phases of problem solving, from problem structuring, diagnosis, solution development, through to implementation. For example, using cause–effect logic we depict the current situation identifying what needs to be changed, in a 'current reality tree'. Combined with the EC process to identify a promising direction for the solution, we then use cause–effect logic again to create a 'future reality tree'—mapping the likely effects of the strategic path we have chosen to follow, making sure it delivers what is desired, while also avoiding any undesirable side-effects. Then we explore how this strategy can be enacted, identifying actions that must be taken to overcome obstacles standing in the way, in a 'prerequisite tree' and, if necessary, more detailed plans are similarly developed and identified in either a 'transition tree' or a 'critical chain' for project management. For a fuller description of the TOC methodology, its methods and associated TOC protocols, see Scheinkopf (1999), Dettmer (1998, 2007), Kendall (1998), Smith (2000), Cox *et al* (2003, 2005). For an overview of how the TOC suite of methods contribute toward all phases of problem solution

Table 1 Assumptions for the EC

Arrow (Box)		*Assumptions*
Box A	A1	Minimising total costs is desirable.
AB	AB1	Facility costs are a significant part of total costs.
	AB2	Inventory holding costs are a significant part of facility costs.
	AB3	We pay for the facilities.
AC	AC1	Delivery costs are a significant part of total costs, as they include transport, and installation costs.
	AC2	We pay for delivery from facilities to the customer.
BD	BD1	Each facility incurs costs.
	BD2	Total inventories increase with the number of warehouses, that is, the more warehouses, the greater the total facility costs.
	BD3	There are economies of scale in warehousing, such that one central warehouse is cheaper than several warehouses.
CD′	CD′1	Delivery costs are only reduced if we have more warehouses, because ...
	CD′2	Warehouses can be spread over the region, and because ...
	CD′3	We can make use of bulk transport for the main routes, and more suitable local transport for local deliveries.
	CD′4	The shorter the distance involved in deliveries, the lower the cost of skilled personnel needed for delivery and installation.
DD′	DD′1	One central warehouse AND multiple warehouses cannot exist at the same time, because multiple warehouses are not possible in a one-warehouse system.

Table 2 Injections for the EC

Arrow (Box)	*Assumptions*	*Injections*
Box A	A1	Minimizing total costs is less desirable than say maximising profits. A focus on minimizing costs may harm revenues.
AB	AB1	Reduce facility costs—investigate alternative sites, rental *versus* owned property.
	AB2	Simplify/streamline order processing/storage/picking systems.
		Apply buffer management concepts to reduce inventory while improving SC performance.
	AB3	Get someone else to pay for the facilities, so they don't count towards our costs.
AC	AC1	Apply buffer management concepts to reduce total delivery costs. Consider total costs not just for deliveries but also returns, repairs, replacements.
		Investigate cheaper delivery options—maybe contract out or bring back in-house.
		Examine service level options.
	AC2	Could get customers to bear some of the delivery costs. For example, get customers to uplift goods from a regional depot rather than offer free delivery.
BD	BD1	Several small facilities may be cheaper than one large one.
	BD2	All facilities need not be the same: can have small depots or even just transfer locations on motorway lay-bys. ***
	BD3	Smart holding of stock can reduce stock requirements while maintaining service levels.
CD′	CD′1	Delivery costs can still be reduced by having depots or sites for transfer, not necessarily warehouses. ***
	CD′2	Review service standards instead, relaxing time to deliver.
	CD′3	Make product simpler and supply clear instructions so customers can do installation themselves. This could be offered as an option for customers not wanting to wait for delivery.
DD′	DD′1	Can have one warehouse to hold goods, and transfer sites at multiple locations, to minimize both delivery and facility costs simultaneously.
		Have warehouse open some of year, especially in distribution systems dealing with seasonal products.
		Have temporary depots—for example, ice-cream or coffee stalls, that open in the tourist season.
		Have one warehouse for one part of the system and multiple warehouses in another part of the system.
		At certain times of the year, or under certain conditions, like festivals or special events, open up extra distribution outlets.
		Have complementary systems: use other retailers' systems. One might have one central warehouse, and another may have an excellent network of outlets—that way you have the best of both.

Notes: Finding DD′ injections can be quite difficult. In such situations we find it helpful to use the separation principles from TRIZ—the theory of inventive problem solving (Mann, 2007).
Assumptions marked *** are discussed in Section 3.2

as defined by Mingers and Brocklesby (1997), see Davies *et al* (2005).

3. A directed comparison

We will now reflect on our learning from this exercise by comparing the solutions, processes, aims and intent of the two different approaches, before exploring the implications for OR/MS modelling more generally.

3.1. Comparing solutions

The facilities location problem was tackled using a specialized MIP constrained optimization modelling package on mainframe computers (Mabin, 1981), and contributed to the field of knowledge at the time. The focus was on finding the best solutions, given a range of scenarios of demands and service-level requirements, which then effectively dictated the costs of the alternatives. Considerable effort went into trying to find the lowest costs for each of the cost elements for each scenario, but the basic tradeoff was not questioned.

Interestingly, similar approaches are still used, but computational software is much faster (see eg, Sridharan, 1995; Melo *et al*, 2006). Consequently, more recent work such as that of Melo *et al* has allowed numerous variants and modifications to be solved using more elaborate and powerful models. However, the basic underlying assumptions (eg, that facility costs exhibit economies of scale) appear to remain unquestioned.

In contrast, the EC process requires a questioning of the problem as stated, and seeks to identify ways of avoiding, or at least ameliorating, the impacts of the tradeoff. In this case, we suggest that the ideas from the EC would have yielded a lower overall cost for any of the demand and service combinations solved via the MIP, and we provide some rationale for this view in the following section.

3.2. Comparing processes

In fact, two of the ideas listed as injections in the later EC analysis (shown with *** in Table 2) were incorporated into the original MIP model, as a way of reducing the costs for that part of the system, namely, using different kinds of transhipment points instead of physical depots. Such transhipment points would contribute to a low-cost solution as firms would keep transportation costs low while incurring little in the way of facility costs. We note that transhipment points had the same effect on transportation costs as having many warehouses, while facility costs were close to that of a single warehouse. The main disadvantage of having transhipment points was identified as relating to the delays incurred in transhipping, which, in turn, impacted on delivery service levels, which was also being modeled.

It is also worth noting that the use of transhipment points was incorporated into the MIP in such a way so as to fit with, and be constrained by, the implicit assumptions and structure of the MIP formulation—the use of a MIP formulation, *per se*, was not questioned. Nor was the choice of cost minimization *versus* profit maximization questioned—they were assumed to be equivalent. Nor was the impact of using transhipment points appreciated as a way of challenging the central tradeoff—rather what was done represented a belief of what most people would do in trying to find the best cost for each demand and service-level combination to use within the MIP framework that we had already decided on.

Very recent work on the topic also stays within the MIP framework, where possible. Berman *et al* (2008) have recently sought to define and examine the related Transfer Point Location Model and its variants, attributing the concept of transfer points to O'Kelly, citing a 'hub and spoke model', (and a 'mini-hub concept' (. Berman *et al* also stay within an MIP framework, where possible, using heuristic programmes only where they are more suitable for problems too large/complex for MIP.

Research into framing effects (Russo and Schoemaker, 1990, 2002; Bazerman, 2008) underlines how powerful our extant conceptual frames can be in constraining our view, being subject to 'escalation of commitment' and the 'fallacy of sunk costs' being just two well-known biases. Furthermore, commitment to a prior frame, or a modelling approach, provides an unconscious anchor that in normal situations prevents us from seeing, recognizing, appreciating and using new knowledge, and Bazerman (2008), Russo and Schoemaker (2002) suggest that conscious and deliberate attempts to reframe are needed to overcome such biases.

The use of the EC process therefore represents such an attempt to reframe the problem, and also to mitigate the impact of any unconscious judgemental biases, and does so in a systematic, but systemic fashion. Even good OR/MS practice can be improved by adopting such complementary frameworks, frames and processes. The idea of using transhipment points was surfaced through an *ad hoc*, somewhat intuitive, but unstructured process. When incorporated in the costings, they contributed to a significant improvement in final solution costs. However, for various reasons, linked to the nature and purpose of the research and the relationship to the client, the modelling approach was not reassessed. It appears that even when practitioners surface another solution, it may not be recognized, its significance may not be appreciated or understood, unless it is perceived through another lens or frame. Otherwise, it is more likely that they will persist with their original frame.

The authors have found the use of the EC frame in harness with standard OR/MS modelling approaches to be particularly fruitful (Mabin and Davies, 2003). On reflection, it is noted that had the EC process been used to explore the original problem systematically, other injections would likely have been generated, and other ways of resolving the problematic situation may well have been found, without the need to use or be dependent upon the MIP formulation. In addition, other ways may have been identified of reducing the costs within the system, even further.

In the EC analysis above, for example, we have listed more than a dozen suggestions or avenues that the retail organization could have explored or used to reduce their actual costs (and/or improve profits). More significantly perhaps, the EC process represents and has provided a unified systems framework for understanding in what regard each of these diverse and sometimes conflicting strategies may be beneficial.

One of the noted benefits of the EC process is that it prompts us to ask the 'right' questions, ones that are directed to the tradeoff itself. For example, just asking, 'How can we get low distribution costs with only one central warehouse?' may be enough to spark a raft of ideas. As Jackson *et al* (1994) argue, the EC:

> *stimulates creativity by providing a structure and objective which directs and focuses imagination* rather than merely listing possible alternatives or brainstorming. It takes the analyst's knowledge of the costs and systems involved, and pushes the analysis deeper ... it is intuitively appealing because we know that the best solutions are those which cause the problems 'to evaporate' and that the solutions of last resort are compromises. When the problem disappears there are no losers (*our emphasis*).

If the decision maker cannot make the problem disappear, Jackson *et al* recommend that if something can be done which improves the situation, then it should probably be pursued. It is also suggested that the effort to make the problem disappear should never be abandoned—for perhaps there is an assumption that has not yet been uncovered, or that the 'problem' is not the core problem, or the objective is incorrect or poorly defined. Of course, these latter views represent aspects of the contribution of the EC to the problem-structuring process.

It is interesting to note how the developments that have taken place since the original research (and which are listed as injections in Table 2) have contributed to the emerging field of Supply Chain Management—SCM, and are now standard SCM. One wonders if the EC process had been used at the time (had it been known), whether these ideas and injections would have surfaced then. We can only postulate a response based on our backgrounds in OR/MS and several years' experience of using the EC process. Such experience with the process provides the confidence to move beyond the constraints manifest of traditional thinking modes—accepting that we are in the horns of a dilemma—and to facilitate the generation of new and better solutions that had not been contemplated before, or that would have been hidden or down-played by traditional thinking using traditional frames.

3.3. Comparing aims and intent and assumptions

The revisiting of this problem also provides the opportunity to reflect on how the intent of the two approaches has impacted on developments in the field that have taken place. Over the past 30 years, publications in the area of mathematical programming for the facilities location problem have concentrated on new and improved, better, more efficient, solution techniques for the problem—as given—and its many variants (for an excellent review, see Melo *et al*, 2006).

In contrast, developments and use of the EC process have been applications-oriented and focused on exploring various aspects of the problem to seek better solutions by asking why the problem exists and whether it really does need to exist. Rather than solely looking for better solution techniques to effect an acceptable tradeoff, use of the EC process drives a search for better solutions, first, by questioning the need to trade off, and then by seeking to remove the cause(s) of the tradeoff. It seeks to nullify or at least ameliorate the downside of the problematic situation, that is, the EC process seeks to explore ways of resolving the problem (Ackoff, 1978), rather than just solving the given problem (in Ackoff's sense), or seeking better solution techniques to the problem.

4. Applying the learning implications elsewhere—generalizing to math modelling practice

The importance of surfacing implicit assumptions and challenging these assumptions cannot be overstated. Such assumptions include the acceptance of the need to trade off one objective against another, assumptions about the data, about the context, and about the goal or objective of the decision maker. Each set of assumptions is considered below, before suggestions are offered about possible fruitful use of the EC process and OR/MS methods in multimethodological use.

4.1. Assumption: tradeoffs are unavoidable and acceptable

The mathematical programming approach starts with an implicit assumption that a compromise is both inevitable and acceptable if our outcome measures are commensurate. Breakthroughs in our thinking come by challenging this paradigmatic point of view.

Our learning from experience is that we often accept the need to trade off objectives, to accept a compromise, when in fact there is no need to do so. We can often have the best of both worlds if we expose our implicit assumptions and challenge them. For example, facility and transport costs can be minimized simultaneously through practices such as using transhipment points rather than depots, by shipping goods only as needed rather than holding stock at all the warehouses/depots, and by other practices that are now accepted as exemplary supply chain practices.

The EC process provides a useful check by prompting us to step back, and state the problem in a high-level way, forcing us to question why we believe that, for example, minimizing transport costs inherently conflicts with minimizing warehouse costs necessitating a tradeoff. The EC process not only encourages us to question the assumptions concerning our acceptance of the need to trade off one objective against another, but also to discover whether our acceptance of 'optimization', and what is to be optimized, is appropriate.

4.2. Assumptions concerning the data and context

Breakthroughs also arise through challenging any of the 'givens'. In any of the usual tradeoff situations, there are many 'givens', such as the cost of facilities and the cost of transport, which the so-named 'optimization' model takes as givens. The EC frame encourages us to question the assumptions concerning these 'givens', prompting us to question why we believe that, for example, minimizing facility costs can only be achieved by having one warehouse and no depots. We may discover, for example, that the cost of depots may be eliminated almost entirely through transhipment points rather than physical depots. Or, we may question the context we have assumed, which dictates for example that inventory costs are a given, and realize that they could be reduced if we could persuade suppliers to retain ownership of the inventory in our distribution system—as they do in some other industries. This has an added advantage that suppliers are encouraged to supply according to actual demand, rather than to often less-than-reliable forecasts.

4.3. Assumptions concerning the objective function

As Jackson *et al* (1994) note, the EC process forces us to question whether our objective (stated in the EC in box A) is really a valid objective. It is often found that the chosen objective is spurious. For example, for the facilities location/allocation MIP above, minimizing cost may not be a reasonable objective—and minimizing cost might lead to cost-cutting actions that jeopardize overall profits, whereas it might be better to aim directly to maximize profits. Often in mathematical programming, it is assumed that minimizing costs is equivalent to maximizing profits, but the two can yield different results, which begs the question of whether we should minimize costs in organizations that are profit-making organizations!

Similar questions concerning the choice of objective functions have been raised by long-standing OR/MS scholars such as Zeleny (1981) and Gass (1989). Such issues are often overlooked when we build our models, in our desire to 'optimize' and due to our focus on the method rather than the solution. As seen above, solutions unencumbered with compromise can exist if we step outside the mathematical model or frame, and although we may come across them in the modelling process, we often ignore them for many reasons that can include being both deliberately pragmatic and/or even unwittingly affected by one's paradigmatic position. The following section offers some suggestions about how such matters may be addressed by deliberate use of a multimethodological, multiple framing approach, incorporating the use of the EC process.

5. Discussion

5.1. Improving the benefits of mathematical programming in general

Mathematical programming approaches require the construction of a mathematical model that encompasses understanding and modelling of the component costs. However, in real cases as in the above case, the collection of data is not an insignificant task. For example, the modelling of facility costs requires an understanding of inventory needs for a warehouse of a given size serving a given area to meet a specified service level, in order to calculate the holding costs for such inventory, as well as facility construction, maintenance and operating costs. Delivery costs depend on the nature of the delivery system: vehicles, routes, personnel, etc.

We therefore recommend that before launching into a massive costing and modelling exercise, the EC process could play a significant role in problem-structuring, and provide a check on the assumptions implicit in such an exercise. It may well uncover options for further investigation before the mathematical programming is developed. Or it might suggest that a different approach shows promise—such as a focus on streamlining the supply chain operations, improving forecasting of demand, and establishing better communication throughout the supply chain, reducing the reliance on forecasts, so that the same service level can be provided with lower inventories.

The time involved in doing this EC analysis would almost certainly pay off in terms of better understanding of the system to be modelled. It would create much discussion of the system, its nature, its goals, etc, and in doing so produce a clearer understanding between modeller and owner of the system. It may also save considerable modelling time. But more importantly, it could lead to better outcomes by improving the actual physical system, rather than 'optimizing' a notional system based on unquestioned assumptions and implicit constraints.

We note several papers that have sought to validate the usefulness of the TOC framework by comparison with mathematical programming frameworks. For example, Ronen and Starr (1990) have shown that the theoretical fundamentals of OPT (Optimised Production Technology, an early form of TOC methodology) can be seen to have close parallels with basic models of OR/MS, decision sciences, operations management and systems theory. They differentiated between 'small OPT'—the scheduling technique and 'big OPT'—the overall management framework. However, the focus of Ronen and Starr was mainly on 'small OPT' and production scheduling issues. Other work has also demonstrated that product mix decisions tackled via LP also benefit from the use of TOC frames (see, eg, Goldratt, 1990b; Luebbe and Finch, 1992; Mabin and Gibson, 1998; Mabin and Davies, 2003).

In addition, tradeoffs are very apparent in goal programming, where it is accepted that:

> it is almost impossible for the decision-maker to achieve 'ideal' goals without the expense of other goals. The multi-objective problem inherently signals conflict among multiple objectives or goals (Min and Storbeck, 1991).

In this field, the debate has been fierce as to whether goal programming is optimization or satisficing, although Min and Storbeck argue, quoting Lane (1970), that the difference between the two is not much in reality. According to Eilon (1972):

> Optimizing is the science of the ultimate; satisficing is the art of the feasible … the satisficer put(s) his constraints first and then look(s) for a feasible solution … tradeoffs are a direct implication of any method that converts multiple objectives into a single dimension.

In some cases, 'constraints' may be super-ordinate objectives, a view in keeping with Eilon's recommendation that there is far more to be gained from scrutinizing and ranking constraints than from creating a super utility function to '*delight … the optimizer*'. However, Eilon stops short of questioning the need to trade-off objectives. This leads us to suggest that his definitions of satisficing and optimizing could be extended to define the EC process as

> the art of systematically questioning the feasible, to find a way of simultaneously meeting two opposing means of achieving a common objective.

5.2. Linkages to multi-criteria decision analysis (MCDA) and other OR/MS approaches

Besides mathematical programming, there are other methods and modelling approaches that could also be candidates for use in harness with the EC process, and that could also benefit from the exercise of multiple framing. Multi-criteria decision analysis (MCDA) and decision-making is an obvious example where the tradeoff between competing objectives is considered explicitly. Moreover, there is an explicit acceptance of the need to compromise in the absence of one alternative that performs best on all criteria. As Belton and Stewart (2002) and Goodwin and Wright (2004) argue, the role of MCDA is not simply to find the 'right answers' or, perhaps, the best compromise for a given problem or derived model; modellers need to look further for insights. They could take the discussion beyond the modelling process to the level of debating how all criteria might be achieved simultaneously, and could do this earlier in the problem-solving process perhaps, and in a more structured way, by using the EC. In our experience of using MCDA for selecting, for example, a candidate for a job, the MCDA often comes down to a final tradeoff between Person A and Person B on two high-level objectives that the decision maker will often find uncomfortable to resolve. At this stage, we have found the EC useful in prompting further questions that lead to an achievement of both objectives simultaneously.

Similarly, simulation and heuristic modelling address the desire to do as well as possible on many conflicting criteria, under a range of different conditions. Any attempt, therefore, to describe a meta-problem or identify a meta-decision should include the circumstances under which all criteria would be maximized simultaneously, and extend to a search for a strategy to achieve such a position. The EC process offers an approach to guide such discussion. In related problems, for example, modelled using decision trees, the choice is portrayed as choosing one of a set of mutually exclusive options—and here, too, the EC process could help by prompting the question of how one might get the advantages of the various options simultaneously.

5.3. EC for the OR modellers' toolbox

By helping to guide and structure our thinking to re-examine hidden assumptions and improve on standard solutions, the EC can be viewed as a useful process tool to add to the OR/MS modellers' toolbox. This paper has shown how the EC process can be of benefit even when tackling supposedly quantitative optimization problems, by drawing out non-quantitative elements, in a manner akin to that exemplified by Soft OR methods. The role of Soft OR as an aid in problem structuring has long been recognized, though not without its share of debate about appropriateness and efficacy. However, as Reisman and Oral (2005) note, the roots of Soft OR can be traced back to the earliest of OR workers and writers, who adopted an interdisciplinary and pragmatic approach that encompassed both hard and soft systems thinking.

Murphy (2005) argues that developing such soft skills is essential, and that such development occurs as the OR person moves from novice to journeyman to expert. The implication is that the skills are gained as implicit, tacit knowledge, picked up on the way through experience. We would suggest that the tools and approaches of TOC facilitate this process, and that they can catalyse the further development of learnable soft skills, which are of value to OR/MS modellers. We suggest that these benefits arise because the tools and approaches have methodological coherence and are methodologically sound with respect to underpinning philosophical assumptions (Davies *et al*, 2005). In addition, the tools are relatively straightforward to use, and utilize a visual and logical framework that will appeal to many modellers.

Our objective, here and elsewhere (Mabin and Davies, 2003; Davies *et al*, 2006; Mabin *et al*, 2006) has been to raise awareness of the usefulness of the EC—and other TOC thinking processes—and to encourage OR/MS educators and modellers to contemplate using TOC alongside their usual methods as an integral part of their modelling exercises. Jackson *et al* (1994) warn that using the EC process may not be straightforward initially, given its differences to traditional problem-solving approaches, but that benefits accumulate quickly from practice. Certainly the EC process not only complements traditional OR thinking, requiring and guiding the modeller to surface assumptions that underpin standard OR models, but also provides a systematic process for doing so. Moreover, it is our view, too, that the EC process can be quick to learn, and quick and powerful to use. We note that, as well as Jackson *et al*'*s* guide, Scheinkopf (1999) and Khaw (2005) provide numerous constructive teaching examples of the EC-in-use, while Dettmer (1997, 1998, 1999, 2003, 2007) and Cox *et al* (2003) provide comprehensive illustrations of the EC and other TOC methods for those wishing to learn and work with the methods.

6. Conclusion

This paper set out to demonstrate the value of using the EC process, from the multimethodology known as the TOC, in situations usually tackled by traditional OR/MS methods. While several researchers have shown, for example, how the EOQ problem can be revisited using the EC process to resolve or find better solutions to inventory problems, most EOQ-related papers reflect applications or extensions that do not make use of the EC—perhaps because TOC research has gone unreported, unheeded, perhaps due to the choice of publication outlet, a lack of appreciation, or a lack of understanding. As a result, the potential for using the EC process for examining inventory-related problems has not been realized. In addition, the potential to use the EC in harness with OR/MS more broadly remains largely untapped.

This paper has explored the use of the EC process in a standard OR/MS modelling situation—the facilities location or location/allocation problem—and shows how the EC process can enhance the MIP solution. Given the central role of tradeoffs in other types of OR/MS models, we argue that the EC would also be a valuable tool in addition to the OR/MS toolbox. We also suggest that our experience indicates that the use of the EC in multimethodological intervention by OR/MS modellers would be beneficial, and that, as a corollary, modellers would benefit from the EC becoming an integral part of their suite of problem-structuring and modelling tools—a view mirroring earlier calls by eminent OR/MS scholars to use models as thinking aids (Gass, 1989; Rothkopf, 1996). Given that the acquisition of soft skills has gained importance among OR/MS modellers, we then acknowledge that the tools and approaches of TOC, such as the EC process, may contribute to, and can catalyse the further development of a broader set of soft skills.

The facilities location case examined here has shown how the EC is able to help us explore ways of going beyond compromise solutions. It does so by asking a set of directed questions that prompt us to surface and challenge the assumptions that we typically make when framing problems using traditional OR/MS modelling methods. We note that although our investigations began at the level of an operational dilemma, the use of the EC process can make it possible to set the debate in a strategic context. By exploring possible solutions through the use of the EC process, we can move from a tradeoff situation (operational level solution) to one of 'trading on' the possibilities uncovered by the EC (strategic-level solution).

An advantage of the EC process is that it focuses thinking on the tradeoff, drawing attention to the broader system goal, and forcing the modeller to surface and make explicit the many assumptions that give rise to the tradeoff. Such use of the EC would help to confirm which elements indeed required a tradeoff and which elements could be better handled another way. In our experience, many standard modelling assumptions—otherwise left implicit—would be surfaced by the EC and when challenged, found to be inappropriate or unnecessary, thus leading the way to better solutions. The revised model developed after such rethinking may well be quite different to the model initially conceived. While good OR/MS encompasses the explicit statement of assumptions at the start of, and then throughout, the modelling exercise, in reality, we often dismiss, disregard or overlook the valuable step of challenging those assumptions without a guiding process in place.

The EC process can be seen to provide firstly, a means of conceptualizing tradeoffs that complements the traditional mathematical programming or calculus-derived analytical view in terms of the system goal; secondly, a means of questioning assumptions, asking pertinent questions; thirdly, a means of conceptualizing the counter measures or actions we seek to develop as part of the OR/MS modelling process—and to show why they might work; and finally, the EC helps provide a means of directing creative energy to avenues that show most promise.

More generally, we note that the broader set of TOC thinking process tools can be helpful in the problem-structuring phase to explore the implicit interactions and boundaries of a problem, allowing better use of optimization methods once the limits of possibility for the system have been identified. Rothkopf (1996) has argued:

> that no operations research model is ever complete. Therefore it is dangerous to stop thinking once the model is built. To be effective, one must use models as aids to further thought.

We would add that modellers should use a variety of thinking frames at the problem-structuring phase to prompt the modeller to consider other avenues before building a model in detail. Mathematical models can still be used, after the EC process is invoked, to find a most preferred tradeoff, but the form of that tradeoff may be very different to the one initially conceptualized.

While most OR/MS effort has focused on formulating problems and finding efficient solution methods for those problems as formulated, the EC process seeks to resolve, nullify or at least lessen the problematic situation. It helps by structuring our thinking in a directed, creative and productive way, looking for ways around the problem, searching for better solutions, not just better solution techniques. The EC allows us to move from finding the best solution for a given system, to making changes to the system itself to give an even better solution.

We conclude that the EC process has value in becoming a part of the OR/MS problem-solving process. Its use is recommended especially during the process of problem definition, problem-structuring and model formulation phases, recognizing that the EC process is likely to surface implicit dilemmas or constraints, surface the assumptions that give rise to them, and then to challenge such assumptions, before moving on to confirm or change the modelling approach, refine the model, collect data and find solutions. In this way, the EC can be a valuable tool contributing to different phases of the problem-structuring/problem-solving process, and contributing to OR/MS in the quest to realize the vision of the 'Science of Better'.

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