

■ MILES G. NICHOLLS, Feature Editor, Graduate School of Business, RMIT University

In the last Research Issues column, John Davies and Vicky Mabin wrote about the Theory of Constraints and its usefulness in solving business problems (*Decision Line*, March 2009). In this article, the concept of Mixed-mode Modelling is discussed as it, like the Theory of Constraints, is not as well known as some of the more traditional mathematical modelling approaches commonly used to solve real-world problems. A simple example is given to illustrate the Mixed-mode Modelling approach. I would very much like to hear from readers about any not so well-known approaches to solving problems that they might be familiar with. I welcome articles from readers which highlight other approaches to solving management science problems that are also not “mainstream.” [Miles Nicholls, Feature Editor]

Mixed-mode Modelling—What Is It and How Can It Help?

by Miles G. Nicholls, RMIT University, Melbourne, Australia

The first question to be answered is why would an alternative approach to solving a traditional production optimization problem be required? It has long been recognized that in the real world ‘optimal’ solutions for many production process problems don’t exist. The reality is that in many circumstances ‘best practice’ is what OR practitioners aim for. The reasons for this stem from many causes including the fact that data associated with production processes are often corrupted and/or missing and that the production processes themselves are sometimes not fully understood. Additionally, many processes rely heavily on the subjective input of the process workers on the shop floor, who introduce further uncertainty and unpredictability into their resultant behavior and output. The use of Mixed-mode Modelling has been utilized to help solve these types of problems. We attempt in this article to briefly define Mixed-mode Modelling and highlight its usefulness in solving production process problems. The ability of Mixed-mode Modelling to deliver significant savings to industry (very important in financially challenging times) suggests that it is worthy of greater use.

The second obvious question is ... “What is mixed-mode modelling”? The

term is used to describe the process of bringing together the ‘soft’ and ‘hard’ sub-models which then, through an heuristic solution process (which is itself ‘soft’), arrives at a ‘best practice’ solution to the problem at hand. Mixed-mode Modelling can encompass (at least in a general context) the combining of a group of sub-models which are either all hard or all soft. However, in this article the mixing of hard and soft models is alone considered as this is a common occurrence in practice. For the interested reader, the concept of Mixed-mode Modelling was more recently fully developed and explored by Lehaney (1996), Lehaney and Clarke (1997), and Mingers and Brocklesby (1996), and further extended and explored in Nicholls, Clarke and Lehaney (2001).

The various models (hard and soft) in a Mixed-mode Modelling problem are initially independently ‘solved’ using hard or soft solution algorithms/heuristic (as applicable), with the appropriate flow of information (and solutions) exchanged between the relevant sub-models. Often a sub-model cannot be solved until the solution of another model is arrived at and passed on (e.g., a soft sub-model which determined the amount of labor available



Miles G. Nicholls

is a professor of business modelling in the Graduate School of Business at RMIT University in Melbourne, Australia, where he is also the director of research. He received his MEd and PhD degrees from

Monash University in Melbourne, specializing in econometrics and operations research. He has spent more than 15 years managing research as well as researching in his areas of interest—mixed mode modelling and production and process modelling. Miles has published in excess of 80 refereed articles and conference papers including articles in *Journal of the Operational Research Society*, *European Journal of Operational Research*, *Operations Research*, *Journal of Global Optimization*, and *Journal of Heuristics*. He has also been involved with the DSI and the WDSI for many years and served as WDSI president from 2004 to 2005.

miles.nicholls@rmit.edu.au

would be needed for the solution of the hard production planning model). Many soft sub-model's solutions are arrived at using consensus, expert panels, or Delphi approaches and involve the collective 'wisdom' of management and appropriate in-house experts. The solution arrived at will then usually be considered further by management panels who may impose their own judgement on some aspect of the solution and then send that information back to the appropriate areas for the solution process to commence again. In effect, the solution heuristic is almost always iterative. Indeed, there will normally be a range of solutions present from which management (or whatever panel approach is being used) will make the ultimate selection, thereby arriving at 'best.'

In the Mixed-mode Modelling discussed in this article, there is no overall *analytical* solution technique, no optimality, and certainly no single 'right' answer. Additionally, the solution heuristic may well be set up so that the solution procedure is repeated at regular intervals as new and more accurate information and data become available. Figure 1 epitomizes such an approach using a modified example taken from Nicholls and Cargill (2001), where the human resources management (HRM) and production planning/scheduling (PPS) departments of a business are required to find best practice solutions to their own areas, with the PPS requiring direct input from the HRM department (i.e., labor availability). Following this, the business needs to arrive at an overall best practice, which may (as already suggested) require the alteration of the departmental solutions arrived at (a subjective iterative process).

In Figure 1, each of the operational areas of the PPS and HRM departments together with Management Assessment are subject to the environment (E), which would include such factors as, for example, the global financial crisis. Further, there are inputs to each of the areas as well, relating to aspects of their operations that might not be fully under their control. For example, in the PPS department, the costs of raw materials and their availability would be such examples of factors (I₁). In the HRM

department it might be the Occupational Health and Safety Acts, Labour Laws, etc (I₂); In the Management Assessment area, shareholder considerations and corporate social responsibility might be factors (I₃). The demand for products and their market prices are essentially the key input for the PPS department (although the prices and the range of products could also be altered by Management). With this information, PPS set out to maximize the profit using, say, linear programming (a hard model), utilizing all the relevant information they have. However, one of the major inputs to their model will be the amount of labor available according to skill sets. This part will be influenced heavily by the HRM department's solution, where their main mission/objective (in this example) is to oversee a of y% of the company's permanent labor force in the current year. Additionally, there will be environmental factors (E) at work here. For the HRM department, the required labor reduction will be occasioned by the use of (for example) natural attrition, voluntary redundancies, or with a more severe impact on productivity, forced redundancies. The areas of labor reduction (e.g., cleaners, furnace maintenance, etc.) would be determined in conjunction with the PPS department. The restrictions faced by HRM in achieving this objective could be that reductions in productivity should be below a specified amount, that industrial relations difficulties should also be below a specified level, and that erosion of skill sets must not occur in excess of technically established limits. In this example, the HRM department will use a soft heuristic (possibly panel consensus or the expert panel approach) to arrive at their solution (see Nicholls and Cargill, 2001, for more details). This solution (i.e., the labor availability by area) will then be passed on to the PPS department as input to their solution process as well as to management for consideration.

Management assessment (a soft 'model') would then be used to determine whether the overall solution obtained was the best for the business. Has the right amount of 'social conscience' been incorporated into the strategies developed by the HRM department in order to

achieve the required reduction in the labor? Best practice is then achieved by the Management Assessment feedback being passed onto the PPS and HRM departments, and the solution process already described, iterating until management judge best practice has been achieved. In this example, the soft models associated with the HRM department and Management Assessment has triggered the need for mixed-mode modelling.

In the industry, the need for Mixed-Mode Modelling can stem from many other complex problems (other than the use of soft models) such as missing knowledge (the tacit knowledge problem [TKP]) surrounding a process and unobservable data that is key to a sub-production process (see Nicholls and Cargill, 2008, for a discussion of these problems). Both of these circumstances are present in the aluminium smelting industry and the tacit knowledge problem per se is present in float glass and the refrigeration industries. In aluminium smelting, the real-time on-line behavior of the smelting process is not totally understood and the impact that the factory floor operators have on the process can be considerable and varied, affecting production significantly for days at a time. Additionally, measuring the 'efficiency' of the smelting process is at best a 'guesstimate' since there is no way of knowing (in an industrial context) the exact amount of aluminum produced in a given time. This information is an essential input into the mathematical model of the smelting process. In the case of float glass, the TKP exists with respect to ensuring that the ripples and bubbles on the float glass are negligible. For refrigeration, the TKP centers on the design of the refrigeration unit since there is no analytical way of determining the optimal (or even 'best') design of the cooling distribution system and cooling space that meets the customers' specifications and complies with refrigeration standards. The design of refrigeration systems is achieved through simulation and then the application of tacit knowledge by the refrigeration engineers in an iterative production process taking (in many instances) considerable time. The interested reader might care to see

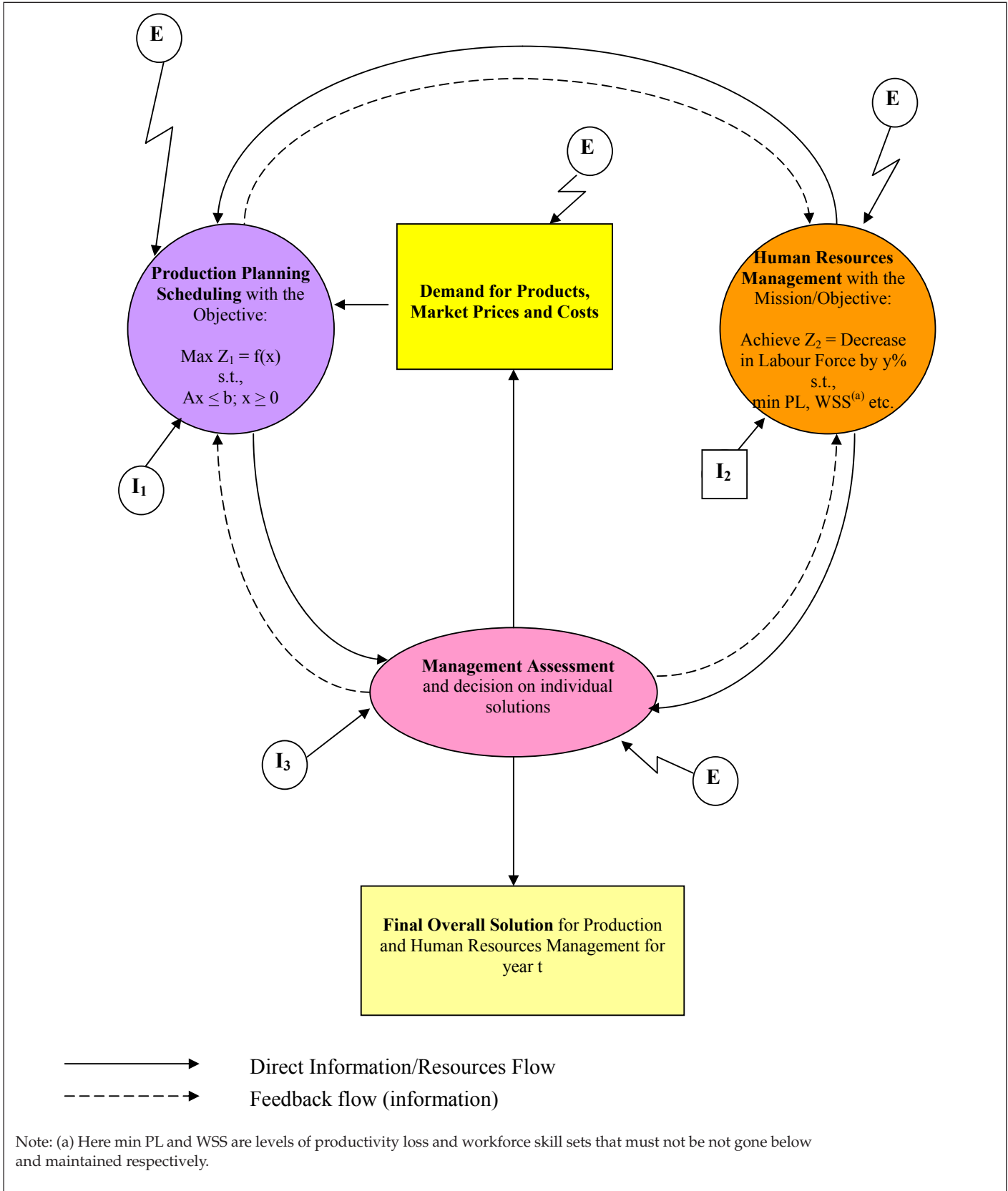


Figure 1: The Mixed-mode Modelling Approach to attaining best practice solutions.

Nicholls and Eady (2008) for a description of this problem and the Mixed-mode Modelling approach adopted for arriving at a best practice solution.

In order to develop 'best practice' production and operations for aluminium smelters and minimizing the make-span for new refrigeration designs, Mixed-mode modelling comes to the fore.

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