The Future of OR: Decision Support Systems and Information Technology

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Abstract

We discuss the evolution of operations research (OR) since its inception. Recently, the field has been greatly influenced by the electronic revolution, causing the practice of OR to be much more widespread than in previous decades. In the past, in order to address complex problems arising in industry, many OR practitioners have relied on constructing large-scale models and have attempted to solve them using optimization techniques, such as mathematical programming (MP). There is a growing body of opinion questioning whether such an approach, on its own, can deal successfully with many of the complex, ill-defined, difficult-to-model issues now facing OR practitioners. This has given rise to other approaches, such as soft systems methodology, to tackle what Ackoff termed today's "messes". We suggest that the attempt to optimize models still has, and will have for a long time to come, a valuable role to play. However, we discuss how the power of MP can be enhanced by incorporating its models and methods within a decision support system which takes advantage of modern information technology. Such a system, containing MP subroutines, can often be used to answer certain "what if " questions and to make suggestions. Compared to MP alone, a decision support system usually provides greater flexibility, can deal with a far wider range of practical issues, allows for its users' local knowledge and inspiration, and attempts to enhance the powers of its users, rather than replacing them by outsiders. These ideas will be illustrated by some practical New Zealand case studies.

1. The Evolution of OR

As most readers of this paper will know, operations research (OR) had its beginnings in World War II, when British military authorities faced pressing problems that were not amenable to any known scientific methods. These problems arose from the development of new technology and its application to military operations, such as radar and the location of aircraft detectors, and asdic and the detection of submarines. To make best use of the resulting hardware, and to analyse the data that its use produced, teams of scientists, from a wide variety of backgrounds, were formed. After 1945 there was a growing realization that this approach, with a diverse team which built and optimized models, could be used to great effect in the world of commerce and public administration. Although this theme was, and still is, continued in Great Britain, especially in the coal and steel industries, breakthroughs occurred in many parts of the world, many in the United States. In the US, standardized models, both deterministic and stochastic in nature, have been devised for a wide variety of human endeavour, along with companion solution techniques. With spectacular increases in computer power, more complex models and larger numerical instances of them have been progressively analyzed over the decades. This trend spread throughout the developed world from the mid 1950's, along with other themes within OR.

The modelling/optimization approach was a large part of OR theory and practice in the 1960's to 1980's. However from the early 1980's there was a growing opinion among knowledgeable commentators of OR that this approach was not completely adequate in all practical instances. Criticism came from, among others: Churchman, Machol, and Ackoff in the US; Daellenbach in New Zealand; and Beer, Eden, and Checkland in the UK. Many of these people suggested: systems thinking, soft systems methodology, and related techniques as more appropriate than mathematical programming (MP) for many complex, ill-defined, difficult-to model issues that OR practitioners were beginning to face. The 1990's have seen a revolution in computer and information technology that has had a significant affect on OR practice. Today, there are less specialized OR groups within organisations and very few groups with a diverse range of skills that were seen in the 1940's. A much wider range of individuals are OR practitioners, even if they themselves do not realise it. In this decade we have seen: the rise of the spreadsheet, easy access to inexpensive OR software, simple communication and the spread of OR knowledge via the internet, and other forms of modern information technology. This had lead to more individuals than ever before being engaged in OR, often alone, and sometimes with little OR training or education.

The implications of these phenomena for OR will be discussed in the remainder of this paper. It is laid out as follows. In the next section we shall discuss deficiencies in the MP approach and in Section 3 how the notion of the decision support system (DSS), can often enhance OR practice. The ideas discussed are illustrated with some case studies in Section 4. In Section 5 we shall outline how other developments in information technology can also aid OR. We end the paper with some overall conclusions and a summary in Section 6.

2. Deficiencies in the Mathematical Programming Approach

As was discussed in the previous section, the use of MP and related techniques to solve large-scale models of practical industrial scenarios has been a significant part of OR practices. However, it is sometimes the case that, especially for complicated problems with conflicting objectives, that this approach is not adequate by itself. Some of the reasons for this are that MP sometimes: provides a single, "optimal" answer, attempts to optimize according to a single, unrealistic criterion, is based on a model that fails to capture many of the realities of the practical situation, includes only hard (non-violatable) constraints, cannot provide answers within reasonable computational time (let alone not online), can be used only by specialists, requires large-scale computer hardware, software, and data input, is inflexible, and ignores the local knowledge and inspiration of users.

Despite this seemingly damning list of objections, MP has been, and will continue to be a valuable part of the OR practitioner's toolkit. What we suggest is that when some of the difficulties just listed, or others, arise that MP be employed, where appropriate, but be embedded within a DSS. We now go on to discuss the implications of this suggestion.

3. The Decision Support System as an Aid to OR Practice

The decision support system (DSS) has emerged as a computer-based approach to assisting decision makers (including manufacturing engineers) to address semi-structured problems by allowing them to access and use data and analytic models (Turban [11]). Such systems have the following characteristics. They: are interactive computer-based systems, are aimed at semi-structured problems, utilize models with internal and external databases, and emphasize flexibility, effectiveness, and adaptability. These characteristics have guided much of the research in the DSS area, but the potential benefits of the DSS in the business environment have not yet been fully realized. Nevertheless, many successful DSS applications have been reported in the literature (Arinze et al. [1] and Couillard [3].) Most of these applications are either large-scale systems built to facilitate well-defined and repetitive decision tasks, or else they are small PC-based systems offering quick and economic routines to support one-time decision making (Islei et al. [9]). Although the definition of the DSS concept has been elusive (Bonczek et al. [2] and Er [4]), the field has flourished with the development of computer technology. Keen [10] reviewed a decade of DSS development and concluded that there is a need for a balance between each of the three DSS elements: *decision*, *support*, and *systems*. He felt that more research effort on the decision component was required to restore this balance, as the technology for the system component was no longer a bottleneck. To achieve "the mission of the DSS – to help people to make better decisions", Keen stressed the need for an active supporting role for "decisions that really matter". We now focus on the decision component of the DSS.

PC technologies are becoming accepted and incorporated into organizations and our personal lives. PC-based systems have the potential to improve both individual and organizational performance. As decision makers recognize the potential benefits, many companies are investing in information technology. PC-based systems have been generally hailed as a revolution that will change the nature of professional work and transform the way most professional people function in their jobs. It is expected that almost all knowledgeable workers are likely to have their own PC to perform both stand-alone tasks and network services in the near future. Despite the proliferation of microprocessor-based systems, the potential benefits of these systems as aids to decision making have not been fully realized, due to poor design and low acceptance by users. It is recognized that individuals are sometimes unwilling to use these systems, even if they may increase their productivity. While some DSS's may have an impact on individuals and organizations, the adoption and acceptance of these systems among decision makers has been limited. This may be due to the inflexibility in the systems, as well as their narrow design. Therefore, it is important to understand the environment of the decision makers and the type of support they need in order to make effective decisions, and to examine the models appropriate for addressing their problems.

Many DSS's have a basic structure which is illustrated in Figure 1. The model and solution technique bases are included to incorporate MP techniques. Clearly, they could include all appropriate models and their companion solution techniques that may be useful in order to gain insight into the scenario for which the particular DSS is designed. These models and techniques may not necessarily be confined to the classical, deterministic models such as linear, integer, nonlinear, and dynamic programming, but also those from areas such as queuing, scheduling, inventory, and others. The models and techniques bases are included in order to be used, as necessary, to solve certain sub-issues or precise questions that arise during the overall analysis of the main scenario. They can be invoked to answer "what if " questions, to perform sensitivity analysis, and to provide precise solutions to sub-problems that can be modelled exactly. For example within a vehicle routing DSS, a travelling salesman problem (TSP) model and various TSP solution techniques could be included. Then, if it has been established that a given vehicle will visit an identified list of clients, the TSP model and a TSP solution technique could be invoked to establish a least-distance tour. This illustration will be discussed in more depth in Section 5.

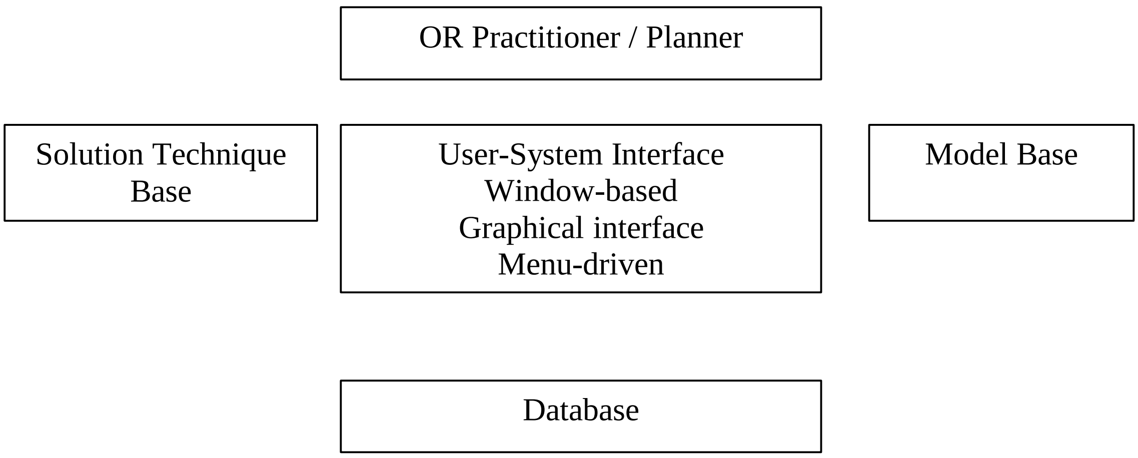

Figure 1. The Structure of a Decision Support System

However it must be stressed that any DSS should be much more than just a mere collection of models and solution techniques. Although this can be quite a valuable aid to the implementation of MP, in terms of user friendliness and convenience, it should be only a small part of any DSS. The essence of the DSS is the user-system interface that allows the planners to: experiment, input local knowledge and inspiration, deal with unstructured situations, be flexible, allow for multiple objectives, and soft (violatable to some degree) constraints. As an example, an educational course timetabling DSS may have, as its primary purpose, the identification of a feasible timetable, without the optimization of any objective functions. The timetablers will "play" with the DSS, inputting various course-room-teacher-time slot combinations; noting various statistics that the DSS displays. Judgements as to the worth of various combinations are often made on grounds that difficult to quantify and virtually impossible to model. Nevertheless, suggestions can be made by the DSS, based on various assignment, matching, and allocation models and solution techniques from the bases in Figure 1. This example is also discussed further in Section 5.

In this section we have described the basic elements of any DSS and how appropriate OR models and solution techniques can be incorporated into it. We shall now go on to illustrate the ideas that we have introduced by outlining some DSS's that were designed for various organizations.

4. Some DSS Case Studies

4.1 Layout Manager : A Facilities Layout DSS (Foulds [5])

Computer Automation (Ireland) ltd. (CAIL) is a manufacturer of printed circuit boards and commercial and industrial computers located on an industrial estate in Dublin, in the Republic of Ireland. The company began experiencing difficulty in matching the productivity of its rivals in the highly competitive microcomputer manufacturing market. After examination, it became increasingly clear that part of the cause of the decline in productivity was due to inefficiencies in the mechanical assembly (MA) area, where the computer parts are actually put together to create the final products. It became obvious that a significant problem in MA was caused by the travel of workers, parts, and equipment necessitated by the assembly sequences. The total distances travelled by each of the categories just mentioned was grossly excessive, due to poor spatial allocation of the MA operations and facilities. There are two distinctive features of the MA high productivity when the product mix, or levels within it, change significantly. The most effective (temporary) layout for the current production schedule was traditionally found by shuffling templates. However, rapidly increasing changes in the schedule rendered this approach less and less effective. It was then that the management invited the author to study the MA operation in order to recommend areas for improvement in its physical layout. Recognizing the importance of judgemental considerations and the need for rapid layout design decisions in a volatile environment, we felt that current layout computer programs offered little benefit. Instead, we decided to develop a DSS to address the MA layout design issue. One of the first tasks in this development was to establish appropriate criteria by which the productivity of layouts can be judged. Different product mixes and levels require different criteria, involving factors of facility adjacency and transportation times. This DSS addresses the issue of multiple objective criteria in a semi-structured decision environment.

4.2 FleetManager : A Vehicle Routing DSS (Igbaria et al. [8])

FleetManager is a successful milk tanker routing DSS that has generated a spectrum of benefits for the Westland Dairy Company, in Hokitika, New Zealand. Much of the benefit is derived from the characteristics and attributes of a classic DSS given below. It supports but does not replace the decision maker. It does not try to provide the ‘answers’ nor impose a predefined sequence of analysis. It supports semi-structured decisions where parts of the analysis can be systematized for the computer, but where the decision maker’s insight and judgement are improved. It combines modelling techniques with database and presentation techniques. It emphasizes ease of use, user-friendliness, user control, and flexibility and adaptability. It supports all phases of decision making. It interacts with other computer-based systems, mainly with the company mainframe system to download and upload information. The success of FleetManager can be attributed to an extensive user participation and involvement, an evolutionary approach to system development, flexibility and simplicity of system architecture, a committed and informed sponsor (mainly the Transport Office manager), accessibility and transferability of models and data, availability of graphics, and clarity of insights by using both judgemental and analytical models. The development and implementation of the system was enhanced by good relationships and close collaboration between the potential users and developers. Westland’s use of FleetManager has improved its vehicle-scheduling process by reducing the deployment of drivers and vehicles, using existing staff and vehicles more efficiently, and thereby reducing costs. In addition, it has freed up time for the schedulers and managers to improve productivity and manage people instead of running shifts and schedules manually. It provides powerful tools to create schedules, choose plans, generate alternative plans, and to assess alternative plans with respect to the given criteria. The system allows the scheduler to allot vehicle routes automatically, minimize the total distance travelled, and override routes created manually. It allows for more than one source or destination, skip-a-day clients, and multiple shifts, as well as allowing fine-tuning. The system has generated tangible and intangible benefits. In addition to the reduction in labour costs, it can benefit the schedulers by fine tuning of the existing schedules, creation of entirely new schedules, strategic planning for new sites, efficient fleet utilization, and rendering flexibility to plan for and cope with unexpected situations. The DSS also allows the scheduler to carry out an ad hoc analysis through “what-if ” queries. It provides the scheduler with a better understanding of the business since the system alerts the users to illogical outcomes, such an unvisited suppliers and overloaded tankers. This DSS allows MP to be used to address technical sub-problems, while giving the schedulers flexibilty and control concerning more broad issues that are notoriously difficult to model.

4.3 SlotManager : A University Timetabling DSS (Foulds and Johnson [6])

SlotManager is a DSS that has recently been developed and implemented at the Waikato Management School to improve the course timetabling process. Although it has been developed in the context of a particular university and school, the only significant constraint on its general application is that the teaching situation being timetabled operates on a slot basis. That is, the teaching week is partitioned into a number of three-hour and four-hour slots. Each course is assigned to exactly one slot, for example, Monday, Wednesday, and Friday at 09.00. It is therefore a specific DSS only in the sense that it applies specifically to the timetabling process. It does not automate the process but, instead, helps timetablers by providing powerful and wide-ranging tools to designate the required slots, allocate courses to feasible slots and rooms, and create a wide variety of reports on the outcome of the process. Some of the benefits of the DSS can be measured, such as the time taken by the timetablers to produce an acceptable timetable. The system has clear benefits, even if they are not easily quantified. Usage of the increasingly scarce resource of teaching rooms has demonstrably improved, and there is clearly a greater level of acceptance, on the part of both students and teachers, of the perceived quality of the resulting timetable. Furthermore, when the inevitable disputes arise over the slots or rooms allocated to courses, these are more efficiently handled by a system which can show the alternatives (or lack of them). In particular, the "what if " questions concerned with a perceived unsatisfactory allocation can be much more effectively explored and, if possible, resolved. SlotManager is designed to augment the expertise of an experienced timetabler, usually in a situation where timetables evolve from one year to the next, rather than being created, *ab initio*, on each occasion. The reactions of experienced timetablers who have used SlotManager have been, on the whole, positive and it has been accepted as an indispensable aid to timetabling at The Waikato Management School. This DSS addresses the issue of a lack of an objective function in an unstructured decision environment.

4.4 DirectionManager : A Traffic Planning DSS (Foulds [7])

This DSS was designed to aid traffic planners to decide which streets should be declared one-way (sometimes temporarily) in an inner-city traffic environment. The model base includes user-equilibrium traffic assignment, network design, are capacity constraint, turn prohibition models, and solution techniques for these models, based on MP. This DSS provides an example of the relationship between a DSS and an expert system, i.e. a system that learns with use and displays artificial intelligence.

As we indicated in Section 1, we shall now go on to discuss wider issues within information technology and how they can enhance OR practice.

5. OR and Recent Advances in Information Technology†

We live in a world in which technological and social change are extraordinarily rapid. We have public policy issues such as: global warming, ozone depletion, and acid rain. And in the industrial arena we have global competition spurred by technological advance and international market forces. This environment creates many opportunities for OR approaches to contribute to industrial success in the contemporary world of New Zealand business. It is not hard to come to the overwhelming conclusion that validated practices, carefully implemented, are vital to industrial success. We shall go on to study the factory scene. However most of the lessons learnt there carry over directly to the service industries – even to universities. One of the emphatic messages we, as OR practitioners can convey is the need for flexibility. One way to make factories more flexible is through leading edge information technology. One approach is to harness OR to plan, schedule, and control factory operations. This can lead to the implementation of processes that are so simple, standardized, and reliable that they can be managed visually. Also, information technology that links final sales points to manufacturers is just starting to come into its own. One challenge is to improve, and ultimately make obsolete, the heavy-handed, dysfunctional information systems that have been running plants for decades. Now for something that makes this of vital interest to New Zealand industry. Here is a quotation from Mr Konosuke Matsushita of

† This section was inspired by a plenary address by John Little, ORSA.TIMS, Philadelphia, 1990.

Matsushita Electrical. “We in Japan are going to win and the industrial west is going to lose; there’s nothing much you can do about it because the reasons for your failure are within yourselves. Your firms are built on the Taylor model; even worse, so are your heads. With your bosses doing all the thinking while the workers wield only screw drivers, you’re convinced deep down that this is the right way to run a business. For you, the essence of management is getting the ideas out of the heads of the bosses and into the hands of labour. We are beyond the Taylor model; business, we know, is so complex and difficult, the survival of firms so hazardous, in an environment increasingly competitive and fraught with danger, that their continued existence depends upon the day-to-day mobilization of every scrap of intelligence”.

Whether or not Mr Matsushita’s forecast is correct, he forcefully articulates a critical idea – the need for empowering and enhancing the effectiveness of people at all levels of industrial organizations. Other themes are closely related : the pervasive focus on quality and continuous improvement. Success in global competition requires a new degree of attention to human resources. Several other concerns are relevant. The reduction of lead times in new product development can provide a competitive edge. Some companies are pushing for simultaneity, that is, parallel but coordinated activity, often in different physical locations. At the same time there is a desire for flatter organizations with fewer managerial layers, and for the replacement, at least in part, of hierarchical organizations by more market-like structures. Many global companies wish to take advantage of their geographical dispersion to tap knowledge and skills throughout the world.

Where does OR fit in all this? Hopefully everywhere, but it will not happen automatically. There is no room for complacency. However there are certain new opportunities, which relate only peripherally to early perceptions of industrial management. One of these ideas involves empowering the organizational front line. In the past, OR practitioners have built systems for end-users largely as extensions of themselves. In other words, they solved the problem and delivered the solution to the potential end users. A different goal is to give people systems with which they can solve creatively their own problems. We can boost industrial productivity by developing such tools for the salespeople, telephonists, and factory workers. In particular, if we can provide them with the means to monitor, understand, and improve continuously their own performance, real gains can follow. These gains are now being accrued in marketing, manufacturing, the services, and financial operations. What conclusions can we draw for New Zealand industry? Efficiencies and improved service levels provided by OR in operational systems are essential to the firms using them and cannot sensibly be abandoned. Airlines will continue to develop better systems to reallocate planes after air traffic disruptions. Foodstuffs producers will build better systems to analyse bar code data on supermarket products. These systems will lead to more efficient operations, marketing, consumer products, and, of paramount importance, enhanced customer value. We shall have better integrated manufacturing systems because of multiple levels being tied into computerized information systems. However if New Zealand OR is to remain modern, it must take on new challenges. This gets us back to a point made earlier : empowering front line people. Here are some examples. Some firms have huge new databases on sales and markets. Sometimes they need to be dispersed to the field and made useful to local sales people, who can combine OR and information technology with their own special knowledge of local conditions. The sales people need data analysis systems, on command, to provide fact-based dialogue with their customers. Another example is a system that empowers the ultimate customer. For instance, a forest products manufacturer is stimulating down-stream demand by making it easier for do-it-yourself customers to plan their own home remodelling projects. Such customers who want to build say, an outside wooden deck attached to their house for barbeques, can easily design it, using the system at a kiosk in the hardware store. The deck is visually displayed and manipulated with a mouse, with costs monitored as changes are made. After the design is complete, a push of a button prints the final result and a bill of materials. Another opportunity lies in supporting the goal of simultaneity and time compression. In this regard, it is important to provide tools to assist cooperative work. If we are to shorten lead times, multiple persons will have to work on different aspects of the same problem, at the same time, but in a coordinated way - computer-assisted cooperative work supported by group decision support systems.

What can we conclude? The complexity of industrial enterprise now requires end-user focussed information systems, often computerized. These are necessary in order for New Zealand organizations to function efficiently and effectively. The challenges include: the assimilation of information systems so that local knowledge can be used easily, support for flat organizations and cooperative work, and the empowerment of front line people, even to making them semi-independent.

6. Conclusions and Summary

In this paper we have discussed the implications of recent advances in information technology on OR. First we have outlined why the traditional OR approach of using MP to manipulate classical models is sometimes inadequate to address complex, semi-structured, planning issues in today's industrial world. Instead we have suggested that these techniques may sometimes be usefully embedded, as subroutines, within a DSS. This often leads to the decision makers having their powers enhanced, rather than to their being replaced. Such an approach does not attempt to provide "answers" to "problems", nor to impose a predefined sequence of analysis. It supports semi-structured decisions where parts of the analysis can be systemized for computer use, but where the decision makers' insights and judgement are enhanced. It is often amenable to modelling, OR solution techniques, and graphical presentation for parts of the overall scenario. It emphasizes ease of use, user-friendliness, user control, flexibility, and adaptability. It supports all phases of the decision making process and is capable of interacting with other computer-based systems.

We have illustrated these notions by describing four case studies of DSS's which have been implemented to address practical issues in actual organizations. We have also discussed the wider issues of recent advances in information technology and how they can be used to enhance OR practise. We believe that these developments are very significant for the evolution of OR. If they are embraced effectively then OR is likely to have even more impact on economic development and the quality of life.

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