Operations Research

Publication details, including instructions for authors and subscription information:
http://pubsonline.informs.org

The OR/MS Ecosystem: Strengths, Weaknesses, Opportunities, and Threats

ManMohan S. Sodhi, Christopher S. Tang,

To cite this article:
ManMohan S. Sodhi, Christopher S. Tang, (2008) The OR/MS Ecosystem: Strengths, Weaknesses, Opportunities, and Threats. Operations Research 56(2):267-277. https://doi.org/10.1287/opre.1080.0519

OPERATIONS RESEARCH
Vol. 56, No. 2, March–April 2008, pp. 267–277
ISSN 0030-364X | EISSN 1526-5463 | 08 | 5602 | 0267

DOI 10.1287/opre.1080.0519

The OR/MS Ecosystem: Strengths, Weaknesses, Opportunities, and Threats

ManMohan S. Sodhi
Cass Business School, City University London, London EC1Y 8TZ, United Kingdom,
m.sodhi@city.ac.uk

Christopher S. Tang
Anderson School, University of California, Los Angeles, California 90095,
ctang@anderson.ucla.edu

This paper is dedicated to Arthur Geoffrion, who serves as role model of a great researcher, educator, and practitioner.

We believe that research, teaching, and practice are becoming increasingly disengaged from one another in the OR/MS ecosystem. This ecosystem comprises researchers, educators, and practitioners in its core along with end users, universities, and funding agencies. Continuing disengagement will result in OR/MS occupying only niche areas and disappearing as a distinct field even though its tools would live on. To understand the reasons for this disengagement better and to engender discussion among academics and practitioners on how to counter it, we present the ecosystem's strengths, weaknesses, opportunities, and threats. Incorporated in this paper are insights from a cluster of sessions at the 2006 INFORMS meeting in Pittsburgh ("Where Do We Want to Go in OR/MS?") and from the literature.

Subject classifications: operations research; management science; SWOT analysis; ecosystem; change management.
Area of review: OR Forum.
History: Received April 2007; revision received August 2007; accepted November 2007.

1. Introduction

The purpose of this paper is to stimulate further discussion among OR/MS academics and practitioners on how to overcome the challenges that the OR/MS community is facing, especially in the business school. We believe that these challenges are a result of research, practice, and teaching becoming increasingly disengaged from each other since the 1970s when similar issues began to attract vociferous debate. While this disengagement may exist in other academic disciplines in the business school, we restrict our attention to OR/MS.

Even though OR/MS has survived and even flourished with doomsday warnings in the backdrop, disengagement continues unabated. *Researchers*, especially those in academia, strive to publish in journals that focus on results of questionable value to education or practice. *Practitioners*, conscious of having to solve real-world problems for their clients quickly, sometimes fall back on shopworn methods without receiving insights from researchers who have developed superior approaches. *Educators* focus on subject matter and tools that do not benefit from practice or even from research.

Various authors have proposed different approaches for strengthening OR/MS from a perspective of educators (e.g., Powell 2001, Grossman 2003), of practitioners (e.g., Ormerod 2002), or of researchers (e.g., Geoffrion 1992). We believe that to understand the challenges facing the OR/MS community and to find solutions, we need to take a holistic approach. We do so by viewing the OR/MS community as a business "ecosystem" with its core comprising *educators*, *practitioners*, and *researchers*.[1] *End users*, i.e., senior or middle managers and engineering leaders in the private and public sectors, *professional societies*, *universities*, and *research funding agencies* sustain the core and nurture the ecosystem as a whole. If the core communities in the OR/MS ecosystem are not engaging much in supporting each other to meet end-user demand, the ecosystem may not survive and OR/MS may end up occupying only niche areas.

In this paper, we present the strengths, weaknesses, opportunities, and threats (SWOT analysis) for the ecosystem to set the stage for discussing how end-user demand can be increased and how links between the various core communities to each other and to end users can be strengthened. We incorporate insights from materials presented in the cluster "Where Do We Want to Go in OR/MS?" during the 2006 INFORMS meeting in Pittsburgh,[2] commentary in the OR literature, and our own experience in university and in industry. While we do not seek to be prescriptive, we find that efforts to strengthen the identity of OR/MS in education, practice, and research could be a good start to improve end-user demand and to strengthen the links that sustain the ecosystem. To this end, practitioners can take a stronger interest in education as guest lecturers or project sponsors and educators can better stake out the operations

area in the business school following the link between marketing and marketing science.

A key lever for researchers could be to get OR/MS journal editors to review where OR/MS should be placed between (1) deductive research and axiomatic systems (Euclid, Bertrand Russell, and Alfred Whitehead), (2) inductive or empirical research (Roger Bacon), and (3) the so-called "real-world" applications. For example, the editors could insist on stronger links between assumptions and real-world situations for deductive research to distinguish OR/MS from mathematics, and between analytical results and practical implications for empirical research to distinguish OR/MS from the social sciences. They need not compromise on methodological rigor but could still reinforce the multidisciplinary nature of OR/MS for finding practical solutions to real operational challenges.

2. The OR/MS Ecosystem

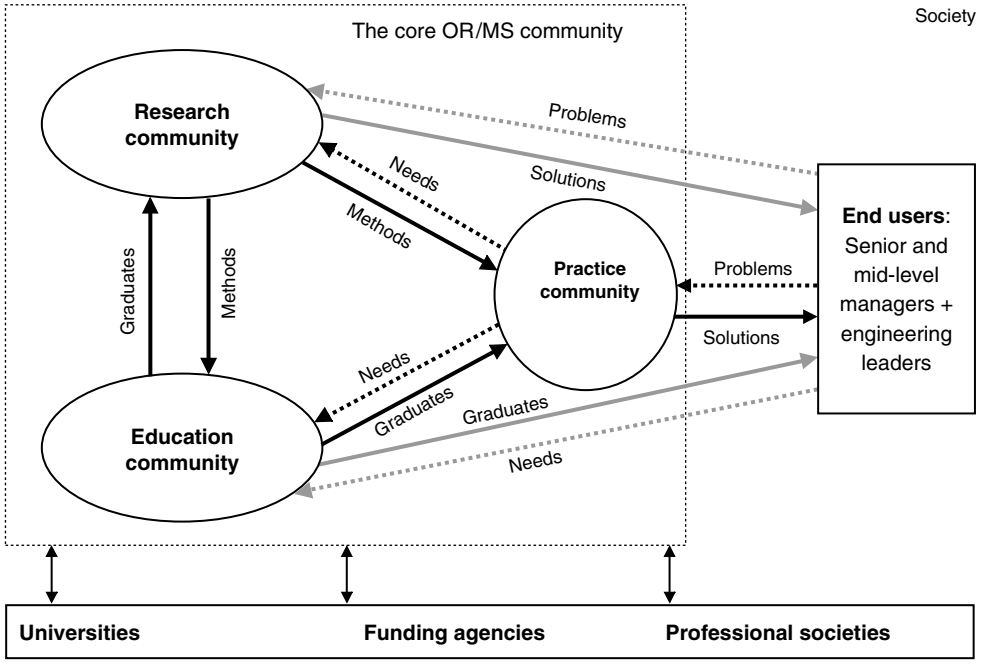
OR/MS was started by scientists in the United Kingdom and in the United States to examine ways of making better decisions in the different areas of military operations during WWII (see e.g., Kirby 2000). The success of OR/MS military applications motivated others to develop and apply OR/MS tools to solve similar problems arising in industry starting in the late 1940s. Many companies created OR/MS departments for internal consulting. Gradually, many engineering and business schools created new groups and programs—OR, MS, operations management, decision sciences, system engineering, etc.—to meet the need for OR-trained graduates and better OR methods. OR/MS continued to flourish during the 1970s and 1980s in universities and in industry despite questions about the directions of development within the community. Indeed, throughout the last 50 years of the 20th century, the field of OR/MS evolved from a group of isolated researchers solving military problems to a well-developed ecosystem (Figure 1). Kirby (2000) provides a historical perspective on the evolution of OR/MS since 1970.

The *end users* determine the "market" for OR/MS services. These mid-to-senior-level managers and industry leaders are ultimately the "customers" who have needs that can be met by practitioners, educators, and researchers. *Universities* (and business schools) provide the physical home for researchers, educators, and students to develop and transmit the vast body of scientific knowledge about OR/MS. *Professional societies* such as INFORMS and the Operational Research Society of the United Kingdom (ORS) provide, among other things, a forum for interaction among and within the various communities of the OR/MS ecosystem. *Funding agencies* such as the National Science Foundation (NSF) in the United States and the Engineering and Physical Sciences Research Council (EPSRC) in the United Kingdom provide opportunities for funded research related to OR/MS.[3]

The core OR/MS communities within the ecosystem are:

(1) **The Education Community:** OR/MS educators impart OR/MS knowledge to students or as continuing education to practitioners or to end users in the workplace.

Figure 1. The OR/MS ecosystem.



Note. Adapted from INFORMS Roundtable (2006). The OR/MS ecosystem involves other players (university administrators, public policymakers, etc.), but we show only entities directly involved in OR/MS education, practice, and research activities.

(2) **The Practice Community:** Practitioners from various sectors—airlines; healthcare; IT and software; manufacturing; and services—apply OR/MS tools to develop operational systems such as revenue management, logistics planning, or scheduling, and solve important strategic problems such as supply chain design for end users.

(3) **The Research Community:** Researchers make their home in research centers (e.g., IBM, the RAND Corporation), business schools (e.g., OR/MS, OM, IS, marketing departments), engineering schools (e.g., computer science, industrial engineering, logistics, operations research, system engineering), and other departments (e.g., applied mathematics, applied statistics).

The health of the practice community depends critically on the end-users' demand for OR/MS services. Without awareness of the benefits of OR/MS through education or good past experience with applications, end users would not perceive any need for OR/MS services. If end-user demand is strong, the practice community will thrive as will the need for OR-trained graduates that will help the education community to thrive, and the need for OR/MS knowledge and methods that will help the research community to thrive as well. To find ways to increase end-user demand and to strengthen the interactions among the education, research, and practice communities, let us first examine the current strengths, weaknesses, opportunities, and threats of the ecosystem (Table 1).

3. Strengths

Despite the familiarity of the strengths of OR/MS among academics and practitioners, it is worth summarizing these strengths because they can also be weaknesses (§4).

3.1. Wide Spectrum of Research

OR/MS research spans a spectrum. At the practice-driven end, it grapples with complex real-world problems.[4] The journals *Interfaces* and *Journal of the Operational Research Society* provide many examples of such applications. At the theory-driven end, it takes on traditional values of generality and elegance from mathematical theory. No one would dispute that activity at both ends of the spectrum has been fruitful.

3.2. Drawing on Multiple Disciplines

OR/MS draws on applied mathematics, computer science, economics, engineering, and statistics among other disciplines to solve problems relevant to industry and society. This is the employers' wish as well: they want OR/MS graduates to have broad skills in modeling, programming, statistics, forecasting, simulation, etc. (Sodhi and Son 2007). OR/MS also exploits the power of mathematics to obtain elegant and powerful solutions for end users. As the "universal language," mathematics ensures that OR methods can easily be shared among researchers and practitioners around the globe, and the explicit assumptions of its models provide a focus for informed engagement by all those affected.

3.3. Applicability to a Wide Range of Domains

OR/MS is the "application of the methods of science to solve complex problems arising in the management of large systems of men, machine, materials, and money in industry, business, government, and defense" (Gass and Harris 2001, p. xlii). As such, OR/MS modeling approaches and tools can be applied to problems arising in different functional areas (e.g., finance, marketing, operations) and those arising in different sectors (e.g., airlines, government, health care, manufacturing, telecommunications). Brown (2006) summarizes various powerful OR/MS tools and methods that apply to a wide range of domains.

3.4. Synergy with Information Technology

OR/MS exploits computers and information technology to provide tremendous added value for businesses. Enterprise-wide solutions like enterprise resource planning (ERP) that did not originally benefit from OR methods are not known to provide any significant return on investment unless enhanced by add-on OR/MS applications. Kettinger et al.

Table 1. SWOT analysis for the OR/MS ecosystem with its core communities of educators, practitioners, and researchers.

3. Strengths	4. Weaknesses
3.1. Wide spectrum of research	4.1. The imbalance in OR/MS journals
3.2. Drawing on multiple disciplines	4.2. Unclear identity
3.3. Applicability to a wide range of domains	4.3. Excessive tools-orientation
3.4. Synergy with information technology	4.4. The makeup of professional societies
5. Opportunities	6. Threats
5.1. Developing new and extending existing enterprise IT applications	6.1. Improper use of OR/MS tools
5.2. New computing platforms	6.2. Dispersion of OR/MS practitioners
5.3. Globalization and risk	6.3. Weakening position in business schools
5.4. The environment	6.4. Slow growth in visible employment
5.5. AACSB's reversal regarding the MBA curriculum	

Note. Numbers refer to the corresponding sections and subsections.

(1994) found that the systems with high OR/MS content tended to yield higher profit and market share for companies over a 10-year period.

The above strengths have enabled OR/MS to make major impacts in many sectors, and 35 years of the Edelman competition and numerous successful published applications are testimony to this positive impact.

4. Weaknesses

OR/MS has a number of weaknesses as it exists today, some of these weaknesses being the flip side of the strengths outlined in the previous section.

4.1. The Imbalance in OR/MS Journals

OR/MS journals exhibit all the hallmarks of good research: (1) abstracting problems to generate replicable (and mathematically provable) results applicable to a wide range of real-world problems, and (2) focusing on a narrow aspect to extend the literature to solve, with some exceptions, a narrow part of a complex problem. To this end, OR/MS research journals are inclined toward abstract papers that either obtain results with deductive logic following a narrow set of axioms or propose innovative solution methods that focus on a narrow part of an overall problem. This is in contrast to the complexities of real-world problems that require multiple approaches—none of which may be novel, mathematically sophisticated, or even replicable in other contexts.

While reliance on mathematics is a strength of OR/MS as discussed earlier, OR/MS research is retreating from real-world applications. Reisman and Kirschnick (1994, p. 583) show that between 1962 and 1992, the number of pages devoted to *untested* theory in *Operations Research* and in *Management Science* grew dramatically, while the number of pages devoted to true applications decreased correspondingly. Ormerod (1998) raised the same concern about OR/MS journals. Recently, Rothkopf (2002) commented that researchers from some of the research universities publish very few papers for practitioners in *Interfaces* or the practice section in *Operations Research*.

Without testing in the "real world," there is no correcting force to prevent OR/MS from becoming "too mathematical." Improvement on something already published by garnering more mathematical results under slightly different or more general assumptions is one of the formulas for getting a new paper published, which in turn advances a young researcher's career. Perpetuation of this research culture could result in what we view as excessive self-referentiality. Few articles published in leading journals could be viewed as being *directly* relevant to practitioners, let alone end users.

It does not help that practitioners are but little engaged in OR/MS journals. The editorial boards for *Operations Research, Management Science*, and *Manufacturing and Services Operations Management* almost exclusively comprise academics. Even the practitioner-oriented journal *Interfaces* has only two practitioners on its 26-member editorial board. Lack of practitioner involvement is possibly a consequence, but it also reinforces the self-referential and mathematical nature of OR/MS publications[5] that are now so theoretical and self-referential that practitioners find them of little relevance and are motivated further to disengage from the journals. Less than a quarter of INFORMS practitioner members think that the flagship INFORMS journals, *Management Science* and *Operations Research*, are relevant to them (Abdel-Malek et al. 1999).

4.2. Unclear Identity

OR/MS as a field continues to have an unclear identity not only among end users but also among researchers and educators (Corbett and Van Wassenhove 1993, Geoffrion 1992, Lilien 1987, Ormerod 1998). The underlying reason is that OR/MS draws on multiple disciplines for its tools and techniques, *and* applies these tools to a wide range of domains. Moreover, these domains of applications have long co-opted these tools and techniques so that the distinctive identity of OR/MS is no longer clear.

While most universities, individual departments, and leading journals pay lip service to the value of multidisciplinary research, they actually push researchers in narrower disciplinary directions. "Multidisciplinary" research entails taking the results and methods from an underlying discipline as such, but applying these in conjunction with results and methods from other disciplines to a new area of application. Results of such research are viewed by academic scholars as less rigorous or less innovative than within-discipline research. This perception creates pressure on OR/MS researchers to focus more on methodology-grounded research in one of the underlying disciplines than on real-world problems that require multiple disciplines to tackle. Consequently, OR/MS researchers become indistinguishable from researchers from these underlying disciplines, which make the identity of OR/MS as a discipline unclear.

The application end of OR/MS has an unclear identity as well. Multidisciplinary fields (e.g., marketing science—arguably a subdiscipline of OR/MS) thrive when they have a scope of topics that is well staked out and, over time, build enough literature to call themselves "disciplines" in their own right. However, as the application domain of OR/MS collectively is so large, it is difficult for anyone outside the area to view the literature as a single body that could eventually become a "discipline" in its own right.

4.3. Excessive Tools-Orientation

OR/MS is perceived to have become a tool-oriented discipline that provides general mathematical results instead of a problem-oriented discipline that provides solutions. For example, the Committee on the Next Decade in Operations Research report (CONDOR 1988) suggested research

directions focused on tools—mathematical achievements to date and their promises for the future. Ackoff (1979, 1987) traced the devolution of OR/MS from a profession defined by the problems it solved to a profession now defined only by the tools it employs. Wagner et al. (1989) expressed concerns regarding the shift away from the problem-solving roots of OR/MS and the lack of the study of the *practice* of OR/MS including problem formulation, change management, and communication. Mesquita and Santoro (2004) comment that the difficulty of explaining OR approaches prevent the use of OR-based models in practice in the Brazilian pharmaceutical industry that includes such multinational firms as Aventis, Novartis, and Pfizer.

The tools-oriented focus is reflected in education as well. Jordan et al. (1997) surveyed 20 leading MBA programs and reported that most of the OR/MS courses were tool based (i.e., they contain the introduction of many OR/MS tools such as linear programming, integer programming, networks, decision trees, simulation, etc.), which failed to serve the problem-oriented needs of the MBA students including problem definition, model formulation, and spreadsheet analysis. Grossman (2001) provides some insight into why most OR/MS courses are tool based. Recently, based on a study of 1000-plus job ads in OR/MS, Sodhi and Son (2007) reported that OR/MS education may not meet employers' needs, for example, communication, project management, and leadership. To our knowledge, these nonanalytical subjects are not included in most OR/MS programs.

4.4. The Makeup of Professional Societies

OR/MS professional societies are *dominated by academics*, which reduces the interaction between academics and full-time practitioners. Former INFORMS President Richard Larson commented that 75% of the members of INFORMS have PhDs, and most of these are from academia (Horner 2004). This may make it difficult for INFORMS to nurture the practice community and the research (and possibly education) communities, despite the existence of the INFORMS Roundtable and the launch of the annual INFORMS Practice Conference since 2001.

5. Opportunities

There are many opportunities to help the whole ecosystem to thrive.

5.1. Developing New and Extending Existing Enterprise IT Applications

There are many successful examples of innovative OR applications by information technology companies in the areas of supply chain planning (i.e., advanced planning systems (APS)), customer-relationship management (CRM), and product life cycle management (PLM) (Sodhi 2001). As more real-time information about inventory, sales, and orders becomes available with improved IT including RFID, there may be specific points in the supply chain where real-time OR/MS could improve the value obtained from RFID transaction data (Chopra and Sodhi 2007).

Revenue management in the airline industry is an area almost synonymous with OR/MS; therefore adapting OR/MS revenue management models from airlines or hotels to retailing, gaming (e.g., casinos), or entertainment (e.g., theme parks) is an obvious example of extending existing applications. Besides revenue management, process industries have long been innovative in their use of mathematical modeling—some of their methods could be applied to service situations where work "flows" across workgroups just as materials flow in manufacturing processes in, for example, the chemical industry. For researchers, this may present an opportunity to bring mathematical modeling and rigor to the *lean manufacturing movement* that is beginning to take hold in the service sector after the acclaimed success of automaker Toyota in manufacturing.

New needs and the availability of new information that can support OR/MS-based analytical approaches emanate from existing sectors such as health care or new technology-enabled sectors such as e-commerce and mobile telephony. The rapid growth of the service and information economy throughout the world also presents opportunities (c.f., Apte and Nath 2004, Karmarkar 2006, Ratliff 2006). The Internet and e-commerce present opportunities for OR/MS to exploit real-time data and increased computer power to improve supply chain operations, product design, marketing, customer service, etc. (c.f., Sodhi 2001). The special issues co-edited by Geoffrion and Krishnan (2001, 2003) provide examples of research and application opportunities in this area.

The past success of the OR group at Bell Labs proved the usefulness of OR/MS in the telecommunications sector (c.f., Dawson et al. 2000). With innovations in this field proceeding at a frantic pace (mobile phones, broadband communications, etc.), new analysis of what works best for a given technology can broaden the OR/MS application base. For example, researchers at MIT are trying out an approach that takes anonymized data from two mobile phone companies, Telecom Italia and Mobilkom Austria, to develop a real-time map of where mobile phone subscribers are at any given time (*The Economist* 2007). This information creates opportunities for real-time transportation planning and, in the long run, for traffic light placement and even housing.

5.2. New Computing Platforms

Computing platforms such as Web services via the Internet and grid computing can provide expansion of the potential market for OR/MS. They can give an impetus to the development of new nonserial algorithms or other ways of processing information for OR/MS models. Efforts such as NEOS (network-enabled optimization systems) seek to

exploit these opportunities. We note, however, that parallel computing was something of a missed opportunity in the 1980s and the 1990s despite such notable exceptions as Bertsekas and Tsitsiklis (1989). In general, OR/MS efforts in the late 1980s and early 1990s did not fully exploit theoretical and practical advances in computer science such as theoretical models of computers (e.g., parallel random access memory) or of computation (e.g., nondeterministic computation introduced by Dijkstra 1976) and correctness proof systems (e.g., Hoare 1969, 1978; Chandy and Misra 1988; Apt and Olderog 1991).

5.3. Globalization and Risk Management

The trend toward globalization of not only supply chains but also "service" chains (e.g., offshoring of IT-based services to India) provides opportunities for perfecting the design of such services. The added risks associated with globalization call for incorporating more explicit risk into models and for risk-management methods. The multiple sources of uncertainty and the need to rationalize capacity worldwide create opportunities to marry managerial approaches such as scenario planning with mathematical programming models (e.g., Sodhi 2003).

5.4. The Environment

There is an increased social awareness of the need to decrease carbon emissions and energy consumption. Energy efficiency is a well-studied domain for OR/MS models. However, issues such as carbon neutrality and trade-offs in large systems such as the retailer's supply chain starting from its suppliers (or even its suppliers' suppliers) all the way to its consumers' buying (or even consuming and then disposing) the product may require new ways of modeling and solution. For example, a large-scale OR-based model called MARKAL has been developed in a cooperative multinational project by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency for identifying low-cost energy systems and cost-effective responses to emissions restrictions (www.etsap.org/markal/main.html).

Reverse supply chains that entail picking up discarded white goods and electronic goods for the manufacturer also require new models. Modeling and management issues pertaining to this subject have been the topic for special issues of *Production and Operations Management* (Guide and Van Wassenhove 2006) and *Computers and Operations Research* (Verter and Boyaci 2007).

5.5. AACSB's Reversal Regarding the MBA Curriculum

In 2003, The Association to Advance Collegiate Schools of Business (AACSB) reversed its 1991 stance of eliminating OR/MS from the MBA core curriculum by including a statement that calls for every MBA student to be taught "statistical data analysis and management science." This reversal is an opportunity for OR/MS educators in business schools to bring OR/MS back into the curriculum (Grossman 2003).

6. Threats

The OR/MS ecosystem is facing various types of forces and trends that threaten the well-being of the ecosystem and hence its constituent communities.

6.1. Improper Use of OR/MS Tools

As more OR/MS tools are being disseminated rapidly beyond the traditional OR/MS community (e.g., Geoffrion 1992, Ormerod 1998), the awareness of OR/MS could increase. However, without proper OR education, improper use of these tools could happen because some users may not be aware of the benefits and limitations of the approaches associated with these OR/MS tools. Bad outcomes due to improper use of OR/MS tools can give OR/MS a bad name to the extent that the failing tools are attributed to it.[6]

6.2. Dispersion of OR/MS Practitioners

Dispersion of practitioners to other groups in their organizations was well under way by the 1970s. In the 1980s, well-established OR/MS groups in industry were closed down during the recession in the United Kingdom and the United States, which dispersed practitioners (Fildes and Raynard 1997, Fildes et al. 1999).[7] Such dispersion can weaken the identity of practitioners of the science and art of OR/MS and consequently the visibility of OR/MS as a field. Fortunately, many "internal consulting" groups still remain (e.g., as of this writing, more than half of the INFORMS Roundtable member companies have such groups).

6.3. Weakening Position in Business Schools

The dispersion of practitioners in industry is mirrored in business schools. The removal of OR/MS from MBA core requirements by the AACSB and the consequent elimination of OR/MS from the core curriculum by business schools such as Chicago, Dartmouth, Harvard, Stanford, and UCLA may have contributed to OR/MS academic groups in many business schools merging with others. Examples include the Operations and Information Management Department (OPIM) at the Wharton School and the Decisions, Operations and Technology Management group (DOTM) at the UCLA Anderson School. While such "mergers" bring OR/MS academics into closer contact with other disciplines and hence with broader areas of application, the OR group loses some autonomy in terms of curriculum design, faculty recruitment, student admissions, etc. These mergers eventually diminish the visibility of OR/MS and eventually the number of OR/MS educators and researchers in business schools.

6.4. Slow Growth in Visible Employment

Employment associated with OR/MS is facing slow growth, at least in the United States. According to the 2006 statistics reported by the U.S. Bureau of Labor Statistics (BLS),[8] employment of operations research analysts in the United States is projected to grow more slowly than the average across all occupations through 2014. Specifically, this reflects slow growth in the number of jobs with the title "operations research analyst" that typically require a masters' degree. Moreover, the median salary for an OR/MS analyst is lower than that of jobs at the same level in other functional areas of management such as marketing. Although this may seem counter to the growing need for advanced analysis in industry, the BLS numbers undoubtedly underscore the diminishing awareness of OR/MS or "operations research" as the umbrella field that provides advanced analytical solutions. Many such jobs now carry other titles. This is further evidence that OR/MS has an identity problem as a profession.[9]

7. Some Observations on What to Do

We must be realistic about what any single entity in the ecosystem can do in the short term. Indeed, we can think of a Nash equilibrium between universities, researchers, and journal editors that impedes, at least in the short run, any unilateral changes by any party to the current incentive systems, research topics, or publication criteria, respectively. For example, without editors of top journals committing themselves to deliver on their lip service to multidisciplinary research, it would be suicidal for junior researchers in academia to start working on challenging practice-motivated problems requiring a multidisciplinary solution instead of safely continuing to further narrow aspects of methodology. Despite the prisoners' dilemma, some actions can be taken unilaterally by any community. To improve the well-being of the ecosystem, it is evident from our ecosystem (Figure 1) that we must (1) increase demand from end users, and (2) improve the interaction between the education, practice, and research communities so that all three communities can flourish with job satisfactions.

7.1. Increase End-User Demand

As we noted earlier, we must increase the end-user demand that ultimately powers the entire ecosystem. To achieve this goal, OR/MS academics and full-time practitioners could seek ways to expand the pool of end users who are aware of the benefits of OR/MS. Here are some examples.

Because successful OR/MS applications at the operational level (e.g., revenue management) can be recognized at the strategic level that gets more attention from end users, OR/MS educators, researchers, and practitioners could rebalance the focus between strategic and operational levels. Hoffman (2006) suggested that because OR/MS has been successful at the operational level—29 out of 42 Edelman Prize finalist articles between 1990 and 1999 were purely operational according to Bell and Anderson (2002)—one may use this success to get access to and earn the confidence of senior management.

Professional societies could create journals or magazines with a broader appeal to end users.[10] This publication must address practical managerial issues and how OR/MS can help end users with their most important decisions. Such a publication could also serve as a promotional tool for practitioners and as an educational tool in business schools. OR practitioners could help in arguing for such a publication.

Professional societies could work ceaselessly toward a clear brand image of OR/MS globally. A clearer brand image would better distinguish OR/MS professionals from software engineers, nonanalytic "business intelligence" experts, or applied mathematicians. Although INFORMS has a marketing campaign that promotes OR/MS as the "Science of Better" on a dedicated website (http://www.scienceofbetter.org/) with success stories to convey to end users what OR/MS practitioners can do for them, it must also help educators and researchers understand and convey the same brand image to all audiences including students, colleagues, and friends.

OR/MS researchers and practitioners in western economies could work with their counterparts in Brazil, Russia, India, and China (BRICs) and other evolving economies to increase the end-user demand for OR/MS services such as resource allocation policies in the public and private sectors. For example, they can study the unique issues associated with China's manufacturing industry, research the complex decisions that must be made by Indian companies struggling with the growth of their information technology and communications industries, and work with Brazilian scholars on topics related to alternative energy and natural resources.

Practitioners and academic researchers could seek opportunities in technology-led emerging industries to increase end-user demand in these industries. They can learn about these emerging industries, e.g., nanotechnology or mobile telephony, by attending industry conferences focused on the underlying technology or on its use in industry. As academic researchers learn about how an industry is changing, they could present their practice-driven research in conferences frequented by practitioners (and end users). Professional societies can guide their practitioner members—for example, the INFORMS Roundtable's Strategic Planning Team includes paying attention to promising new application domains among its 18 strategic goals for the practice community.

A long-term view of increasing end-user demand as well as increasing the supply of students for OR/MS education is to increase the awareness of OR/MS among students in high schools. For example, INFORMS has a public awareness committee that has created materials and video tapes to be used by high-school teachers. Kenneth Chelst of Wayne State University formed an organization

called "High School Operations Research" (www.hsor.org) in 1996 to offer teaching materials (lecture material, cases, videos, and teaching notes) for high-school math teachers to teach OR to their students as part of applications of mathematics. The organization also offers volunteer-led workshops for high-school teachers.

7.2. Strengthen the Researcher-Practitioner, Researcher-End-User Links

Researchers could shift their emphasis in research methodology (Karmarkar 2006) with the aid and encouragement of editors of research journals, professional societies, universities, and funding agencies. Instead of focusing narrowly on mathematical models already in the literature, researchers could try harder to model real phenomena in the scientific tradition and then validate these models. This shift would require researchers to conduct empirical studies (as in finance, marketing, and economics), case-based research (as in strategy, operations management, and human resource management), and application-based research (as in engineering). Interestingly, some researchers have formed a section in INFORMS for Behavioral Process Management with an annual conference (Schultz 2007). To make this shift practical, editors will have to embrace this shift in the research paradigm and guide referees accordingly. They could try to increase the involvement of practitioners in the research publication process, although this is an uphill battle due to the lack of short-term rewards for practitioners. Such involvement would encourage the submission and proper review of articles that are relevant to practice. It would be especially helpful if editors encouraged practitioners to publish their perspectives about real industry challenges.

As practitioners move from manufacturing to services in line with macroeconomic changes in western countries, academic researchers could shift their focus to services as well. The self-referential nature of OR/MS research retards shifting focus from manufacturing to services. To break this vicious cycle, Karmarkar (2006) suggested that researchers should explore growing sectors of the economy such as the service and information-intensive industries instead of continuing to focus on manufacturing.

Funding agencies could encourage the interaction of academics with practitioners and industry end users. To do so, they could (1) support events and programs that bring these people into closer contact, and (2) call specifically for the kinds of practice-driven research proposals that academic promotion and publication incentives cause to be underrepresented. Many funding agencies are already quite aware of the need to do this. The National Science Foundation initiated a program called Grant Opportunities for Academic Liaison (GOALI) in 1989 to support industry-university linkages. This program provides research grants for faculty, students, and postdoctoral fellows to gain research experience through short-to-medium-term stays in industry settings. Research projects include those that are OR/MS-related (Martin-Vega et al. 2002). The Sloan Foundation and other funding agencies have similar programs that encourage researchers and educators to interact with practitioners or end users (c.f. Tang 2006). In the United Kingdom, the EPSRC generously funds academic research conducted in partnership with industry. Still, funding agencies could do more, especially in consultation with universities and with end users in industry.

There are good examples of practice-driven research (and education) activities. The Stanford Global Supply Chain Forum, founded in 1995, provides an environment for researchers and educators to work closely with practitioners and end users from member companies to conduct multidisciplinary supply-chain-related research projects and write teaching cases (Lee 2006). The Fishman-Davidson Center for Service and Operations Management at the Wharton School is another forum for academics to interact with practitioners and end users in the service industry. Other examples are the Logistics Institute at Georgia Tech and the Deming Center at the Columbia Business School (Fraiman 2002).

OR/MS professional societies could create forums for interaction between OR/MS researchers from different areas and practitioners, possibly along with end users. These forums would provide leadership in shaping the research and education priorities in OR/MS. One possible model is the Marketing Science Institute (http://www.msi.org). Founded in 1961, MSI is committed to initiate, support, and disseminate leading edge studies conducted by scholars that address research issues specified by member companies. Currently, over 100 universities and 70 sponsoring companies are members of MSI. Top research priorities identified for 2006–2008 are (1) connecting innovation with growth, (2) connecting customers with the company, and (3) connecting metrics with marketing strategy.

Business schools (and universities) could modify their reward and incentive systems to improve interaction between research and practice, and to create a better balance between methodology-driven and application-driven research.[11] Quite often, research-oriented business schools measure research productivity based on the number of publications in research journals that tend to value theory and methodology over business application. Such business schools could provide incentives for researchers (and educators) to interact with end users and OR/MS practitioners.

However, the question remains why a leading business school should change its hiring and promotion criteria unless the pressure from industry is compelling. As publications in leading OR/MS journals guide business schools in matters pertaining to career advancement, perhaps the editors of these journals can more readily catalyze the interaction between researchers and practitioners (and end users) than business schools or universities.

7.3. Strengthen the Educator-Practitioner, Educator-End-User Links

There is much that educators themselves and in conjunction with practitioners could do, aided in this effort by universities. For example, educators could improve the way OR/MS courses are designed and delivered. Educators can obtain innovative ideas for teaching OR/MS from the articles published in *INFORMS Transactions on Education* (http://ite.pubs.informs.org).

Educators on their own could enlist practitioners to help motivate student interest because the best way to convince students of the benefit of OR/MS is for credible people from industry and government to relate their experiences. Moreover, these practitioners can play an important role in developing students' problem solving, communication, and project management skills. Although it is difficult for full-time practitioners to find the time, practitioners can serve as project sponsors and judges for case competitions. By taking a more active role in education, these practitioners can help increase students' interest in becoming OR/MS practitioners or end users.

Educators and practitioners could work together to co-develop programs to meet the emerging needs of industry. For example, to teach students new ways of managing and analyzing massive data sets, the statistical software vendor SAS and North Carolina State University co-developed a master's degree program in data analytics in 2006.

Educators could also work with their counterparts from other disciplines in creating new programs so as to reinforce the multidisciplinary nature of OR/MS for end users. For example, Magnanti (2006) reported that MIT has two multidisciplinary programs between Sloan School of Management and the Engineering School; one called Computation for Design and Optimization and the other called Leaders for Manufacturing.

Educators could train students to meet the needs of end users in industry and government. To do so, it is useful to know what teaching approaches are likely to provide a solid education in foundation subjects and what the most pressing industry needs are. Birge (2006) suggested applying the problem-solving aspect of OR to the "problem" of how to teach OR. He suggested changing the pedagogy toward cooperative learning via business games and inductive learning via practical examples. Miyaoka (2005) summarized her students' learning experience derived from a competitive business game developed by Littlefield Technologies. Also, Sodhi and Son (2007) inferred from more than a thousand OR job advertisements from industry that communication, project management, and spreadsheet skills are in great demand in addition to modeling, statistics, programming, and general analytical skills.

Educators could also help improve students' ability to communicate problem definition, model formulation, OR concepts, methods, and solutions to end users. A model may be that provided by Keller and Kros (2000) in instituting written and oral communication requirements within an MBA-level OR/MS course.

Educators could sharpen their students' project management skills by requiring students to do projects with companies. Based on his experience, Grossman (2002) and Armacost and Lowe (2003) report that such projects enable students to develop their skills not only in project management (problem definition, project scoping, data collection, and analysis) but also in communication, leadership, and client management. Simultaneously, such projects increase end users' appreciation for the value of OR/MS and create potential job opportunities for OR/MS students.

Fildes et al. (1999) highlight the importance of spreadsheets (and of simulation) in contributing to OR groups' performance in companies. Many in the education community, especially in business schools, already believe this. Grossman (2003) exhorts developing a spreadsheet-based quantitative analysis course. The large and growing number of textbooks for management science and statistics using spreadsheets for computation makes it easy for educators to do so. Educators can also benefit from teaching workshops created by Powell (2001) demonstrating real OR/MS applications in marketing, finance, and accounting. However, educators must be careful not to make OR/MS synonymous with such tools or to imagine that spreadsheets alone would make OR/MS relevant in the absence of foundational training (e.g., Groleau 1999).

8. Conclusion

The above ongoing and proposed activities are intended to increase end-user demand and to strengthen the interactions among different interest groups of our OR/MS ecosystem. These interactions can generate momentum for educators, practitioners, and researchers to interact and help restore the well-being of the OR/MS ecosystem. Just as there is a vicious cycle associated with estrangement, there is a virtuous cycle associated with healthy flows between the various communities in the OR/MS ecosystem.

It is difficult not to conclude that academics should take the lead in improving the health of the ecosystem through improved interaction between the practice, research, and education communities. After all, academics comprise a bulk of the research community, nearly the entire education community, and at least a part of the practice community. Moreover, they tend to run OR/MS professional societies, have a near monopoly on editorial positions at OR/MS journals, and are well placed as teachers, administrators, course directors, etc. to urge fresh thinking at the school and the university level.

For an ecosystem to thrive, efforts have to be made in increasing healthy interaction on many fronts. Specifically, as articulated in §7, we believe that (1) academic journals editors could serve as catalysts for making the ecosystem healthier by publishing more multidisciplinary papers that reflect the core strengths and uniqueness of OR/MS, (2) researchers could initiate efforts for strengthening the links with end users and practitioners, and (3) educators

(especially in business schools) could enlist support from practitioners and end users to motivate more students to become OR/MS practitioners or end users.

Endnotes

1. A business ecosystem is an economic community supported by a foundation of interactive organizations and individuals. See Moore (1993) for details.
2. See http://uclacluster.jot.com for details.
3. For a more comprehensive listing of U.S.-based funding agencies, see http://www2.informs.org/Funds/funding.html.
4. Practitioners and academics have created libraries of OR problems related to practice that enable algorithm developers to check applicability and to benchmark. Of these, NETLIB (www.netlib.org) is the most well known, having been accessed 438 million times as of August 1, 2007. To solve such problems, practitioners and academics have also created open-source software as part of the computational infrastructure for OR (www.coin-or.org).
5. We note the exceptions provided by *Interfaces* and the *Journal of the Operational Research Society*.
6. Another consequence of the popularization of OR ideas is their inevitable debasement as evident in the corruption of the notion of "optimality" reflected in the frequency with which words like "maximize," "minimize," and "optimize" appear inappropriately in the popular business lexicon and in promotional literature circulated by information technology companies.
7. One reason could be that such groups did not have a high enough profile with senior management because these groups often were not involved in senior managerial decisions and were perceived as merely problem solving, not as problem defining or problem structuring (c.f. Bell and Anderson 2002).
8. See http://stats.bls.gov/oco/ocos044.htm for BLS data.
9. Even modeling-oriented jobs in the finance sector seek "physics or mathematics" graduates who have much less training than OR/MS graduates for developing and using the wide range of models such jobs entail.
10. This publication is in contrast to *Interfaces* or the *Journal of the Operational Research Society*, which target OR/MS practitioners and academics.
11. At Cass Business School, a publication in *Harvard Business Review* carries the same weight as one in *Management Science*; both journals appear in the *Financial Times* list of 40 influential business journals.

Acknowledgments

The authors thank the other presenters at the cluster "Where Do We Want to Go in OR/MS?" at the 2006 INFORMS Pittsburgh meeting: in addition to the authors, these were Charles Beall, John Birge, Gerald Brown, Scott Ellis, Marshall Fisher, Karla Hoffman, Uday Karmarkar, John Little, Irv Lustig, Thomas Magnanti, and Don Ratliff. The authors are grateful to Charles Corbett, Kevin McCardle, and Kumar Rajaram for organizing the cluster along with one of the authors. Last but not least, thanks to Charles Corbett, Marshall Fisher, Robert Fildes, Karla Hoffman, Uday Karmarkar, Michael Trick, John Raynard, the associate editor, and three anonymous referees for their comments on an earlier version of this paper.

References

Abdel-Malek, L., C. Wolf, F. Johnson, T. Spencer III. 1999. OR practice: Survey results and reflections of practising INFORMS members. *J. Oper. Res. Soc.* **50**(10) 994–1003.

Ackoff, R. L. 1979. The future of operational research is past. *J. Oper. Res. Soc.* **30**(2) 93–104.

Ackoff, R. L. 1987. Presidents' symposium: OR, a post mortem. *Oper. Res.* **35**(3) 471–474.

Apt, K. R., E. R. Olderog. 1991. *Verification of Sequential and Concurrent Programs*. Springer Verlag, New York.

Apte, U. M., H. K. Nath. 2004. Size, structure and growth of the US information economy. Working paper, Southern Methodist University, Dallas, TX. http://www.anderson.ucla.edu/documents/areas/ctr/bit/ApteNath.pdf.

Armacost, A. P., J. K. Lowe. 2003. Operations research capstone course: A project-based process of discovery and applications. *INFORMS Trans. Ed.* **3**(2) 1–25.

Bell, P. C., C. K. Anderson. 2002. In search of strategic operations research/management science. *Interfaces* **32**(2) 28–40.

Bertsekas, D. P., J. N. Tsitsiklis. 1989. *Parallel and Distributed Computation: Numerical Methods*. Prentice-Hall, New Jersey.

Birge, J. 2006. Where do we want OR to go in education and vice versa? INFORMS Annual Meeting, Pittsburgh. http://uclacluster.jot.com/Education.

Brown, G. 2006. Greatest hits in operations research. INFORMS Annual Meeting, Pittsburgh. http://uclacluster.jot.com/Research.

Chandy, K. M., J. Misra. 1988. *Parallel Program Design*: *A Foundation*. Addison-Wesley, Boston.

Chopra, S., M. S. Sodhi. 2007. Finding the bang for the RFID buck in the supply chain. *Supply Chain Management Rev.* Forthcoming.

CONDOR. 1988. Operations research: The next decade. *Oper. Res.* **36**(4) 619–637.

Corbett, C. J., L. N. Van Wassenhove. 1993. The natural drift: What happened to operations research? *Oper. Res.* **41**(4) 625–640.

Dawson, C. S., C. J. McCallum Jr., R. B. Murphy, E. Wolman. 2000. Operations research at Bell Laboratories through the 1970s: Part I. *Oper. Res.* **48**(2) 205–215.

Dijkstra, E. W. 1976. *A Discipline of Programming.* Prentice-Hall Series in Automatic Computation, Englewood Cliffs, NJ.

Economist, The. 2007. Go with the flow. (March 8). Retrieved April 4, 2008, http://www.economist.com/search/displaystory.cfm?story_id=8766053.

Fildes, R., J. C. Raynard. 1997. Success and survival of operational research groups: A review. *J. Oper. Res. Soc.* **48**(4) 336–360.

Fildes, R., J. C. Raynard, W. R. Crylmble. 1999. The management of OR groups: Results of a survey. *J. Oper. Res. Soc.* **50**(6) 563–580.

Fraiman, N. 2002. Building relationships between universities and businesses: The case at Columbia Business School. *Interfaces* **32**(2) 52–55.

Gass, S. I., C. M. Harris, eds. 2001. *Encyclopedia of Operations Research and Management Science*. Kluwer Academic Publishers, Boston.

Geoffrion, A. M. 1992. Forces, trends, and opportunities in MS/OR. *Oper. Res.* **40**(3) 423–445.

Geoffrion, A. M., R. Krishnan. 2001. Prospects for operations research in the e-business era. *Interfaces* **31**(2) 6–36.

Geoffrion, A. M., R. Krishnan. 2003. E-business and management science: Mutual impacts (Part 1 of 2). *Management Sci.* **49**(10) 1275–1286.

Groleau, T. G. 1999. Spreadsheets will not save OR/MS! *OR/MS Today* **26**(1).

Grossman, T. A. 2001. Causes of the decline of the business school management science courses. *INFORMS Trans. Ed.* **1**(2) 51–61.

Grossman, T. A. 2002. Student consulting projects benefit faculty and industry. *Interfaces* **32**(2) 42–48.

Grossman, T. A. 2003. Getting down to business. *OR/MS Today* **30**(3) 78.

Guide, V. D., L. N. Van Wassenhove. 2006. Special issue on closed-loop supply chains. *Production Oper. Management* **15**(3–4).

Hoare, C. A. R. 1969. An axiomatic basis for computer programming. *Comm. ACM* **12**(10) 576–583.

Hoare, C. A. R. 1978. Communicating sequential processes. *Comm. ACM* **21**(8) 666–677.

Hoffman, K. 2006. Opportunities and challenges for OR in the next five years. INFORMS Annual Meeting, Pittsburgh. http://uclacluster.jot.com/GettingThere.

Horner, P. 2004. The science of better synergy. *OR/MS Today* **31**(6).

INFORMS Roundtable. 2006. Where do we want to go in OR/MS practice? INFORMS Annual Meeting, Pittsburgh. http://uclacluster.jot.com/Practice.

Jordan, E., L. Lasdon, M. Lenard, J. Moore, S. Powell, T. Willemain. 1997. OR/MS and MBA. *OR/MS Today* **24**(1) 36–41. Detailed 2/96 report available at http://education.forum.informs.org/magnanti.html.

Karmarkar, U. 2006. Leading a double life. INFORMS Annual Meeting, Pittsburgh. http://uclacluster.jot.com/Research.

Keller, C., J. Kros. 2000. Teaching communication in an MBA operations research/management science course. *J. Oper. Res. Soc.* **51**(12) 1433–1439.

Kettinger, W. J., V. Grover, S. Guha, A. H. Segars. 1994. Strategic information systems revisited: A study in sustainability and performance. *Management Inform. System Quart.* **18**(1) 31–58.

Kirby, M. W. 2000. Operations research trajectories: The Anglo-American experience from the 1940s to the 1990s. *Oper. Res.* **48**(5) 661–670.

Lee, H. L. 2006. Personal communication to C. S. Tang. Stanford Business School, Stanford, CA.

Lilien, G. L. 1987. MS/OR: A mid-life crisis. *Interfaces* **17**(2) 35–38.

Magnanti, T. 2006. Engineering education and operations research. INFORMS Annual Meeting, Pittsburgh. http://uclacluster.jot.com/Education.

Martin-Vega, L. A., L. M. Seiford, D. Senich. 2002. GOALI: A National Science Foundation university-industry liaison program. *Interfaces* **32**(2) 56–62.

Mesquita, M. A., M. C. Santoro. 2004. Analysis of models and practices in production and inventory management: A case study in Brazilian pharmaceutical industry. *Revista Producao* **14**(1) 64–77.

Miyaoka, J. 2005. Making operations management fun: Littlefield Technologies. *INFORMS Trans. Ed.* **5**(2). http://ite.pubs.informs.org/Vol5No2/Miyaoka/.

Moore, F. J. 1993. Predators and prey: A new ecology of competition. *Harvard Bus. Rev.* **71**(3) 75–86.

Ormerod, R. J. 1998. Beyond internal OR groups. *J. Oper. Res. Soc.* **49**(4) 420–429.

Ormerod, R. J. 2002. On the nature of OR: Taking stock. *J. Oper. Res. Soc.* **53**(5) 475–491.

Powell, S. 2001. Teaching modeling in management science. *INFORMS Trans. Ed.* **1**(2) 62–67.

Ratliff, D. 2006. It is not a fair world. INFORMS Annual Meeting, Pittsburgh. http://uclacluster.jot.com/research.

Reisman, A., F. Kirschnick. 1994. The devolution of OR/MS: Implications from a statistical content analysis of papers in flagship journals. *Oper. Res.* **42**(4) 577–588.

Rothkopf, M. H. 2002. Editorial: Leveling the field? The fourth *Interfaces* ranking of universities' contribution to the practice literature. *Interfaces* **32**(2) 23–27.

Schultz, K. 2007. Personal communication to M. S. Sodhi.

Sodhi, M. S. 2001. Applications and opportunities for operations research in Internet-enabled supply chains and electronic marketplaces. *Interfaces* **31**(2) 56–69.

Sodhi, M. S. 2003. How to do strategic supply chain planning. *Sloan Management Rev.* **45**(1) 69–75.

Sodhi, M. S., B. G. Son. 2007. What industry employers want from OR/MS graduates: Inferences from the content analysis of a thousand O.R. job ads. Working paper, Cass Business School, City University London.

Tang, C. S. 2006. How to create change within the Camelot? INFORMS Annual Meeting, Pittsburgh. http://uclacluster.jot.com/GettingThere.

Verter, V., T. Boyaci. 2007. Special issue on reverse logistics. *Comput. Oper. Res.* **34**(2) 295–619.

Wagner, H. M., M. H. Rothkopf, C. J. Thomas, H. J. Miser. 1989. The next decade in operations research: Comments on the CONDOR report. *Oper. Res.* **37**(4) 664–672.