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FORCES, TRENDS, AND OPPORTUNITIES IN MS/OR

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The purposes of this paper—a revised and extended version of the Omega Rho Lecture given at the November 1991 ORSA/TIMS Joint National Meeting—are to assess some important aspects of the current MS/OR situation and to draw some conclusions about desirable future emphases. To these ends, it identifies and discusses four *forces* of historic importance (the microcomputer and communications revolutions, the dispersion of MS/OR in industry, and academia's unbalanced reward structure), three major *trends* (rapidly disseminating MS/OR tools, declining enrollments of native-born students, and persisting management apathy toward MS/OR), and five outstanding *opportunities* (ride the computer and communications revolutions, support dispersed practitioners, focus on the service sector, stress embedded applications, and go into the quality business). An underlying theme is that the field will flourish in proportion to how astutely individuals, organizations, professional societies, and universities adapt to the changing realities within which MS/OR lives.

The management science/operations research (MS/OR) profession is where it is today largely because it has been subjected over the years to certain powerful forces. The purposes of this paper are to assess the most prominent forces and the trends which they have helped to induce, and to derive some conclusions concerning how these forces and trends can be harnessed for the long-term good of the profession.

The first section discusses four of the most important forces impacting MS/OR: the microcomputer and communications revolutions; the dispersion of MS/OR in industry; and an academic reward structure strongly biased toward theory. The second section considers three of the most significant trends: rapidly disseminating MS/OR tools; declining interest of native-born students in MS/OR studies; and persisting management apathy toward MS/OR. These two sections include a summary of the consequences of each force and trend for MS/OR as a profession and for individual professionals. These consequences suggest directions in which individuals, professional societies, universities, and other organizations may wish to move.

The third section, the principal focus of the paper, takes up five promising opportunities for MS/OR to flourish in the kind of world implied by the forces and trends described previously: riding the microcomputer and communications revolutions; supporting dispersed practitioners; focusing on the service sector; stressing embedded applications; and going into the quality business.

Most of the consequences for individuals wishing to capture the opportunities envisaged here are imperatives: *learn about . . . think about . . . allocate some time to . . .*, and so on. These accumulated imperatives may seem overwhelming, especially for someone at an early career stage. But there may be some comfort in recognizing that many of the suggested activities count doubly or even triply in terms of career objectives, can be dispatched by course work or occasional seminars, can be shared with others if one works in teams, and can be spread out over the different seasons of a career. The burdens on professional societies, universities, and other organizations lie more heavily.

This paper carries some personal biases of which the reader should be aware. One is that its focus is not on government or military contexts but on the private sector, excluding engineering. Another is that, for practical reasons of my own experience, I am addressing the situation in the United States.

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MAJOR FORCES ACTING ON MS/OR

Since the destiny of MS/OR is determined significantly by powerful external forces, those who wish to succeed in this field should be fully aware of them. Not to be is like trying to fly a plane without understanding the forces of gravity, lift, thrust, and drag; the results of such ignorance could be unpleasant—even fatal.

The four forces discussed in this section are the ones I believe to be of the greatest importance during the last decade or two. The first two—the microcomputer and communications revolutions—are obvious to even the most casual observer of the MS/OR scene. The third—the dispersion of MS/OR in industry—may be the least understood. Finally, I comment on academia's preoccupation with theory. In each case, I offer an interpretation of the general consequences for individual professionals, as well as for MS/OR as a whole.

The Microcomputer Revolution

Everyone is aware of the stunning revolution in small computers (including workstations) and associated software. Driven by technological progress in microelectronics and strong market demand—more than 50 million microcomputers have been sold to date in the U.S.—the microcomputer revolution is expected to continue apace for some years yet (Hennessy and Jouppi 1991).

Consequences for MS/OR. The impact has been enormous because, in less than a single decade, the profession's main physical tool has become ubiquitous and inexpensive. This has many important consequences for MS/OR, virtually all of them good:

- The benefit/cost ratio of most MS/OR applications continues to improve thanks to the decreasing cost of computation.
- In contrast to prerevolutionary days, there is seldom a computation-cost barrier to doing MS/OR applications even at the lowest levels of an organization, or in very small organizations, or in geographically remote locations. This vastly increases the potential market for MS/OR.
- Convenient access to microcomputers, the competitive scramble for better user interfaces, greatly improved software development tools, the object-oriented paradigm, and other advances have notably shortened development times for many MS/OR applications. (For nice examples of improved productivity in applying mathematical programming, see Wagner 1988.)
- Microcomputers have brought a large measure of freedom from the frustrations and constraints (organizational, political, and technical) that accompany having to rely on mainframe computers and data processing departments. This, in turn, has triggered a boom in end-user computing.
- A large and increasing percentage of potential MS/OR clients are personally familiar with microcomputers, and so tend to be less resistant to computer-based MS/OR proposals. I believe that this effect, which began only a decade ago, already has done as much for the acceptability of MS/OR as the roughly three decades worth of classroom exposure to MS/OR given in management and engineering programs. Computer applications seem natural to computer literates, and, in any case, self-contained MS/OR applications on a desktop machine are far less intimidating psychologically than were the mainframe applications of yesteryear.
- MS/OR groups have lost one of their relative advantages, namely, easy access to computers and mainframe data bases. Ubiquitous computers empower dispersed MS/OR practitioners and others not identifying with MS/OR, such as quantitatively-oriented MBAs, who now have the means to apply MS/OR software with little or no assistance from MS/OR professionals.
- Affordable high-resolution graphic displays offer new opportunities for data visualization as a prelude to modeling, and for more realistic and even animated presentation of results to users (now common in simulation).
- Microcomputers greatly facilitate communication and demonstration-based selling for vendors and consultants, both internal and external. Demonstration diskettes are now the rule for most MS/OR software vendors.
- The slick user interfaces of the better commercial microcomputer packages set a standard that client-visible MS/OR application programs must attain, or risk looking unprofessional by comparison.
- The decreasing cost of computation is significantly altering the optimal balance, in research and practice, between mathematical and computational approaches to problems. For example, it is sometimes almost as easy nowadays to simulate the transient behavior of a queueing system under realistic assumptions as it is to use an analytical solution describing steady-state behavior under unrealistic assumptions. Efron and Tibshirani (1991) lucidly explain this general idea in the context of statistics.

Consequences for the MS/OR Professional. There are two important ones to consider:

1. You have a major handicap if you are not knowledgeable about microcomputers: basic architectures, operating systems, software development tools, and leading application packages. This knowledge can be acquired through courses, workshops, and independent study. Do not overlook the newer workstations, whose price/performance ratio is improving so fast that many professionals grossly underestimate their potential.
2. Make a habit of thinking about the possible uses of microcomputers for significant tasks as they arise, keeping in mind that new technologies typically are used first to facilitate work as it has been done traditionally, and only later to depart from tradition in creative ways.

The Communications Revolution

The communications revolution comprises such developments as cellular radio, digital switching, fax, fiber optics, inexpensive micro/mainframe links, multimedia, network technology (local area, wide area, client-server, etc.), and satellite transponders and navigational aids. These technologies spawn distributed data bases, EDI (electronic data interchange), electronic markets, E-mail and voice mail, enterprise networking, on-line information systems, and innumerable other applications. An information infrastructure is rapidly coming into being that will rival the importance of existing infrastructures like the national highway, telephone, and electric power systems (Hopper 1990, Dertouzos 1991).

Advances in communications receive almost as much press as advances in microcomputers, and may have equally profound implications. The two revolutions go hand-in-hand and are occurring for similar reasons. Of their relationship, Peter Keen says, "We're moving from computing with telecommunications as an add-on to networking into which computing fits" (Keen 1991).

For convenience, I include under this heading much of what is sometimes known as the "data explosion" associated with the mass deployment of scanners, sensors, and other data acquisition equipment, proliferating data base applications, rapid progress in high-density storage media, and the burgeoning information services industry. To illustrate, Little (1991) points out that the introduction of universal product code scanners increased the amount of data available to consumer-packaged-goods marketing analysts by two to three orders of magnitude. For another example, Pfizer receives about 50 million records/month on pharmacies, most of which now are equipped with computer terminals (Arvesen 1991). As CONDOR (1988, p. 620) puts it, "Data availability, once the Achilles heel of OR, is now a driving force."

Consequences for MS/OR. There are several important ones to consider:

- A network of workstations is more cost effective than a mainframe computer in many applications. Moreover, since data development has always been an expensive and time-consuming activity in most MS/OR projects, more plentiful data, and cheaper and faster data acquisition and transmission, are a boon. Thus, like the microcomputer revolution, the communications revolution is improving the benefit/cost ratios of many MS/OR applications. The impact of the new economics is evident at one of the largest MS/OR consulting firms, which implements nearly all of its new applications on a network of workstations (Cook 1991). They do this for two reasons: first, to save mainframe expenses, and second, to facilitate access to mainframe data in real-time applications that support local decision making.
- Communications systems and their applications offer numerous opportunities to apply MS/OR. For example: coordinated inventory management with dispersed stocking locations (Cohen et al. 1990); electronic markets and EDI systems (Malone, Yates and Benjamin 1989, EDI Forum 1991); global manufacturing and logistics planning (McElroy and Trafton 1991); network design (Nigam 1989); optimal vehicle routing with on-board satellite navigation (Spreitzer 1989); and resource allocation and site selection in telemarketing (Spencer et al. 1990, Quinn, Andrews and Parsons 1991). Sometimes the kinds of questions that arise lead to fundamentally new research topics; a good example is provided by recent pioneering work on inferring waiting-line statistics from computer-generated transactional data produced by automatic teller machines, mobile radio networks, and other kinds of computerized service systems (Larson 1990).
- There is an accelerating trend toward *enterprise networking* (Hopper 1990, Rash 1991), a main goal of which is to deploy small computers and integrate local area networks sufficiently that everyone in an organization can have convenient electronic access to everyone else in the entire organization no matter what their location. The reality today is far short of this goal where heterogeneous networks are involved, but progress in this direction makes it easier for MS/OR practitioners to stay in close touch with one another

and with their clients and users, makes it easier to do multi-installation applications, and facilitates distributed modeling and co-development of new applications.

- Network-accessible data sources (financial data, geodata, government statistics, etc.) provide new opportunities to build parts of some models more quickly and economically.
- The communications revolution has led to heightened senior management awareness of the strategic value of information (Keen 1988). Since MS/OR can be viewed as being in the business of producing high-grade information, this creates an opening for MS/OR to capture the attention of senior management for some types of MS/OR applications.
- The developments of the communications revolution that call for centralized administration tend to make an organization's information systems (IS) function more important, which, in turn, presents opportunities for MS/OR to the extent that IS and MS/OR cooperate. At the same time, other developments are empowering people at all levels of an organization, leading to more decentralized decision making (Malone and Rockart 1991) and thus more opportunity for dispersed MS/OR professionals.

Consequences for the MS/OR Professional. There are two important ones:

1. You have a major handicap if you are not familiar with information technology and its applications as they relate to the communications revolution and data explosion.
2. Make a habit of thinking about the operational, tactical, and strategic uses of information technology, and about the possible roles for MS/OR in these uses. For example, ask yourself what your organization would do differently if it suddenly had low-cost infinite bandwidth available for data transport, or if local/wide-area network boundaries were suddenly to disappear.

Dispersion of MS/OR in Industry

There is only one term to fairly describe the conduct of MS/OR in industry today: *dispersed.* The idea that MS/OR is conducted mostly by organized groups of MS/OR professionals is a myth. MS/OR is practiced mainly by individuals in myriad types of staff groups and functional areas.

The most dramatic aspect of dispersion is the long-term net decentralization and disbanding of MS/OR groups. This began about 25 years ago (Radnor and Neal 1973), and has been confirmed repeatedly by industry surveys. For example, Bradbard et al. (1987) found 43% fewer MS/OR groups in 1985 than in 1975. My recent discussions with industry leaders, recruiters, and others indicate that decentralization/disbanding finally may have run its course, as reports of new or growing groups roughly match reports of an opposite nature.

Decentralization has been interpreted as a sign of maturity and success by some members of the MS/OR community, while others see it as a sign of failure. In a special report to the TIMS Council, the Management Science Roundtable, whose representatives are senior MS/OR leaders from industry, rated this the most severe among seven problems facing the profession (MSR 1986). My own view is that if decentralization is a "victory," then—at least until now—it has on balance been Pyrrhic.

A less dramatic aspect of the dispersion of MS/OR in industry is the gradual diffusion of MS/OR ideas into managerial thinking (Wagner 1988), and into numerous functions and processes throughout many organizations. Seldom, however, are these ideas identified explicitly as MS/OR. It is difficult to know the true extent of *this* victory, but certainly it is more genuine than Pyrrhic.

The degree of dispersion, for whatever cause, apparently is much larger than most people realize. According to a landmark Bureau of Labor Statistics report (BLS 1990), there are about 55,000 Operations Research Analysts in this country. From this, it follows (Samuelson 1990) that there are about 48,000 persons in this category who belong neither to ORSA nor TIMS, but many of whom may be doing work that we would consider to be MS/OR—or at least related to this field. It seems highly unlikely that more than a few thousand belong to an organized MS/OR group. Thus, there may be as many as an order of magnitude more dispersed practitioners who do MS/OR work than there are in organized groups.

Causes of MS/OR Dispersion. There are quite a few:

- Lack of functional responsibility makes an MS/OR group an easy target for cost cutting in a budget crunch and overly dependent on senior management champions, all of whom eventually move on.
- There has been a shift for at least a decade toward leaner staffs in headquarters, flatter organizational structures, and greater decentralization. The consequences for MS/OR and other staff specialties like long-range planning often have been dire. The Appendix provides an example taken from my correspondence about five years ago with the president of a large company that was dispersing its central MS/OR group.

• Traditional MS/OR techniques have long been diffusing into other disciplines and professions such as actuarial science, applied mathematics, computer science, finance, industrial and other kinds of engineering, logistics, marketing, and operations management (PoKempner 1977, Gray 1979). This makes the capabilities of an MS/OR group less unique and increases the likelihood of MS/OR ideas being used when needed by individuals or groups with different professional identifications. Moreover, in this age of good MS/OR microcomputer software, a similar effect occurs each time a quantitatively-oriented MBA applies an MS/OR technique without much assistance from an organized MS/OR group. The impact of this diffusion of traditional techniques on the MS/OR profession has been evident for many years; for example: "The well known optimization and simulation tools have now been incorporated into the analytical tool kits of many who are not Management Scientists. In my company these others are far larger users of simulation and optimization than are the professional Management Scientists" (Hoffman 1975). The company referred to is Standard Oil (Indiana). Is it purely coincidental that its central MS/OR group—one of the most respected in industry—was subsequently disbanded?

• The bandwagon effect is long since over; MS/OR is no longer novel, and therefore is less likely to capture the senior management attention needed for group formation. The bandwagon effect moved on to DSS, AI (especially expert systems), neural networks (which *Science* 1991 calls a "hot field"), and other panaceas.

• Many MS/OR groups failed to achieve sufficient success with truly strategic problems. As John Little puts it, "Many of the problems worked on by industrial OR groups were tactical in nature and, as a result, senior management gradually lost interest in high-level groups" (Little, p. 533). Inadequate progress on strategic applications was judged by MSR (1986) to be the fourth most serious of seven problems facing the profession. The reasons cited in that report for this state of affairs include:

> Strategic studies are very difficult; they require more maturity, lots of trust, political and social skills, and a knack for qualitative as well as quantitative analysis.
>
> Interdisciplinary teams are best for truly strategic problems. But our profession has somehow lost this inclination.

Such comments notwithstanding, it is only fair to note that MS/OR has had its share of strategic impacts (Kirkwood 1990).

• The computer/communications revolution greatly increases the practicality of dispersed MS/OR work (as well as the work of organized groups).

Few of the above causes of dispersion have to do with how MS/OR is practiced. Yet it has been suggested that MS/OR practitioners themselves bear some responsibility for unwanted dispersion. Alleged reasons include arrogance, poor listening and communication skills, insufficient interest in the business and its competitive problems, and ineffectual marketing and packaging of MS/OR.

Consequences for MS/OR. They are mostly unfortunate; only the first is an unmitigated benefit:

• MS/OR is being used even more widely, and in more ways, than one would surmise from the journals and meetings of ORSA and TIMS.

• Having more MS/OR specialists in functionally-oriented jobs increases opportunities to introduce good MS/OR technology that meets recognized functional needs and is fairly simple. On the other hand, fewer MS/OR groups means fewer opportunities to introduce improved but relatively complex MS/OR technology into practice. This is so for two reasons: reduced in-house technical competence, and disruption of the social network by which practitioners find out about improved technology (MS/OR groups seem to be much more interested in the academic/practitioner interface than lone practitioners are).

• Dispersion tends to exacerbate the often lamented identity problems of MS/OR: the profession and its contributions are insufficiently well known to its potential clients, its beneficiaries, and the public at large. See Teach (1991) for the most recent confirmation of this situation.

• Dispersion tends to shorten the already short career paths available to people who want to continue in MS/OR. It also reduces the opportunities for MS/OR to serve as an incubator for higher-level managers, a function that some central groups have performed with great success (e.g., Machamer and Smith 1980, Davidson 1981). This comment from an internal IBM report is a valid lament: ". . . management science . . . career pathing is complicated by the dispersal of this talent and its associated identification problems and by the fact that, when identified, the talent resides in many functional areas serving a variety of managerial levels, focusing on problems with a diversity of depth and breadth." Shorter career paths will, in turn, discourage very able people from entering MS/OR or staying in it.

• Dispersion is an obstacle to cross-functional applications, which usually require multitalented MS/OR teams and senior management involvement. This is a particularly grave consequence because such applications are an increasingly important area of opportunity for MS/OR. As pointed out in the internal report quoted in the previous point: "... management science has its greatest impact when interfunctional problems are to be attacked—and centers of management science competence are most effective in addressing these problems."

• Much of the demand for MS/OR practitioners has moved away from those with only specialized skills and toward those with generalist and functional skills. Many observers—including the author of The Conference Board's independent study of MS/OR (PoKempner)—see this as a potentially fatal threat to maintaining the critical mass of technically qualified practitioners needed to do advanced applications and sustain the health and relevance of MS/OR's academic infrastructure. Without such a critical mass, these observers say, MS/OR is doomed to sterility.

• A corollary of the previous point is that the educational preparation of Master's-level practitioners needs to be changed if demand is to be satisfied. This was identified in MSR (1986) as the number two problem facing the profession. Another corollary is that the industrial market for MS/OR Ph.D.s has become more concentrated in industrial research laboratories and consulting firms.

• First-generation decentralized practitioners may not regenerate themselves. For several reasons, it is much easier for an MS/OR person to move into a dispersed position from an organized MS/OR group than directly from school at the entry level. It follows that the population of MS/OR people in dispersed positions will tend to diminish with the attrition of those who got there by being decentralized.

• Dispersion tends to cause good people to leave the profession to the extent that they like to work with other good people with similar interests (Ranyard 1989).

Consequences for the MS/OR Professional. There are two important ones:

1. Be realistic about where most industrial MS/OR jobs are: in dispersed positions rather than in organized MS/OR groups. If you are a practitioner, this has strong implications for your choice of educational and professional development investments.
2. Be a perpetual student of the causes of unwanted dispersion, and try to become invulnerable.

There may be lessons to be learned from one of MS/OR's neighbors, MIS, which also has been experiencing pressures in the direction of dispersion. One such pressure arises from the *downsizing* trend. The most militant form of downsizing advocates replacing most large computers by networks of small ones, while a more benign form is content to encourage the migration of many applications from mainframes and minicomputers to networked microcomputers. Even the benign form is a threat to centralized MIS. Consider this statement by the system architecture manager of a manufacturing company:

> [Downsizing will] radically affect the end user. Not only are we changing the hardware, but we're changing our philosophy of what DP is. Our strategy is to eliminate the central [MIS] staff as we know it today. There will probably be more programmers than ever, but they will be working in the end-user departments or at the divisional level, not at the corporate level (Ryan 1991, p. 232).

Does this sound familiar? Note that there are also pressures in the direction of upsizing and centralization (e.g., von Simson 1990), some of which may have parallels for MS/OR.

The Theory-Oriented Academic Reward Structure

Two facts conspire to create a powerful force on the academic development of MS/OR. First, a sufficient number of publications in top journals like those of ORSA and TIMS is a necessary condition for appointment and promotion at nearly all research-oriented schools. Second, theoretical contribution has come to be the most reliable publishability criterion by far for the top journals. It follows that Ph.D. students and young academics at research-oriented schools feel obliged to make theoretical research their top priority, and they do.

Given this situation, and the fact that teaching is the only other appointment/promotion criterion that can approach research in importance, is it any wonder that few academics choose to make a priority of integrative or applied work? Yet widespread, successful practical application of MS/OR is the only real justification for academic MS/OR programs in the first place.

Next to the stimulation provided by real applications, I consider this force to have been the dominant one shaping the evolution of MS/OR in academia, just as the previous force (dispersal) has been the dominant one outside of academia.

This force is not unique to MS/OR. Many of the nation's research universities exhibit similar symptoms to a greater or lesser extent in many other fields.

There has been active discussion at some institutions of possible remedial actions. My own university, for example, has just launched a university-wide debate on this and related issues, which have been nicely crystallized in Pister et al. (1991).

Consequences for MS/OR. There are a number that are important:

- MS/OR now has an awesome theoretical base, and there is a plentiful supply of fine theoreticians.
- The preoccupation of academia with theory sometimes results in excellent work that strengthens the foundations of MS/OR for decades to come (witness most of the contributions recognized by the Lanchester and von Neumann prizes). But more often, the result is work that is highly incremental or so specialized that eventual application is unlikely. In the words of a recent review panel (ORSA 1991), "... much of what is published is apparently never again applied or built upon. This results in wasted pages and spurious signals to promotion committees, and it fogs the image of our field to outsiders." Peter Keen, not known for veiling his views, puts it more strongly:

> The theory is largely weak, the research is mediocre and far too confined in themes and methods, and most of the publications are mediocre. ... Ten years ago, MS owned both the intellectual and technical base of the field. It has lost the technical base and has seen the intellectual base trivialized and disregarded. The key for me is re-establishing the message that MS represents a powerful approach to problem definition and problem solving, showing that the approach is targeted to relevant problems, and demonstrating that MS professionals have the needed attitudes, listening skills, and respect for real decision makers needed to have an impact (Keen 1991).

In other words, rigor mania can lead to rigor mortis when relevance is neglected.

- MS/OR practitioners commonly complain that academia is not doing the kinds of things that could help them. For example, a preeminent practitioner who used to be an academic has said, "Too often, academicians are encouraged to spend their time on meaningless research by an outmoded tenure and reward system" (Cook 1990, p. 27). Such feelings may be widespread. One indication of this is that many practitioners judge even the leading MS/OR journals to be of little or no use (Bradbard et al.), although *Interfaces* is a conspicuous exception.
- Academic programs in MS/OR tend to become narrower and more specialized. Constantly expanding technical topics tend to crowd out studies of business and government, to the probable detriment of preparation for applied work.

Many academics join the practitioners in bemoaning the direction taken by academia over the last two decades or so. I have been among them on occasion. But such laments do not cut to the heart of the matter, which I believe to be this: *there is a fundamental mismatch between supply and demand for MS/OR technology.* Academia, largely decoupled from the economic fortunes of its practitioner constituency, has forged ahead and produced so far beyond the real-world demand for its intellectual product that its fruit appears to many to lack relevance. This situation is exacerbated by the dispersion of MS/OR in industry, which tends to obscure the visibility of most applications and bias them toward low technology.

How could this mismatch be reduced? The only obvious remedial steps are those aimed at: a) downsizing graduate academic programs in MS/OR, b) transforming the reward structure at some universities into one more friendly to integrative and applied work, and c) increasing the real-world demand for MS/OR technology. The third main section of this paper focuses on the last of these.

It bears pointing out that there may be a slightly devious way to accomplish much the same effect as b) without actually requiring universities to change at all: ORSA and TIMS could simply tilt their publication criteria in the direction of integrative and applied work. Additionally, the local culture of most academic MS/OR units can be changed in this direction if most of the influential members agree that this is appropriate and then *live* that belief.

Consequences for the MS/OR Professional. There are three important ones:

1. If you are a student, strive to balance the time you spend learning technical subjects and the time you spend learning about application contexts.
2. If you are in academia, spend some time doing challenging consulting. Do it for the stimulation, not the money. This experience will confer many benefits on your research and teaching, and will help to promote the health of your chosen profession. The proportion of time you spend doing teaching, research, consulting, and professional service can shift over the years, but do not wait too long before getting some consulting experience; it will stimulate new ideas and lead you to worthwhile research problems. Moreover, your publication record should benefit rather than suffer so long as you avoid routine consulting. A

second and perhaps equally important step that you can take is to give more attention to professional practice in the curriculum, including practical student projects in some courses and summer internships (Miser 1976, Bajgier et al. 1991).

3. If you are a practitioner, allocate part of your time to interactions with academia. Consider providing some incentives to academics to do applied work as a counterweight to the usual academic incentives.

MAJOR TRENDS

Of the important trends evident today in MS/OR (but only partly in response to the causative forces discussed in the previous section), this section discusses three: the rapid dissemination of MS/OR tools, the declining number of native-born students in MS/OR graduate programs, and the persisting management apathy toward MS/OR.

For each of these trends this section interprets the consequences, both for the profession as a whole and for the individual MS/OR worker.

Rapidly Disseminating MS/OR Tools

One of the consequences of the computer/communications revolution is an explosion of commercial activity in MS/OR-related software. It amounts to a massive new distribution channel for MS/OR technology. Consider:

- Tens of millions of spreadsheet installations exist, each offering quite general modeling capability. Spreadsheets have some important limitations for MS/OR applications, such as excessive focus on model instances to the exclusion of model classes, a limited range of mathematical solvers, poor maintainability, and awkward extensibility. But some of these limitations are gradually being lifted, and certain capabilities with great potential are emerging, such as automatic links between separate spreadsheets and between spreadsheets and powerful data base packages. By the end of 1991, Frontline Systems had shipped over a million copies of Lasdon and Waren's GRG2 linear and nonlinear optimization code modified to work with the leading spreadsheet packages. The version shipped also had rudimentary integer programming capability.
- LP packages, including some very good ones, have become a widely and inexpensively available "commodity." Llewellyn and Sharda (1990) list 37 packages for PC compatibles, and several more for workstations.
- Graphically oriented simulation packages have become widely available for microcomputers (e.g., Banks et al. 1991, Swain 1991). At one consulting firm, such packages came into such widespread use among their clients that some resources could be reallocated from basic to more advanced simulation support and to other consulting areas that have not yet achieved such wide client acceptance (Lucas 1991).
- Many nice microcomputer packages have become available for data visualization, decision analysis, expert systems, forecasting, Monte Carlo simulation, multiattribute choice over discrete alternatives, nonlinear optimization, project management, and data analysis/statistics. Announcements and reviews of such packages appear regularly in the *European Journal of Operational Research, OR/MS Today*, personal computer magazines, and elsewhere.
- A recent survey of software for logistics lists numerous microcomputer packages with modeling capability, including 90 for inventory planning and forecasting, 87 for traffic routing and scheduling, and 56 for physical distribution system modeling (CLM 1991a).

These observations show that, whether or not MS/OR professionals like it, give permission, or actively assist, many MS/OR tools are widely available to anyone with a modest budget. Fylstra (1991) calls this the "democratization of operations research." Others view it as vulgarization.

A companion trend is evident in the diffusion of MS/OR techniques into other disciplines and professions, as noted previously (e.g., actuarial science, applied mathematics, computer science, finance, industrial and other kinds of engineering, IS, logistics, marketing, and operations management).

MSR (1986) discussed the emergence of a mass market in MS/OR-related software. The 30 participants in that panel were about equally divided between viewing it as a "problem" versus as an "opportunity." A typical view from the first camp:

> Another aspect of the problem: spreadsheet packages cheapen our profession because untrained people claim to be doing "modeling." Most managers can't tell the difference, and so judge what MS/OR offers by those rudimentary and questionable examples.

A typical view from the second camp:

> There are advantages as well as dangers: we are relieved of routine applications; clients are better prepared as a result when they finally do come to a MS/OR specialist; and some users of these packages may be attracted to deeper involvement with MS/OR.

A third participant offered this constructive suggestion:

> We need to devise "migration paths" from simple, standard modeling applications to more complex ones. This begins with making sure that MS/OR software users a) know where to turn for help in their organizations, and b) understand the value added potential of MS/OR expertise.

There has been only limited discussion to date in MS/OR publications of the professional implications of the rapid commercialization of MS/OR software. For example, veteran observer Saul Gass urges steps to inform untrained users about the importance of always using these tools in the context of the model life-cycle process that he has articulated so well (Gass 1990).

My personal view is that, on balance, this trend is a good one. It enables our technology to have a much greater impact on the world and frees our energies to pioneer new technologies and new applications. There are indeed associated risks—poorly conceived and documented models, excessive emphasis on ease of use at the expense of functionality and deeply analytic thinking, loss of control over data used for decision making, and so on—but I see these as challenges to educators, trainers, and software designers that can be overcome through hard work. In any case, we have no responsible choice but to do what is necessary to ensure that this irreversible trend works to our advantage.

Consequences for MS/OR. There are many:

- Every organization, even the smallest, can now afford MS/OR software tools.
- The MS/OR community no longer has a monopoly on its technology, and so must share it gracefully or be bypassed.
- Among other things, graceful sharing means teaching nonspecialists how to evaluate commercially available MS/OR tools, and how to use them effectively. This mission seems appropriate for related non-MS/OR curricula as well, reaching all the way down to high school, where computerized models are increasingly used to motivate mathematics education.
- Huge numbers of people untrained in MS/OR are gaining access to its tools for the first time, and will a) have failures that will give MS/OR a bad name, b) have successes that will give MS/OR a good name, and c) become candidates for more serious MS/OR assistance at a later date.
- Some managers interpret the ready availability of MS/OR software as lessening the need for staff specialists in MS/OR. It would be prudent to marshal the arguments for why exactly the *opposite* is true.
- The profession's visibility/identity problem is exacerbated to the extent that disseminated tools are not identified with MS/OR, and are used by people from other specialties.
- The overemphasis of much MS/OR-related software on flashy user interfaces and ease of use tends to trivialize MS/OR's analytical approach. We need to combat this tendency.
- Microcomputer tools for MS/OR offer a practical way to enthrall and empower students in virtually all educational programs with an MS/OR component, from undergraduate through Ph.D. programs.
- There is a growing demand among MBA students for courses on how to evaluate and properly use microcomputer tools for decision analysis, optimization, project management, simulation, advanced spreadsheet modeling, and statistics. This demand is not limited to those whose interests are directed toward MS/OR.

Consequences for the MS/OR Professional. There are three important ones to note here:

1. Allocate some time to keeping up with the rapidly developing MS/OR-related software scene through magazines, review services, and other sources. Become familiar with a leading package in most of the major MS/OR-related software categories, and try to understand its proper uses and limitations within the context of established MS/OR theory. Retrain yourself periodically as the state-of-the-art moves forward. (Journal editors take note: there is, at present, a severe lack of substantive MS/OR-related software reviews.)
2. In addition to traditional publications, consider commercial software as an outlet for disseminating your contributions to MS/OR technology.
3. Accept the fact that this trend places a large burden on our community to help nonspecialists make proper use of MS/OR-related software and understand that there is a lot more to MS/OR than is evident in this software. Do your part to help.

Vanishing Natives

The title of this subsection is taken from a recent special section on science careers in *Science*, which identifies the shift from American to foreign-born science students and practicing scientists in the U.S. as one of the top 10 trends pertinent to career choice (*Science* 1991). Certainly this trend is also a strong one in most MS/OR graduate programs in the U.S.;

John White pointed out in last year's Omega Rho Lecture that "the number of U.S.-born graduates from MS/OR programs has steadily declined over the past decade" (White 1991, p. 184). MS/OR-specific statistics are not available, but the situation probably is similar to that in engineering and mathematics, where foreign citizens now earn about half of all Ph.D. degrees (NRC 1989, Pool 1990).

White points out that the influx of international students has been a blessing to MS/OR graduate programs, but betrays deficiencies in the U.S. educational system and places MS/OR in a vulnerable position with respect to its future supply of human resources.

The causes of this trend include the following:

- A declining U.S. educational system, competition from other exciting career alternatives, and perceptions of a poor MS/OR job market diminish the number of Americans who are prepared and motivated to pursue graduate education in MS/OR. See NRC (1989) for a discussion of these and other causal factors in the neighboring field of mathematics, where the absolute number of Ph.D. degrees awarded to U.S. citizens has fallen by about half since 1970. The loss of American students would have led to moribundity for many MS/OR programs were it not for the influx of large numbers of well prepared foreign-born students.
- The U.S. is very attractive to top students from other countries: Graduate MS/OR education here is as good as can be found anywhere in the world (especially at the Ph.D. level), U.S. degrees carry a premium in many countries, and the U.S. is still seen as a land of opportunity, especially in technical fields (which immigrants perceive to prize competence over communication skills).

These causes will be exacerbated during the 1990s by demographic factors. The well known baby boom maximized the number of citizens of graduate school age during the mid-1980s. The trend will be strongly downward through the 1990s before beginning to pick up again around the turn of the century. With a peak-to-valley ratio in excess of 1.4, this is not a small effect.

Consequences for MS/OR. The effects of this trend are mixed:

- Pending reversal of the first cause, MS/OR graduate programs must either downsize or maintain their populations by increasing the proportions of international students.
- Industry recruiters find it difficult to meet their needs from an increasingly foreign-born supply. There are three reasons for this. First, foreign-born Master of Science students usually need to be permanent residents, but few are. (More employers are willing to sponsor Ph.D. students.) Second, strong communication skills are at or near the top of most recruiters' list of requirements (Buckholz 1990, Hoffman 1991), but the proportion of foreign-born applicants who meet this requirement is considerably smaller than for U.S.-born candidates owing to language and (sometimes) cultural differences. Third, the emphasis that many international students place on technical studies necessarily exacts a price in terms of interest and preparation in business and the particulars of application domains.
- Foreign-born MS/OR professionals, with their language and cross-cultural skills, are a key resource for many MS/OR opportunities arising from the powerful trend toward economic globalization (Reich 1991).
- If our profession does not take vigorous steps to assure an ample supply of qualified human resources, then its future vitality will be jeopardized and it may be unable to exploit great opportunities like those to be discussed shortly. At least two remedial directions seem promising.

a. Correct inappropriately pessimistic perceptions concerning the MS/OR job market. For example, we know from the first section that perceptions based on the plight of organized industrial MS/OR groups are out of touch with the current reality of dispersed employment. Seldom is it easy to change long-standing perceptions, but for once MS/OR possesses something close to a quick fix in the form of an authoritative government report (BLS 1990) that pronounces "operations research analysts" the 10th fastest growing among *all* occupations in the 1990s! Faster than accounting, computer programming, engineering, financial management, health services management, management consulting, medicine, and more than 300 other occupations. Moreover, unpublished supporting tables (obtained for me by D. Samuelson) explain where that growth is expected to occur. This conclusion is also found in the *Occupational Outlook Quarterly* (OOQ 1990). These two publications deserve vigorous publicity because job-market perceptions influence graduate-student applications.

b. Make the attractions of MS/OR better known to U.S. high school students and undergraduates. The ORSA videotape is a good step in this direction. Cooperation with the mathematical and scientific communities may be fruitful, as they have an established presence throughout the educational system

and have succeeded in mobilizing a high level of visibility for the need to improve their infrastructure (e.g., NRC 1989).

Concerning the second point, I believe that overtures to the mathematical and scientific communities would be met warmly. One reason is that the (complete) list of topical areas "deserving greater emphasis" in NRC (1989) are: probability, exploratory data analysis, model-building, operations research, and discrete mathematics. And the widely noted report "Renewing U.S. Mathematics" (BMS 1990) explicitly defines statistics and operations research as part of the mathematical sciences, and includes the following topics on its list of 27 "recent research accomplishments and related opportunities": statistical methods for quality and productivity, mathematical economics, parallel algorithms, randomized algorithms, interior point methods for linear programming, and stochastic linear programming.

Consequences for the MS/OR Professional. Two important ones may be discerned:

1. If you are foreign-born, it is vitally important to perfect your language and other communication skills, especially if you are or wish to be a practitioner. This applies not only for entry, but also for advancement. You may take some consolation in the fact that many—perhaps most—native English speakers are poor communicators, especially on paper.
2. If you are foreign-born, consider international work, where your background is a special advantage.

Persisting Management Apathy Toward MS/OR

Most potential managerial clients have been exposed to MS/OR by now: CPMS's Edelman Competition has been uncovering and publicizing success stories for two decades; quantitative methods and statistics courses have been almost universally required by MBA programs for about three decades; and the industrial history of MS/OR is, for practical purposes, in its fifth decade. Given these facts and the obvious importance of MS/OR to management, it is natural to expect a high degree of management enthusiasm by now. Yet management is only marginally less indifferent to MS/OR today than it was decades ago. There are numerous notable exceptions, but only a small proportion of all senior managers recognize the wide applicability of MS/OR within their organizations and insist on strengthening their MS/OR infrastructure.

In other words, the trend is that there is little or *no* trend in the direction of diminished management apathy toward MS/OR. MSR (1986) rated this the number three problem (out of seven) facing the profession. It has numerous causes:

- The root cause, in my opinion, is that it is not the business of managers to be concerned with the power or potential of *any* discipline—whether it is MS/OR, economics, psychology, statistics, or any other field with important managerial applications. Rather, it is the business of managers to be concerned with the management of their businesses. Period.
- It is well known that the MS/OR approach tends to clash with the personal style of senior managers (e.g., Mintzberg 1973, Hammond 1974, Lilien 1987). Moreover, conventional wisdom has it that a personal dislike of mathematics and technical details is one of the reasons why people choose to become managers.
- Many MS/OR professionals communicate poorly. As several participants in MSR (1986) put it, "We have not communicated very well with senior managers. For example, we use too much jargon and do not know how to say *crisply* what we can do or have done."
- MS/OR has a visibility problem. The popular and business press largely ignore MS/OR, sadly even the great success stories. Thus, the management community receives very little external confirmation of MS/OR's worth in the normal course of their reading.
- In some cases, managers fall prey to misunderstandings about MS/OR. One is the belief that the increased complexity of today's problems renders them less amenable to modeling and the simplistic assumptions commonly associated with modeling (independence, linearity, normality, stationarity, steady state, etc.). Another is the belief that the rapidly falling cost of computation now enables problems to be overwhelmed with computer power, thereby rendering MS/OR's elegant approaches less essential than previously. BMS (1990) mentions a similar misunderstanding in the context of the need for mathematics.

I conclude from the first two causes that management will continue indefinitely to be more apathetic toward MS/OR, on average, than we would like. Moreover, I cannot fault the rationality of this posture. Of course, this is not to deny the temporary bursts of interest that can occur in the wake of rare events—like the one triggered by N. Karmarkar—which happen to be picked up by the mass media.

To be fair, I must note that there are astute observers of the MS/OR scene who take a somewhat more sanguine view. Among the most articulate of these is

Harvey Wagner, who believes that:

> . . . the concepts and vocabulary of operations research have become a pervasive part of the thinking of modern American industrial managers . . . many executives throughout the typical large business organization understand the underlying concepts of formal model analysis and make constant use of this language. . . . The progress to watch for in the next 10 years . . . will be evident in the growing and continuing successes of general managers who are making consistent and effective strategic use of formal operations research models (Wagner, pp. 797, 803).

Consequences for MS/OR. There are at least two:

- The MS/OR community can stop hoping for a major management demand pull to materialize. We must accept responsibility for creating our own demand, as by becoming indispensable for important organizational functions or by doing the kinds of things mentioned in the next section.
- Educators should consider intensifying their efforts to provide a better appreciation of MS/OR to students who may be future clients. For example, they could integrate MS/OR material into more non-MS/OR courses in MBA programs, especially the functionally oriented ones like accounting, finance, and marketing. (This is a thankless task at many schools, however, so new incentives will be needed before much more of this will be done.) They could be more aggressive about exposing students to Edelman finalist papers and other outstanding applications. And they could specifically target common management misunderstandings like the ones mentioned in the last cause listed above.

Consequences for the MS/OR Professional. The most important one is to learn how to market MS/OR's capabilities in the context of organizational needs. This involves pondering what MS/OR has to offer in various situations, collecting MS/OR success stories, being a student of organizational behavior, and studying the ways of master practitioners and teachers.

This completes my survey of the main forces and trends as I see them. They provide an essential context for understanding MS/OR's opportunities, to which I now turn.

OPPORTUNITIES

Of the major opportunities facing MS/OR today, I have selected five for recommendation here: ride the computer/communications revolution, support dispersed practitioners, focus on the service sector, stress embedded applications, and go into the quality business. None is in conflict with any of the major forces and trends discussed in the preceding two sections, and most draw strength from them.

The orientation adopted here slants toward the practice of MS/OR because that is the fountainhead of the profession's future vitality. See CONDOR (1988) for a discussion more concerned with theoretical research opportunities.

Ride the Computer/Communications Revolution

Because microcomputers and communications facilities are among the main physical tools of MS/OR, and because MS/OR provides so many opportunities to make good use of them, the computer/communications revolution is an exceedingly powerful engine for the progress and acceptance of MS/OR.

Taking advantage of this engine requires MS/OR professionals to a) maintain an up-to-date understanding of computer/communications technologies, b) be imaginative and aggressive about opportunities to apply these technologies, both to MS/OR work proper and to organizations, and c) become closely identified in the minds of potential MS/OR clients with innovative and truly productive uses of computer/communications technology, and with the ability to add value to all sorts of data through model-based analysis. These are, to some extent, a natural by-product of normal MS/OR activity, but I am proposing that we do these things to a greater degree, and more deliberately, than would be the case if we were not consciously trying to take full advantage of the computer/communications revolution.

The last two require a generous measure of inspiration. It is difficult to plan for inspiration, but there do exist plannable activities that can lay the groundwork for success and perhaps even stimulate inspiration to some extent. These include:

- Establishing an evaluation, recommendation, and training program for useful commercial MS/OR software suitable for end users in such areas as decision analysis, optimization, project management, simulation, advanced spreadsheet modeling, and statistics. This is necessary anyway in response to the rapid dissemination of MS/OR tools as discussed earlier, and it helps acquaint practitioners with the current concerns of end users.
- Promoting advanced workstations and enterprise networking (as discussed in the first section's treatment of the communications revolution).
- Periodically scanning new information technologies for applicability, preferably with an embedded MS/OR component.

• Offering to help re-engineer business processes, especially when this involves significant amounts of information technology (Hammer 1990).

• Helping Information Systems people assimilate better decision technology. IS needs the analytical approach of MS/OR to turn data into information and information into the knowledge and insights required for improved decision making; IS and MS/OR each have much to gain from close working relations, both in academia and in industry.

Riding the computer/communications revolution was by far the number one opportunity identified in MSR (1986), and is so widely appreciated that there is little need to expand upon it here.

Support Dispersed Practitioners

As we saw in the first section, most MS/OR practitioners today are dispersed throughout their organizations. They work in engineering, finance, information systems, logistics, manufacturing, marketing, planning, scheduling, services, and many other areas. Yet it seems that only a small percentage of these practitioners—perhaps as few as 10%—ever come to ORSA/TIMS meetings or read the societies' journals; the rest are, for all practical purposes, isolated from the mainstream MS/OR community.

This isolation is at once a great misfortune and a great opportunity for our profession. I believe that dispersed practitioners would become significantly more effective if they could easily network with one another and with the mainstream, have access to the news and literature of the field, and attend professional development events from time to time. This increased effectiveness should, in turn, translate into much more of the one thing that controls the ultimate destiny of MS/OR: positive impact on the real world. Therefore, the MS/OR community and its infrastructure would be well advised to reorient itself much more toward the needs of dispersed practitioners.

The Role of the Societies. ORSA and TIMS have an important role to play in catalyzing such a reorientation. More than that, I would say that they cannot pronounce themselves truly successful professional societies until they find a way to represent the interests of more than a tiny minority of all professionals doing work related to MS/OR. This would seem to require that the societies a) sponsor an in-depth study to confirm the estimates of BLS (1990), and to probe the reasons for and consequences of decentralization and the other mechanisms of dispersion, b) find out how the needs of dispersed practitioners differ from those in organized groups, c) redesign existing ORSA and TIMS services and create new ones to better meet these needs, and d) undertake an ambitious membership drive among dispersed practitioners. Extensive consultation with dispersed practitioners themselves will be necessary at each step. Such a project has the potential to be epoch-making, and would offer the possibility of greatly increasing ORSA and TIMS membership for the first time in 20 years.

If this project is undertaken, it would be wise to cast it in a broader perspective by simultaneously studying the total MS/OR job market in detail. Presently the job market is poorly understood, partly because of the effects of dispersion, with no comprehensive, generally available statistics or interpretive analyses beyond the remarkable Bureau of Labor Statistics report mentioned earlier (BLS 1990). A first step might be to segment the job market into submarkets. Employment data could be gathered, analyzed for trends and career patterns by submarket, and made available publicly in summary form on an annual basis. This would be a valuable service to graduating students, professionals seeking better work, employers, and educational program designers. Some neighboring fields, like computer science, have had such a service for many years (Gries and Marsh 1992; see also Jarvenpaa, Ives and Davis 1991).

Not only is the need great for ORSA and TIMS to support dispersed practitioners in new ways, but the communications revolution makes this mission much less daunting than it would have been in the past. E-mail, enterprise networking, fax, voice mail, and other capabilities make it easier every year for dispersed practitioners to be in touch with counterparts elsewhere in their organization, and with their users and clients. Their work style is becoming more communications oriented.

Consequently, the time may be right to launch a bold new service specifically for dispersed practitioners: a national network that aims to help them become more effective in their jobs, and to make them an integral part of the MS/OR community from which they are now largely estranged. Participating in a well designed network should be accepted as a natural step by many of them, and ought not to be technically difficult in most cases.

ORSA and TIMS could design and operate such a network. It could offer a variety of useful services such as direct contact with others in all walks of the profession, downloadable software (commercial and otherwise), focused discussion groups, software reviews and surveys, information sources, interactive magazines, notices of meetings, and on-line newsletters and reports. Since dispersed practitioners tend to be strongly

focused on the needs of their organizations, it may be desirable for some services to be industry-specific.

The Role of Universities. To support dispersed practitioners, an important step would be to increase the amount of functional training in MS/OR degree programs. For example, schools of management could increase the number of MBA courses in their Master of Science programs at the expense, presumably, of more specialized training. More generally, to the extent that they wish to train dispersed practitioners, MS/OR curricula also need to develop more realistic teaching materials, develop links to other curricula whose graduates can benefit from MS/OR, stay abreast of rapidly changing industrial technology, stress fundamentals and the techniques most valuable in practice, give serious attention to every step of the modeling life-cycle, teach how to evaluate and properly use the kinds of commercial MS/OR software on which dispersed practitioners largely depend, and give more attention to the interpersonal and other skills needed to succeed as practitioners.

Another useful step would be for universities to offer professional development seminars and courses specifically for dispersed practitioners, possibly on an industry-specific basis.

In summary, I believe that reorienting the academic and professional society components of MS/OR's infrastructure toward the needs of dispersed practitioners has the potential to profoundly improve the evolutionary path of our profession.

Focus on the Service Sector

It is well known that the U.S. economy has been restructuring itself for several decades toward services at the expense of goods production. Industries like automobiles, petroleum, primary metals, and textiles have been shrinking while banking, business services, health services, insurance, public utilities, transportation, and other service industries have been expanding.

Growth of the Service Sector. In the early 1950s, these two sectors had about equal shares of the gross national product. By 1974, services were half again as large as goods production, and by 1986 it was twice as large. The trend continues, with services today about $3 trillion/year. Moreover, a similar shift has been occurring in other industrialized economies. (In all cases, I exclude the government component of GNP and take my figures from Bush 1991.)

The emergence of the service sector looks roughly the same in terms of nongovernment employment. In 1988 there were 2.2 people employed in services for every person employed producing goods, and the ratio is forecast to increase to 2.7 by the year 2000 (BLS 1990). If government employment is included in services, the ratios become 2.8 and 3.3.

The new dominance of the service sector is not only a national economic fact. It is also a reality for our profession: the Bureau of Labor Statistics forecasts 6 new jobs for operations research analysts in this sector for every one in the goods-producing sector between 1988 and 2000 (BLS 1990)!

MS/OR's Response. Has the MS/OR community been giving an adequate share of its attention to services in recent years? My attempts to answer this question suggest a curious schism within the profession: service seems to be grossly underrepresented relative to goods-production in academia, but it seems to be only modestly underrepresented if at all in industry.

Some evidence relating to academia:

- During the last 3 years, the orientation of submissions to *Operations Research* has run roughly 6:1, goods-production over services. Comparable statistics are not available for *Management Science*, but my inquiries there give no cause to hope that the balance is any better.
- A survey of MBA courses at 20 leading schools (Carraway and Freeland 1989) found that 90% of the schools have an elective course in production and inventory systems, whereas only half that number have one in service systems; yet service is much more popular as an elective than production. Material on service was found to have increased during the 1980s in required operations management courses, but the amount of attention devoted to this topic is still small compared with more traditional topics related to production.
- The most recent (November 1991) ORSA/TIMS Joint National Meeting had more than twice as many sessions clearly relating to production as sessions relating to service. I assume that this is typical for these semiannual events, which mainly cater to academia.

In addition, it is my impression of MS/OR textbooks that the goods-producing sector, rather than services, provides the dominant context for the material presented.

Quite a different picture emerges when one examines industry:

- The finalist papers of recent Edelman competitions (the last four) favor service over production,

18 to 10. This suggests that the service sector may be receiving its just share of high-impact MS/OR applications.

- According to the U.S. Department of Labor, the number of Operations Research Analysts employed in the service sector in 1988 was about 2.9 times as large as in the goods-producing sector (BLS 1990). Moreover, this ratio is forecast to rise to 3.7 by the year 2000 because the expected employment growth rate for operations research analysts is twice as high in the service sector. These ratios are significantly larger than what one would expect based on a pro rata share of total employment in the two sectors, which indicates that MS/OR's penetration is highest in the service sector.
- Morgan (1989) reports that none of the 15 industry surveys reviewed provide any conclusive evidence that the service sector uses MS/OR proportionally more or less than the goods-producing sector does. (An earlier survey by The Conference Board—PoKempner 1977—did find a bias: 40% of the responding companies in the production sector had MS/OR groups, whereas only 29% of those in the service sector did.)

I conclude from this and other evidence that, although the service sector deserves about twice as much attention as the goods-producing sector does, it is getting nowhere near that level of attention in academia. The situation looks considerably better outside of academia, but there is still room for improvement.

MS/OR's Opportunity. Could it be that lack of opportunity accounts for MS/OR's underemphasis on research, teaching, and possibly practice in the service sector? I seriously doubt it, based on what I know of the service industries and the high-impact work reported in recent Edelman finalist papers. To say nothing of opportunities at all levels of government, for which much greater efficiency is essential if high expectations for public services are ever to be reconciled with structural budgetary woes. Others in a position to know agree (e.g., Larson 1988).

A tangible indication of MS/OR opportunities in the service sector is the fact that, in the aggregate, productivity has stagnated there since the early 1970s while productivity in the goods-producing sector has continued to rise steadily (Harker 1991, Roach 1991). This is in spite of the service sector's massive investment in information technology (IT): it now owns about 85% of the installed IT base (Roach). Clearly there is a ripe opportunity for MS/OR to boost productivity, perhaps partly by helping to put all that IT to better use. Roach argues that service organizations need better measures of productivity and service quality, and improved activity-based managerial accounting, before proper remedies for productivity stagnation can be found. To an MS/OR person, this is a clarion call for modeling. See Harker for further discussion of MS/OR's potential to improve productivity in the service sector.

Another indication of opportunities for MS/OR in the service sector has just surfaced in a book-length study done for the Council of Logistics Management (CLM 1991b). This study argues that logistics, broadly defined, is as critical to success in the service sector as it is in the goods-producing sector. Moreover, the study concludes that logistics techniques and skills are highly transferable between these sectors, and yet have barely begun to be used. Although I must discount the very last assertion, the study nevertheless poses a provocative challenge to the MS/OR community.

The study estimates that the service sector spends about 75% of its operating costs on logistics-related processes. It observes that, if logistics improvements in service can reach the level achieved in goods-production during the last decade, the savings potential is about $200 billion per year. A significant part of that savings potential could be within reach of MS/OR.

To understand the role of MS/OR in helping to achieve this potential, it is necessary to distinguish between *supply chain logistics* and *service response logistics*. The former has to do with the acquisition and distribution of goods: purchasing, transportation, inventory control, materials handling, manufacturing, distribution, and related functions. The latter has to do with "the process of coordinating nonmaterial activities necessary to the fulfillment of the service in a cost- and customer service-effective way" (CLM 1991b): anticipating customer needs, planning and acquiring service network capacity, and operating the network to fulfill customer requests.

There is a considerable amount of supply chain logistics going on in many service organizations, but usually this is dwarfed by service response logistics. The applicability of MS/OR to supply chain logistics is established in every basic text on MS/OR. Applicability to service response logistics is less strongly emphasized, but it is plain that many applications are possible; for example:

- forecasting models can anticipate customer demands for service;

- inventory models can be adapted to service network capacity management, where too little capacity results in lost service opportunities and too much results in excessive costs;
- location models can optimize the placement of service facilities;
- optimization models can produce cost/service tradeoff curves and allocate resources to facilities, equipment, and other components of the service-providing infrastructure;
- queueing models can facilitate managing waiting times at service facilities;
- simulation and other models are useful for workflow re-engineering;
- work force planning and scheduling models can improve personnel management.

Not only is MS/OR applicable, but the service sector seems to be receptive to MS/OR techniques. The CLM (1991b) survey of banks, high-tech field service organizations, hospitals, and telephone companies revealed that about ⅔ of those who had an opinion believe that mathematical and statistical models and decision-support and expert-system applications will become more important and useful in the next few years. The number who thought they would be *less* so was negligible. Fully 72% of the respondents ventured an opinion in the case of mathematical and statistical models, but only 32% did so in the case of decision support and expert systems, a disparity that may be turned to the advantage of MS/OR.

Thus, it appears that there are ample potential rewards awaiting the MS/OR community if it were to focus a much larger share of its attention on the service sector.

Shifting the MS/OR Focus. What could be done to bring about such a shift of focus?

A good part of the answer lies with the universities, since research and teaching seem to be lagging far more than actual practice. Curricula and teaching materials need to be revised to reflect the ascendancy of the service sector. R.P.I.'s new Center for Services Sector Research and Education, and Wharton's Fishman-Davidson Center for the Study of the Service Sector, apparently are the only two organized centers in the U.S. that focus on service and have a significant MS/OR emphasis.

Another part of the answer lies with the agencies and foundations that sponsor research. By comparison with manufacturing, relatively little support is available for service-oriented research. A few funding initiatives in this area could do much to capture academia's attention.

ORSA and TIMS also could do much to promote the reorientation of MS/OR in the direction of service:

1. They could develop curriculum guidelines for achieving a more balanced emphasis between the production and service sectors. To accelerate the pace of change, this could be followed up with commissions or competitions for service-oriented teaching materials.
2. They could sponsor meetings and publications that focus on service. A newsletter, or even a dedicated section in *OR/MS Today*, would be a good start.
3. They could give special nurturing to service-related ORSA technical sections and special interest groups and TIMS colleges, forming new ones where good opportunities exist.
4. They could lobby research-sponsoring agencies and foundations for new programs and initiatives focusing on service.
5. They could commission a study to follow up on CLM (1991b) from the MS/OR viewpoint. The aim would be to assess the potential role of MS/OR in capturing the huge benefits claimed in that report for the concerted application of logistics skills and techniques to the service sector, and to prescribe specific steps by which this role could be realized.
6. They could seek to cooperate directly with the Council of Logistics Management, the 6,000-member professional society that sponsored CLM (1991b), on joint actions that would strengthen the service sector role of logistics as a functional area and of MS/OR as a technical approach.
7. They could make the service sector a specific target for TIMS' public relations effort in the future. Trade and professional associations that cater to the service sector could assist in spreading the word if we can convince them of MS/OR's potential contributions.

Optimal allocation of resources is supposed to be a specialty of MS/OR. Let us not be guilty of grossly misallocating our academic and professional-society resources.

Stress Embedded Applications

An embedded MS/OR application is a model and its solver, or a derivative thereof, installed as an integral part of a functional host of some sort—such as a business process, an information systems application program, a scheduling procedure, process control software, or even a homogeneous group of front line

workers or a controller for a machine, appliance, instrument, or other device. The application may execute model-based computations automatically with the most current data whenever its host performs its function. Alternatively, an embedded application may permit a considerable degree of discretion as to *how* it is used (as distinct from *whether* it is used), especially if there are many intended users.

The antithesis of an embedded application is the one-shot project, such as a decision analysis of a regulatory issue or a simulation of a proposed factory automation project. Whereas each one-shot project must be sold individually, an embedded application need not be, in the sense of MS/OR technology uses per sale. Once in place, its runs routinely and is no more vulnerable than its host function is to budget cuts, the departure of a management champion, organizational flattening, or staff headcount reductions (the scourges of organized MS/OR groups for the last quarter century). Moreover, embedded applications tend to keep MS/OR people in touch with the host process through periodic maintenance and enhancement activities.

Examples. The use of linear programming for gasoline blending is one of the oldest and best known examples of an embedded MS/OR application (e.g., DeWitt et al. 1989). Other examples are: capital program management at GTE (Bradley et al. 1986), crew scheduling and yield management at American Airlines (Anbil et al. 1991, Smith, Leimkuhler and Darrow 1991), production planning and control of slab casters at Bethlehem Steel (Vasko et al. 1989), real-time vehicle dispatch at Mobil Oil (Brown et al. 1987), and thermal and hydro-unit commitment at SCS (Erwin et al. 1991).

John Little gives an appealing vision of embedded applications that empower particular classes of workers. He sees important opportunities of this sort emerging

> ... from the idea of empowering the organizational front line. Classically we have built systems for end users largely as extensions of ourselves; in other words, we solve the problem and deliver the solution to others. A different goal is to give people systems with which they can create their own solutions to problems. We can boost industrial productivity by developing such tools for the salespeople, the telephone operators, and the factory workers. In particular, if we can give them the continuous means to monitor, understand, and improve their own performance, real gains will follow (Little, p. 541).

Among the examples he offers is "fact-based selling" systems for a sales force. Notebook computers, the mass deployment of which began in 1991, provide a good platform for such applications.

Little's vision can be viewed as the decision support system (DSS) concept applied on a massive scale. Most existing DSSs would not be thought of as an embedded MS/OR application, even when they contain models and solvers, because they need not be used on a regular basis. But it *is* appropriate to think of a DSS as embedded when it is used by all or nearly all of some category of front line workers.

Opportunities for embedded applications have never been better, thanks in substantial part to the computer/communications revolution; once a business function is sufficiently computerized, it becomes ripe for improvement via embedded decision technology. For proof, one need look no farther than American Airlines Decision Technologies, which has built its spectacular five-fold growth during the last three years largely on embedded applications in the service sector (Cook 1991).

A fairly new opportunity for embedded applications arises from the proliferation of microchips and microprocessors in all manner of devices. A familiar example is provided by automobiles, which have had embedded microprocessors for engine control since 1977 to optimize spark firing, ignition timing, and fuel-injection (Minchillo 1991). Today's Nissan Infiniti Q45 has 14 separate computer modules controlling the adjustable suspension, antilock braking, engine, power steering, security system, transmission, and more. The Cadillac Allante has a true local area network linking most of its 22 microprocessors in place of the usual thick wiring harnesses. In a few years, GM cars will contain a 32-bit chip based on the Motorola 68020, which is the heart of a Macintosh II. With the equivalent of a Mac II, a local area network, and at least one transceiver in the vehicle of the future, opportunities for embedded mobile MS/OR technology abound (Spreitzer 1989).

Hardware Applications. One usually thinks of an embedded MS/OR application as being embodied in software. But it can also be embodied in hardware, such as a microchip that implements decision logic. This is becoming increasingly practical as small volume integrated circuit design and fabrication technology improves, and as microchips keep finding new uses in appliances, instruments, machines, and other devices. I believe that great potential now exists to put MS/OR technology into such objects to enhance their usefulness.

This has already begun to occur. For example, a heuristic for finding good hole-drilling sequences for

printed circuit board manufacture has been put on a microchip and sold commercially in programmable drilling machine controllers (Larson 1988).

The most spectacular examples are provided by various products introduced in Japan, starting early in 1990. There is already a billion dollar market there for consumer and industrial products incorporating fuzzy logic chips, and one forecast has the market going to $15 billion by 1995 (JT 1991). Matsushita, Mitsubishi, Sanyo, Sharp, Sony, and others have brought out new products in dozens of different categories, and they are selling extremely well in Japan.

To mention just two of these products: you can buy a fuzzy logic air conditioner with 24% better energy efficiency, and a fuzzy logic elevator that reduces average waiting times by 15–20% and greater-than-one-minute waiting times by 30–40% (Armstrong and Gross 1990). There are chip makers specializing in fuzzy logic chips, more than 2,000 patents have been issued in Japan, and the Japanese government is subsidizing a Laboratory for International Fuzzy Engineering Research at a level of $70 million for five years (Armstrong and Gross 1990, Williams 1991).

I mention these remarkable developments not to promote more work in fuzzy logic by our community, but rather to indicate the magnitude of the impact that could possibly be made by embedding MS/OR applications into consumer and industrial products. The Japanese boom in fuzzy logic products is based largely on fuzzy if-then rule sets with no explicit analytical model in the traditional MS/OR sense. The next step might well be to *use model-based decision technologies to improve product performance even more, and to provide entirely new functionalities.* If such a step could be taken successfully, it would be difficult to imagine any other development that could make a greater contribution to MS/OR's visibility or to its impact on the national economy.

It has been argued that computers will truly have reached their zenith when they have been embedded so subtly and so ubiquitously in everyday objects that most people will cease to be aware of them; they will be aware of their protean functionalities as embodied by the computerized objects (Weiser 1991). Similar arguments could be made that MS/OR applications will have reached their zenith when they have been embedded so deeply in everyday processes and objects that most managers and employees cease to be aware of them even though they may encounter them often each day; people will be aware only of their functionalities as embodied by the processes they facilitate and the objects they vitalize.

Risks and Benefits. Embedded applications present important opportunities for MS/OR, but they also involve some risks. One that has been recognized for many years is that MS/OR can be embedded so successfully that MS/OR's role in achieving the success will be soon forgotten. Hoffman (1975) identified this as a difficulty with respect to middle management operational decision processes at Standard Oil. He saw this occur with statistical forecasting models, inventory control models, and many kinds of LP applications, with IS taking these over. PoKempner (1977) also recognized this risk, calling it an "into-the-woodwork syndrome" that can make MS/OR a victim of its own success.

Thus, an important part of doing embedded applications successfully is to take steps aimed at retaining indefinitely an explicit connection to MS/OR. This seems like the professionally responsible thing to do anyway, except when there is another technically qualified group well suited to long-term oversight. Then it may be appropriate to spin off the application. Note that this is one of the ways in which MS/OR dispersion can occur.

I hope that the reader will not mistake my enthusiasm for embedded applications as implying any disapproval for other kinds of applications. My main intent is to make the point that there is a high-leverage, if somewhat less heroic, way to succeed with MS/OR in addition to the stereotypical one that most of us lust after: doing a large project with high-level sponsorship that leads to compelling recommendations with huge verifiable savings.

Go Into the Quality Business

The quality movement is still very much on the upswing in U.S. industry, after its storied successes in Japan. Originally centered in manufacturing, service organizations have bought into quality in a big way: in a recent survey of more than 200 service organizations, ⅔ reported that they have formal quality programs (CLM 1991b). Informal discussions confirm that interest in quality is growing rapidly in the service sector, a trend that helps to connect this opportunity to one discussed previously.

The quality movement heavily emphasizes cultural changes for managers and workers, but it still has a strong statistical orientation. For example, there are elements of statistical quality control in about 80% of the examination items for the coveted Malcolm Baldridge Award (Valenzuela 1990). Drucker (1990) argues that statistical quality control is one of the four keys to a successful manufacturing business.

MS/OR Opportunities. Since the quality movement is so vigorous and makes such extensive use of statistics, it is only natural that MS/OR practitioners should consider getting involved. Some have, with handsome success at some companies (e.g., Valenzuela 1990, Albers 1991, Lucas 1991, Schwartz 1991). Others have tried to move into quality without success.

Two observations are pertinent to the issue of MS/OR moving into quality. First, conventional approaches to quality lead most employers to strongly prefer statistical over MS/OR training. Unfortunately, statistical techniques have received decreasing emphasis in many MS/OR educational programs over the last couple of decades. The time has come for the pendulum to swing back.

Second, there is controversy within the MS/OR community about whether quality should be viewed as a legitimate domain for MS/OR. Some believe that the quality movement is too mundane in technical content, and contains too large a component of cultural intervention and faddishness. Others believe that modern MS/OR technology can be adapted usefully to this purpose, and that MS/OR professionals are obliged to help their organizations even for applications that might turn out to be technically routine or to require cultural reform. The former view seems more commonly found in academia than in industry, but I join the second camp. MS/OR professionals are well equipped to build models and help design processes that focus on quality as a key objective.

Those who are concerned about the apparent lack of technical challenges may take heart from the Board on Mathematical Sciences report which, as noted earlier, placed "statistical methods for quality and productivity" on its honor role of 27 "recent research accomplishments and related opportunities" (BMS 1990). It discusses four subareas: statistical process control, statistical experimental design, reliability, and acceptance sampling. Additionally, modeling the interplay of cost and quality can be technically challenging as well as of great practical importance (Cook 1991).

Educational Opportunities. A prerequisite for MS/OR to participate meaningfully in the quality movement is much greater attention to quality topics in MS/OR curricula at all levels. The time for this has long been ripe, but progress has been disappointingly slow.

Operations management courses and curricula have been adding material and courses on quality in recent years. According to Carraway and Freeland, 30% of the 20 leading MBA programs surveyed now have an elective course on quality, and 90% of all required operations management courses now cover aspects of quality. However, elective courses on quality, most of which were added to curricula fairly recently, are among the least popular electives (might this be a reflection of faculty attitudes?). And there is no indication that quality is being covered in MS/OR courses at the MBA level, an impression confirmed by perusal of popular introductory MS/OR texts.

A more recent survey of teaching and research in quality within business schools in general and operations management in particular reveals a situation regarded by some as scandalous (Kaplan 1991). For example: at "top twenty" schools, an average of only 12% of available class time in introductory operations management courses is spent on quality; and there were no articles at all on quality in the 1990 crop of 278 articles in *Management Science*, *Journal of Manufacturing and Operations Management*, *Journal of Operations Management*, and *Operations Research*. Kaplan concludes that

> ... business schools completely missed the quality revolution in management. ... While businesses throughout this country and the rest of the world have mobilized their entire organizations on quality, business school professors are still wondering whether quality improvement creates value for organizations, whether research on quality is legitimate for them to do, and whether they will get recognition and be rewarded for performing such research (Kaplan, pp. 19–20).

Yet major progress is being made at a few schools (Roberts 1991).

Opportunities for the Professional Societies. Universities may have been slow to recognize the quality revolution, but professional societies need not be. ORSA and TIMS could be taking a proactive role. Unfortunately, there has been little or no attention as yet to quality opportunities at the council level of either society, but grass roots momentum may be building. For example, there were 15 sessions on quality at the Fall 1991 ORSA/TIMS meeting compared with 2 five years ago and zero ten years ago; the Management Science Roundtable made quality a theme of several recent meetings, with the general conclusion that important opportunities await MS/OR professionals who choose to work in this area; and CPMS included several sessions on quality at its 1991 Summer Conference, with a similar conclusion.

One of the best steps that ORSA and TIMS could make at this time would be to offer their cooperation to the Leadership Steering Committee of The Total

Quality Forum. The mission of this top-level group is to take the quality revolution to universities because "... academic institutions that are slow to embrace TQM, at best, miss the opportunity to lead change and, at worst, run the risk of becoming less relevant to the business world" (Akers et al. 1991, p. 94).

General. The MS/OR community may have a lot of catching up to do in order to be truly useful to management in its quest for quality, but there is no reason why we need to think small. Our objective need not be simply to go from dragging our feet to pulling our weight. Our objective could be as ambitious as *making new model-based approaches the basis for a new phase of the quality revolution.* Such approaches can advance quality goals via models that inform quality measurement, that lay bare the web of influences on quality, and that drive or constrain on quality measures.

An MS/OR campaign in the quality area would be strongly synergistic with efforts to exploit the previous four opportunities, all of which point toward front line workers, who are at the very center of the quality revolution. Specifically: microcomputers and telecommunications empower the front line, dispersed practitioners are closer to the front line than organized MS/OR groups are, the service sector is traditionally more oriented toward front line workers than the goods-producing sector is, and embedded MS/OR applications tend to be closer to the front line than nonembedded applications are.

This concludes my survey of some of MS/OR's great opportunities to flourish.

CONCLUSION

My aim in writing this paper was to identify what appeared to me to be the most influential forces acting on MS/OR, the most important current trends, and some highly promising opportunities for the profession to flourish in the future in light of these realities. There are bound to be differences of opinion about my choices of forces, trends, and opportunities. I hope that others will see fit not only to comment on my choices but also to develop other topics for the MS/OR community to consider.

Some of the topics that I considered but chose not to develop here at length are:

Forces: the competitiveness crisis in U.S. industry, economic globalization, transition to a service and information based economy.

Trends: the increasing popularity of MS/OR in the mathematical community, increasing industrial interest in statistical applications, possibly increasing use of the MS/OR approach by consultants, increasingly narrow Ph.D.-level education in MS/OR, decreasingly rigorous MBA-level education in MS/OR.

Opportunities: assimilate AI more aggressively, cooperate more closely with Information Systems, stress cross-functional and environmental and advanced manufacturing and public sector applications, enhance organizational flexibility and responsiveness (a competitive necessity created by economic globalization and the computer/communications revolution), improve the conduct of MS/OR practice (e.g., more attention to the modeling life cycle and greater exploitation of the object-oriented paradigm, improve the conduct of MS/OR research (e.g., more empiricism, more attention to qualitative issues, and better integration with behavioral science), and target applications in the former Soviet block.

Discussing an opportunity and taking advantage of it are, of course, entirely different things. There is no denying that it will take a great deal of energy to capture the full potential of any of the opportunities that I have discussed. This energy must be supplied by universities, MS/OR-using organizations, professional societies, and, ultimately, by individuals.

Aside from the mass media—which cannot be mobilized on command—only ORSA and TIMS have the leverage necessary to catalyze a major energy shift in the direction of the great opportunities. Would *you* like to see this occur? Would you be willing to help?

If so, I urge you to write to an officer of the professional society of your choice. There is much to be done.

APPENDIX

A Company President Explains the Dissolution of the Central MS/OR Group

What follows is part of a letter from the head of one of the world's largest companies just prior to the final dissolution of its central MS/OR group in the mid 1980s. The CEO at that time happened to have a master's degree from a top university with an emphasis that included management science, but that did not prevent the dissolution from occurring. Contrary to the positive tone of this letter, the head of the dissolved group saw its demise as a blow to MS/OR as a profession.

Dear Professor Geoffrion:

... Management science has made valuable contributions to our business, and we continue to use it extensively throughout the company.

As [company name omitted] has grown and diversified, we have become a decentralized corporation, having [number omitted] major business units. Management Science has followed our organizational alignment and has become integrated into the business units. There has, consequently, been a steady migration of personnel from our corporate center of expertise. This transition reflects our experience of how to implement management science techniques most effectively, and we are now in the last stages of implementation.

We think very highly of [corporate group leader name omitted], and are in the process of identifying a suitable placement for him. The mantle of corporate support for management science will fall upon our R&D organization . . . .

Yours very truly,

[name omitted]
President

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