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AN EXISTENCE THEOREM FOR OR/MS

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(Received December 1990; accepted January 1991)

This paper, which is based on the Omega Rho lecture given at the 1990 ORSA/TIMS meeting in Philadelphia, states the author's necessary and sufficient conditions for effective OR/MS. Then it describes the changing character of this field, considers some opportunities for it, addresses some human resources concerns facing it, and offers a view of what it will do in the 21st century. After addressing some concerns about the higher education culture, it then provides some conclusions about the future of OR/MS.

I grew up in Arkansas and therefore thought that the world revolved around it; when I first learned geography, Arkansas was shown in the middle of the map. But when I went to Japan for the first time I saw a map of the world with Japan in the middle. Three months later a speaker at a manufacturing conference in Birmingham, England, showed a map of the world with England in the middle. Imagine how disoriented I was later to see an Australian's view of the world: not only was Australia shown in the middle of the map, but north was also shown as down! To accept this last view I had to turn my world upside down.

My objectives in relating these different views of the world are twofold: I want you to understand my own biases (view of the world) and I want you to consider adopting a radically different view of our world (OR/MS). In terms of my biases, there is no doubt that my views concerning the future of OR/MS are affected by my experience as an industrial engineer and my time at the National Science Foundation (NSF). At various times, in my research, consulting, and industrial experience I have described my work as operations research because of its applications focus. While at NSF, I have been a strong advocate of team-oriented, cross-disciplinary research on industrially relevant problems; I have also assigned a higher priority to education and human resources initiatives than to research initiatives because of my concerns for the long-term health of the nation's scientific and engineering enterprise.

My second objective is for you to adopt a radically different view of the world of OR/MS. Frankly, I believe the time has come for us to turn the OR/MS world upside down. We must examine it from a different perspective. We must re-examine the very foundations of operations research and management science. We must consider a complete restructuring of OR/MS practice, research, and education. The storm clouds on the horizon suggest that such a restructuring will be needed for OR/MS to survive. In fact, I think the very existence of OR/MS is threatened.

My paper is organized as follows. First, I will state what I believe are the necessary and sufficient conditions for the survival of OR/MS. Next, I will focus on its changing character; third, I will consider some opportunities for it; and fourth, I will address several of the human resources issues it faces. Fifth, I will consider OR/MS in the 21st century, and then, I will address several concerns regarding the higher education culture. Finally, I will offer some conclusions concerning the future of OR/MS.

NECESSARY AND SUFFICIENT CONDITIONS

Under what conditions will operations research and management science continue to exist? I believe the following conditions are both necessary and sufficient:

- solve real-world problems;
- employ cross-disciplinary, team-oriented approaches;
- increase the participation of women, minorities, and persons with disabilities; and
- contribute to strengthening the nation's educational system.

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It is ironic to find the first two on the list, since OR/MS grew out of just such a focus during World War II. The work of cross-disciplinary teams of scientists and engineers on operational problems faced by the Allies gave rise to operations research. Under the leadership of P. M. S. Blackett, a group consisting of three physiologists, two mathematicians, two mathematical physicists, an astrophysicist, and a surveyor made its mark; in fact, it was sufficiently successful to become recognized as "Blackett's Circus," (Gross 1989).

Of further interest is the fact that the conditions that spawned OR/MS also gave birth to the NSF. On July 5, 1945, in response to an invitation from President Roosevelt, Vannevar Bush, Director of the Office of Scientific Research and Development during World War II, submitted a report to President Truman titled *Science—the Endless Frontier*; the report led to the creation of the NSF in 1950 (see National Science Foundation 1990). In his report, Bush made this statement (loc. cit., p. 5):

> Science can be effective in the national welfare only as a member of a team, whether the conditions be peace or war. But without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world.

Later, the report said (loc. cit., p. 17):

> In this war it has become clear beyond all doubt that scientific research is absolutely essential to national security. The bitter and dangerous battle against the U-boat was a battle of scientific techniques—and our margin of success was dangerously small. The new eyes which radar supplied to our fighting forces quickly evoked the development of scientific countermeasures which could often blind them. This again represents the ever continuing battle of techniques. The V-1 attack on London was finally defeated by three devices developed during this war and used superbly in the field. V-2 was countered only by capture of the launching site.

The Secretaries of War and Navy recently stated in a joint letter to the National Academy of Sciences: "This war emphasizes three facts of supreme importance to national security: 1) Powerful new tactics of defense and offense are developed around new weapons created by scientific and engineering research; 2) the competitive time element in developing those weapons and tactics may be decisive; 3) war is increasingly total war, in which the armed services must be supplemented by active participation of every element of civil population."

As reported by Gass (1989), following World War II governmental OR/MS groups were established in the Air Force, Army, and Navy. Since that time, Washington, D.C. has been a relative stronghold for OR/MS. Hence, because the successes that led to the creation of OR/MS were essentially the same successes that led to the establishment of the NSF, one might have expected OR/MS to have been supported strongly by NSF. Such has not been the case. Why? Perhaps the support record is due to OR/MS straying from the focus that spawned it. What we today call OR/MS is quite different from what was called OR/MS in the 1940s and 1950s. (I will have more to say about this later.)

Not only does the survival of OR/MS depend on it returning to its roots by regaining its focus on real-world problems and utilizing team approaches in performing the requisite research, but also it depends on broadening the participation of women, minorities, and the disabled in OR/MS and improving the overall education system, especially the precollege teaching of mathematics and science. The latter two existence conditions relate to the changing demographics in the United States. The difficulty in attracting to OR/MS the segment of the talent pool that is the fastest growing and the deteriorating quality of the nation's precollege education in mathematics and science threaten the continued existence of OR/MS. In studying the talent pool, the so-called pipeline, the NSF has learned that approximately 80% of those entering the work force during the decade will be women, minorities, and new immigrants. For a field that should be especially attractive to all segments of the population, OR/MS is decidedly male in its gender profile and white in its skin-tone. Few role models exist and fewer targeted programs exist to rectify the situation.

Who will the OR/MS professional be in the year 2010? All candidates are alive; the youngest candidates are in kindergarten or first grade. Unless significant changes occur in career preferences by gender and race, OR/MS will face a significant shortage of qualified individuals educated in the United States. In fact, the number of U.S.-born graduates from OR/MS programs has steadily declined over the past decade. Furthermore, because of the success in attracting the world's best and brightest to OR/MS graduate programs in the U.S., many have concluded that there is no cause for concern regarding a future supply of OR/MS professionals. Unfortunately, such an argument overlooks the investments being made by other nations to strengthen higher education. Given the noteworthy contributions of D. Allan Bromley (the Canadian-born Assistant to the President for Science and Technology), Erich Bloch (the German-born former Director of the National Science Foundation), and Nam P. Suh (the Korean-born former Assistant Director for Engineering at the National Science Foundation), to name but a few, it should be

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obvious that I do not decry the number of scientists and engineers we have been able to recruit from abroad. Rather, I bemoan the paucity of American born who are pursuing careers in science and engineering.

The quality of America's educational system is receiving widespread attention, with much of the focus directed toward precollege programs. In his State of the Union address last year, President Bush established the goal of America's high school graduates being the best in the world in mathematics and science by the year 2000. Since that time, some progress has been made, but not enough! As of October 31, 1990, only 3,348 days remained until January 1, 2000.

In many ways, becoming first in mathematics and science is a greater challenge than President Kennedy's goal of putting a man on the moon in a comparable time period. Why? Because the moon stayed in the same relative position! The distance remained the same *during the race*, whereas, while we are improving the quality of mathematics and science in our school systems, so are other nations. Furthermore, President Kennedy's objective was always in sight, at least at night. Finally, the distance to be overcome is much greater than the distance to the moon. As we shall see, the United States has not fared well in recent international comparisons of mathematics and science performance among precollege groups. If we are to become first in the world in mathematics and science, broad and sustained support will be required. And, the federal government will not be able to solve the problem alone; any systemic improvements will require the participation of state and local agencies, as well as the support of industry and the citizenry at large.

THE CHANGING CHARACTER OF OR/MS

Over the past 40 years, OR/MS has changed significantly. Today, the emphasis is on becoming a specialist, not a generalist. Whereas in the 1950s and 1960s, a new OR/MS faculty member would be expected to teach graduate courses in mathematical programming and queueing theory, today's graduates would not deign to cross the deterministic-probabilistic boundary. Furthermore, a higher priority is placed on theoretical research than on applied research; issues of exactness and complexity stand in the way of providing answers to complex problems. Finally, the goals, objectives, and approaches by which an OR/MS professional addresses complex problems has changed; there tends to be a greater fascination with the particular tool than with the results obtained and there tends to be greater emphasis on individual performance than on team performance in problem solving.

From a team-oriented, cross-disciplinary focus on real-world problems, OR/MS research has migrated toward a narrow disciplinary focus on conjectured problems by individual investigators. Rather than focus on being a separate discipline, I believe the OR/MS community should focus on influencing other disciplines to incorporate OR/MS principles and methodologies.

Finally, a review of the program for this meeting indicates that progress has been made in addressing problems of emerging importance to the nation. The emphasis on productivity and competitiveness is certainly encouraging, as are the sessions devoted to problems of current concern. However, what appears to be lacking is the strong participation of those from other disciplines, those who understand the problem from a different perspective, those who do not view the intellectual challenges as narrowly as we. In the future, more attention must be given to inviting speakers to the ORSA/TIMS meeting who understand problems from quite different disciplinary perspectives.

OR/MS OPPORTUNITIES

Again, based on my view of the world, I believe many exciting opportunities exist for OR/MS. Consider a manned mission to Mars, global change, mapping the human genome, materials synthesis and processing, high performance computing, strategic manufacturing, biotechnology, energy, and environmental problems. In each case, there exists a significant opportunity for OR/MS to contribute. In some cases, increased understanding of nature is sought; in others, methods to enhance our quality of life are being pursued. However, in all cases, modeling and simulation are required; in all cases, constrained optimization problems arise; in all cases, probabilistic and statistical issues must be dealt with; in all cases, multiple disciplines are needed to provide the kinds of breakthroughs being sought. Will OR/MS participate, or will OR/MS prefer to focus on less important problems?

One of the greatest strengths of OR/MS is its diversity. If you examine the program for this conference in terms of subjects, speakers, institutions, and approaches represented, the diversity is immediately evident. In fact, as I reviewed the program I was reminded of the book, *Powers of Ten* (Morrison et al. 1982) and a presentation at an IBM Design for Automation Conference at Munich, West Germany. The conference opened with a film on which the book is based; although the film was an American product, it was narrated in German. Since I do not speak German, I depended on the visual message, which was powerful. The film began by showing a person's hand. The camera backed away, showing it was

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a man's hand; the camera moved back further and showed a couple picnicking in a park. Moving back even more, you could see it was a park in Chicago near Lake Michigan. With increasing powers of ten in the distance from the original subject, the camera moved back to a distance of a billion light-years from the original subject, a point at which our galaxy was but a speck in the solar system. Suddenly, the camera zoomed back through space to the subject and began to explore negative powers of ten in distance from the skin. Closer and closer it went into the cellular and atomic structure, until its distance from the skin was 0.1 fermi.

The message I retained from the film is the strength of diversity, ranging from positive to negative powers of ten, spanning the continuum from basic to applied research, from real to conjectured problems, from deterministic to probabilistic formulations, from exact to heuristic solutions, from precise to fuzzy representations, from individual investigators to teams of researchers in groups and centers, from education to research. We need people in OR/MS who are skilled at taking the systems view, as well as people who are more narrow in focus and extremely deep in their understanding of their subject. OR/MS offers diversity in the powers of ten that span from a +25 power to a −25 power. We can assist in modeling and synthesizing new materials being created at the atomic and molecular level; and we can assist in designing new infrastructures, for cities, states, and nations.

HUMAN RESOURCES ISSUES

The human resources issues facing OR/MS are manifold. We will consider the quantity and quality of America's students, changing demographics, OR/MS involvement in precollege and undergraduate education, and the OR/MS literacy of engineers, scientists, and managers in the private and public sectors.

The nation's college and universities are facing a threefold challenge that must be addressed—soon! First, the decline in the size of the college-age population between now and the end of the millennium will reduce significantly the production of engineers and scientists during a time in which science and technology are emerging as the formidable competitive weapons in international competitiveness. Second, the attractiveness of engineering and science is declining among today's students; engineering and science are not necessarily the majors of choice among the nation's best and brightest young people. Third, the demographic shifts that are underway will yield a population that has not opted historically for engineering and science; specifically, engineering and science continue to be less appealing to women, under-represented minorities, and persons with disabilities than to the remaining segment of the population—which is diminishing in relative size!

Given the challenge facing America's colleges of engineering and science, it is especially important for today's educators to increase the appeal of engineering and science to all segments of society; at the same time, degrees in engineering and science must be competitive with the best in the world.

The United States ranked 12th out of 12 in mathematics and 9th in science in a 1988 comparison of average achievement scores for age 13 students. In a comparison of 12th grade achievement scores, among 13 nations the United States ranked 11th in geometry, 12th in algebra, 13th in calculus, 13th in biology, 11th in chemistry, and 9th in physics. Hong Kong ranked 1st in all but one subject and, on an aggregate basis, the United States ranked 13th.

Of course, there are other measures of the quality of our educational system, including the emergence of newly established schools in the United States for children of Japanese assigned to this country. Even though all but the English classes are taught in Japanese, American students have sought admission—even though the schools meet six days a week and stay in session far more days a year than the U.S. schools. Indeed, Richard Celeste, the Governor of Ohio, observed recently that one way to gain support for improving education is to locate Japanese plants in every city in his state. He noted that in the cities where a Japanese school had been established, subsequent bond referendums to improve the public schools had passed with minimal opposition.

In Japan, West Germany, and the U.S.S.R., approximately 98% of high school students take at least three years of mathematics and science; in the U.S. less than 40% do so. In addition to giving less emphasis to mathematics and science, we give less emphasis to school: Whereas our children attend school 180 days a year, students attend school in the U.S.S.R. 205 days, in West Germany 210 days, and in Japan 220 days.

More than a decade ago, a friend from Tokyo told me he thought Japan was faring better in international competition because of the superiority of its educational system. When I challenged him on his claim, he noted that essentially all of their students graduate from high school and nearly 60% attend college. He asked what the statistics were in the United States. I was too embarrassed to tell him about our adult illiteracy rate and high school dropout rate. (I hope he did not see the report for the 1986–1987 school year, when only 73% of our high school seniors graduated. Also, I wonder if he would be

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surprised to learn that many of the lowest rated states are highly ranked in producing collegiate football players. What are our priorities, America?)

It is very clear that our product (OR/MS) is not selling to Americans in today's market; engineering enrollments have declined each of the past 7 years. It is also clear that our product will not sell in tomorrow's market unless significant changes are made in designing, marketing, and producing it. Because of the supply/demand situation that existed for decades, America's colleges of engineering and science have not had to sell their products. For example, in engineering we did not have to do anything to attract students or convince them to major in engineering. In fact, we could tell entering freshmen to look to the right and look to the left to see those who would not be around in 4 years; we were proud of our weeding-out system. Our boot camp mentality was very successful; it succeeded beyond our wildest dreams. As a result, students across the country are telling engineering educators, "I don't need you!"

Attrition during the first 2 years is too great, and it is especially so for women and minorities. For instance, of 40,000 minority students who enrolled in engineering as freshmen, only 14,000 were enrolled in engineering one year later. Why are we experiencing such levels of "leakage" from the pipeline during the first two years of college? Some reasons include a mismatch of interests, poor preparation in precollege programs, career misperceptions, lack of ability, and personal constraints. Often overlooked is the possibility that faculty are doing little to encourage the academically capable student to pursue engineering and science; the manner in which the subjects are introduced seldom portray the excitement of science and engineering. We must improve our product and our image. We need to do a better job of conveying the message that engineering and science can be fun and rewarding. We in academia and industry must involve the media. We must articulate the joy and excitement of making a positive impact on the world.

Unfortunately, our faculty send signals to people that they do not belong in engineering and science. Too many institutions appear to be content with the fact that 2% of engineering faculty nationally are women; 210 of the 421 are untenured assistant professors, whereas 58% of the male faculty are full professors. Because of the large number of faculty attracted to engineering and science in the 1960s following Sputnik, we face a significant number of retirements in the next 10 to 15 years. Who will replace them?

As a result of the student shortage in graduate school we have become dependent on a deficit trade policy with respect to human talent; simply stated, we must import graduate students in order to have an adequate supply of students to fulfill the research and teaching missions of the research universities. Not only do we depend on an open immigration policy, but also we depend on our ability to attract the best and brightest from all over the world to populate our classes and our faculties. Currently, more than half the doctorates in engineering go to individuals who were not born in the United States; likewise, nearly 60% of the assistant professors in engineering were not born in this country.

There is nothing wrong with a deficit trade policy in human talent unless you take a look at the long-term implications. With such a policy, we must continue to recruit from other countries. However, many of those countries are improving their ability to retain their best and brightest, as well as repatriate them. America built its reputation on an open immigration policy. The European exodus connected to World War II and the more recent Asian exodus have benefited America beyond measure. Perhaps the changes that are occurring in Eastern Europe will save us once more. However, I would not want to bet this country's future on it and I think that is what we are doing. We are betting America's future on our ability to continue on the path we traveled in the past.

Unfortunately, because OR/MS is viewed as a graduate program in most universities, very little attention is given to undergraduate education by OR/MS faculty. Furthermore, scarcely any pay attention to precollege education in mathematics and science. Yet, the future of OR/MS depends on an adequate number of highly qualified students graduating from undergraduate programs and pursuing OR/MS. Depending on someone else to solve the problem of improving the quality and attractiveness of mathematics and science throughout the pregraduate school portion of the pipeline is a failing strategy.

Not only must OR/MS faculty engage the precollege pipeline education problem, but also they must rethink their role in undergraduate and graduate education. Currently, OR/MS faculty tend to use a "Washington Monument paradigm" in planning a student's education program. Too many believe that undergraduate students will only have value if they become doctoral students—under their advisement! Too many believe all students are in the university in order to one day become faculty members. For engineering, a new paradigm is needed, one based on the nation's Capitol Building, not the Washington Monument. We need to recognize that the vast number of undergraduate students will enter professional practice. They will help American industry be competitive; relatively few of them should go on for a

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master's program and even fewer should go on for doctoral studies.

We should not focus our educational system on the production of the very few who will be Ph.D.s. Greater recognition must be given to the base of the Capitol, i.e., those who do not go beyond the bachelor's degree. We should make the bachelor's experience a quality experience, one that will benefit the student and industry; for that reason, I would support introductory concepts of optimization and probabilistic modeling being incorporated in all undergraduate engineering and science curricula. Next, we should focus on the few who go on to the dome of the Capitol by becoming graduate students. Also, we should consider the pinnacle of the Capitol, those who might get their doctorate. We must give greater focus to the basic mission of undergraduate engineering and science education; we must pay more attention to the base of the Capitol!

Finally, we need to incorporate OR/MS concepts in the education of a broader constituency, including the general public. Often, decisions are made in industry and government by individuals without an understanding of the fundamental concepts of constrained resource allocation. Tradeoffs are made implicitly and in an ad hoc manner without understanding how to turn win-lose situations into win-win situations.

OR/MS IN THE 21ST CENTURY

What will OR/MS be like in the 21st century? If we continue along the path we have been on, I do not believe we will be important players in solving significant problems that arise. However, I do believe OR/MS methodology will be incorporated in solving most complex problems that arise and are solved by cross-disciplinary research teams. If OR/MS does not explicitly provide the exposure to probabilistic modeling and constrained optimization for engineering and science, it will be provided by the mathematical sciences. As the computer becomes an integral part of precollege mathematics and science, college-level mathematics will place greater emphasis on discrete mathematics, as well as both probabilistic modeling and constrained optimization.

To continue as a separate discipline, OR/MS must be configured as a service discipline. Whereas probably more than 80% of its resources are directed at educating its own students, in the future more than 80% of its resources should be directed toward educating other students. In the future, practically all fields of study will require an exposure to OR/MS, including accounting, education, law, medicine, and the arts. In fact, I believe OR/MS should become a component of any liberal education curriculum.

CONCERNS ABOUT THE HIGHER EDUCATION CULTURE

Before concluding, I will focus on concerns I have regarding the faculty culture that exists in higher education. In this case, my observations are influenced by my experience at NSF. However, my experience as a faculty member for more than 25 years also weighs heavily in my feelings of concern for our profession.

Attempting to Test Quality Into Our Students. We have criticized industry for attempting to inspect quality into its products, while at the same time we have attempted to test quality into our students. Firms that understand the weakness of the "inspecting quality into . . . " are now designing quality into their products; less emphasis is given to inspection and more emphasis is given to front-end planning and design. How does this apply to academia? Entrance exams, tests, quizzes and final exams in courses; and qualifying exams, comprehensive exams, and dissertation defenses are forms of inspection—they are attempts to inspect quality into the product.

I do not advocate an elimination of all inspections, but I do advocate an attack on defects where and when they occur. In industry it is far better to cure the cause of the defect than to continue to reject defective parts! Likewise, in academia more attention needs to be given to identifying the source of the failure. In my judgment, when a student fails a course, it is because of a failure in the teaching/learning process; both the student and the professor are jointly culpable. However, under our current system, only the student pays the penalty for the lack of successful education on the part of the professor.

The Importance of Students to Faculty. How important is the teaching mission of research universities to their faculty? Students know how important they are to the faculty. They are reminded daily of their importance. For that reason, it is not surprising that last minute attempts to recruit undergraduate students to attend graduate school are so unsuccessful; what is surprising is the few faculty who recognize the connection between their own attitudes toward teaching undergraduate students and their recruiting difficulty. You cannot suddenly recruit students for graduate school in the latter part of their senior year and expect them to discount all of the messages you sent during the previous three and one-half years. By the end of the sophomore year, it is fairly obvious which students have high-potential for graduate

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school. Yet, we do not pay much attention to them until they are seniors.

The Tradeoff Between Type I and Type II Errors. In testing statistical hypotheses, we guard against two kinds of error: rejecting an hypothesis that should be accepted (Type I error) and accepting an hypothesis that should be rejected (Type II error). Similarly, educators are concerned with two kinds of errors: failing a student who should pass an exam (Type I) and passing a student who should fail an exam (Type II). Unfortunately, in admission and graduation decisions faculty appear to prefer to make a Type I error rather than make a Type II error. Furthermore, they do not recognize that strategies to reduce one type error generally result in increasing the other error. Most of our entrance criteria and hurdles are installed to minimize the chance of making a Type II error and result in increasing the likelihood of a Type II error.

The Dependence on the Selection Process. Today, there is too much dependence on selection processes and not enough dependence on development processes. We have refined to an ultimate degree the selection process. James Duderstadt, President of the University of Michigan and a member of the National Science Board, has pointed out this aspect of higher education. He noted that universities have depended on selection processes in recruiting students and faculty. Unfortunately, little or no attention is given to developing human potential. The true value added by the educational system must be questioned.

We ensure that only the best students are admitted as undergraduates, only the very best of those are allowed to go to graduate school, only the very best of those will graduate, only the very best of those will be hired as assistant professors, and only the very best of those will become tenured. That process might have worked with the input stream of the past, but it is not likely to be effective in dealing with future input streams.

Picking Up More Pebbles. We must pay more attention to those who might be at the margin—those who, with a little development effort, can be transformed into superstars. We must find a way to effect the transformation. I am reminded of the young woman who was hiking on a mountain trail she had never hiked before. At one point on the trail she noticed a sign that read, "Pick up some pebbles from the pile at the base of this sign. Put them in your pocket. At the end of the day, you will be both glad and sad." She looked at the pile of rocks, chose two of the smallest pebbles, and put them in her pocket. After hiking all day, as she was about to go to sleep she remembered the pebbles. When she removed them from her pocket, she found that they had turned into gold. She was very glad she had picked them up; and she was very sad that she had not picked up bigger and more pebbles.

Taking a Chance on the Marginal Student. We must recruit more of the marginal students; at the end of four years we will be both glad and sad. We will be glad that we paid attention to the ones we did and we will be sad that we did not pay attention to more of them. We must develop a mentoring capability within engineering and science, we must pay much more attention to the development of the human resources made available to us; we must acknowledge their scarcity; and we must replace a weeding-out philosophy with a bringing-in or cultivating philosophy. Instead of looking for reasons to reject, we must place greater emphasis on nurturing and developing. This will require a major change in the culture of engineering and science education.

Lack of a Strategic Focus. In general, faculty lack a strategic focus. We need to develop a better understanding concerning how the courses we teach and the research we do fit into the broader scheme of things within the academic environment; we must stop thinking and acting as though we are islands unto ourselves.

Self-Interest and Discipline Interest Versus Student Interest, University Interest, and National Interest. Our culture places self-interest and discipline interest ahead of student interest, university interest, and national interest. We are much more concerned about what our peers think worldwide in our field, than what our colleagues think in our own university. In recruiting graduate students, we are not particularly concerned about the long-term implications to the nation in our selection. Instead, we want students who will help us maximize the publications that result from our research. It is certainly not in our best interests to graduate such students quickly, the continuity of our research takes precedence over the student's interests. In designing curricula, we want to ensure that our areas of research are included in required courses so we can gain exposure to the best students—never mind that the total number of hours required for graduation is making OR/MS less attractive as a major.

Not only do we treat students in a way that is to our benefit, but also we do the same thing to junior faculty. To ensure that more research support comes to the department, we will only support for tenure the faculty

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who have shown an ability to attract outside funding. Furthermore, because tenured faculty are not as easily encouraged to attract external support, we will vote to increase the time required to get tenure. To put the burden of proof on the young faculty member and remove it from us, we say, "Young faculty member, welcome aboard. We will see you in about six years and let you know whether you are going to receive tenure."

Our treatment of students and junior faculty conveys a clear message concerning our priorities: We put self-interest and discipline interest far ahead of student interest, university interest, and national interest. Few faculty understand or appreciate that what they might do in terms of engaging in a research activity might have some national impact. Our decisions are made with respect to where we have the greatest chance of getting funding support and what the impact will be on our scholarly productivity.

Copycat Objectives. In general, faculty fail to recognize the strength that exists in the diversity within America's education enterprise. There exists an enormous copycat pressure among universities. When a national ranking is released, university faculty, administrators, and trustees immediately look to see which university is ranked first; they want to be just like them. Hence, they hire their new faculty from the top-ranked institutions. The benefit to the nation of our diversity is in danger of being lost. Each institution has something to offer in the grand fabric we have woven. Educational institutions should have unique roles and unique missions; they should stop pursuing a copycat approach. The cookie-cutter approach of stamping out all institutions from the same mold must stop. (In this regard, I think NSF has been a part of the problem, not a part of the solution.) Faculty must refocus on the basics, they must return to the fundamentals and come to grips with the very basis for their institution's existence.

Academic Pecking Order. We are familiar with the academic pecking order that exists. Dating at least to the time of Plato, it goes something like this, "The further you are distanced from reality the more prestigious is your calling." Plato and his associates would not design to engage in manual work; they wanted to stay away from anything that smacked of work. The Judeo-Christian ethic associated woe, agony, and travail with work; the mind-set for many people today is that any job that requires you to get your hands dirty is bad. Many work hard to be able to not work, to retire. Our fondest dream is to be independently wealthy so we do not have to work. The intellectual challenge and the immense satisfaction derived from doing something that benefits mankind is lost within the antiwork philosophy. Engineering, for example, does not appeal to those who wish to avoid work, and within engineering greater prestige is placed on theory than practice, greater prestige is given to analysis than to synthesis, and greater prestige is given to design than to manufacturing.

Despite its roots in dealing with reality, the desire to become distanced from reality, to avoid direct connections to the real world, has infected OR/MS. As a result, much of the OR/MS research that occurs is actually pseudoscientific research. In emulating science, engineering research has lost its differentiation from scientific research.

Risk Aversion. Faculty are a very risk averse species, especially those in engineering. We are reluctant to adopt new paradigms. Yet, I believe that we must adopt them, beginning with the recognition/reward system in the university. Currently, individual contributions are weighed much more heavily than team contributions. The recognition/reward system works against collaboratory education and research. The very idea of having multiple graduate students do a common dissertation is beyond what many faculty can comprehend; to allow such a team effort would put the burden on the faculty to ascertain the contributions of each student, rather than put the burden on the individual student to demonstrate his/her contribution. To allow team research would necessitate that the faculty be engaged in the research. We would have to be closely involved in the research or we would not be able to make value judgments about the contributions of the team members.

The Changing Business of Higher Education. Faculty tend not to recognize the dramatic changes that have occurred in the business of higher education in the past decade. The cost of higher education is almost out of control. It is interesting for those of us in engineering to compute the ratio of the amount of money spent on tuition when we were students to that paid a newly graduated engineer. Now, compare that ratio with what exists today. I believe you will find that the cost of majoring in engineering today is proportionately greater than it was twenty years ago, when compared with the amount earned by engineers their first year.

The Business of Higher Education. We are confronted with the fundamental question that Peter F. Drucker (1974) says every manager must answer, "What business are we in?" Once that question is answered, he argues that managers must answer the question, "What business should we be in?" I have answered those questions for the NSF. Many think the business the NSF

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should be in is the research business. As far as I am concerned, the NSF should be in the human resources development business. We make our investments in people. We make our investments through faculty to reach students. We do this in order to develop a capability in this country that is unmatched anywhere in the world; we want to be sure that we are at the forefront of knowledge by engaging in research to advance knowledge, to advance understanding. Research is the mechanism by which we develop human resources.

Similarly, I think the university's business is not the knowledge business; it is the business of producing knowledgeable people. NSF and higher education are in the people business. We must maintain our focus on people, students, and faculty. Students know very well how important they are to faculty. They are reminded daily of their importance.

Dependence on Federal Funding of Research. It appears that many in the academic research community believe it is their inherent right to receive research support from the federal government—*no strings attached*! Many in academia (including faculty members and university administrators) appear to view the NSF as an academic entitlement program. Such is far from the case! NSF's mission is inextricably tied to the nation's fiscal condition; the economic health of the nation will affect NSF's ability to support research and, I believe, that support should be related to the impact of NSF's research on economic competitiveness. As such, more attention to meeting the needs of U.S. industry is needed in forming NSF's research agenda.

Sloughing off the Dinosaurs. In *Managing in Turbulent Times*, Peter F. Drucker (1980) notes we might have to slough off things that were appropriate in the past. Like dinosaurs, some things we could afford in the past have become extinct relative to today's environment. Everything we do in the university today needs to be called into question. In turbulent times, we must ask if we can afford to do all the things we are attempting to do; in turbulent times we must focus. Can we afford to offer as many majors as we do? Just because a major might have been appropriate in the past does not mean it is appropriate in today's competitive environment.

To make informed decisions, we must have better information concerning the cost of higher education. First, we need a good accounting system, one that provides accurate estimates of costs. Without accurate costs, how can good decisions be made? Even if you are in a business that is not price sensitive, you need to know your costs so you can price your product or service accordingly. With few exceptions, I do not believe that universities have a clear understanding of their true costs. Furthermore, while many university administrators appear to believe that the research program is the *cash cow* for the teaching program, I suspect just the opposite is true! We must examine everything that we are doing in higher education, because we are about to price ourselves out of the business.

Making a Difference Through Research. In OR/MS research, new paradigms are needed. Specifically, more emphasis should be given to making a difference with one's research; less emphasis should be given to publishing yet another paper in a prestigious archival journal that relatively few will read, and its only impact will be to serve as the launching point for another paper by the same author! Less emphasis should be given to pseudo-scientific research and more should be given to industrially relevant research.

In academic research, I believe the educational experience of the student involved in the research is more important than the research results. As such, it is especially important for attention to be paid to the quality of the student's research experience. For I believe that the quality of that experience is far more important than the quality of the research output. Academic research has a twofold purpose: to educate students and produce results; I believe the former is far more important than the latter. Yet, the recognition/reward system in the university places greater weight on the latter than the former.

In academic research, more emphasis must be given to what is in the best interest of the student, what is in the best interest of the nation, and what is in the best interest of the university. Less emphasis should be given on what is in the best interest of the professor. Why do I make such a claim? Most faculty appear to make decisions as to what to teach, what to pursue in research, and which graduate students to support as teaching and research assistants on the basis of what is in their interests, not the students'. As a result, there are few incentives for a professor to accelerate a graduate student's academic program; there is little incentive to recruit American undergraduate students for graduate school as long as there is a ready supply of hard working, uncomplaining, highly capable foreign students; and there is minimal incentive to perform service functions for the university. Unfortunately, the "what's in it for me?" attitude is evident to all, especially the students.

Competitive Benchmarking. Faculty, in general, have failed to perform competitive benchmarking globally. Robert H. Hayes and Steven C. Wheelwright (1984) titled their book, *Restoring Our Competitive Edge: Competing Through Manufacturing*. Perhaps you have

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heard about the experience in Nashville, Tennessee, following the establishment of a Japanese school? Several Japanese executives and engineers were moved with their families to the Nashville area in conjunction with the location of new manufacturing plants. Soon they formed their own school; students go to school six days a week, more hours a day, and more weeks a year than the American students. Upon learning about the new school, several American students applied for admission. Students understand the value of education. They understand that Hayes and Wheelwright should have titled their book, *Regaining Our Competitive Edge: Competing Through Education*. Ultimately, the competition among nations will reduce to the quality of the educational system.

Universities do not have a corner on higher education. Considerable advanced study is provided by professional societies and by industry. AT&T, GE, IBM, and Motorola are among the firms that invest considerable amounts of money in educating their employees. Unfortunately, if faculty were asked to develop a competitive response on behalf of the university, their first reaction would probably be the formation of a committee to study the matter for a couple of years. Most universities have failed to define and develop new markets. Instead, they have continued to depend on the traditional market of students coming directly from high school. They have ignored nontraditional student markets and the continuing professional development market. Many opportunities exist for higher education—but, universities have failed to seize them.

Cooperating to Compete and Restructuring Higher Education. As occurred with industry, academia must learn to use cooperation as a competitive strategy. Since each of us is looking for a competitive edge, we must learn how to do cooperative education and cooperative research with other educational institutions. We must learn how to cooperate across state boundaries. We have got to learn how to cooperate across national boundaries as effectively as the European community. While Europe is learning to cooperate across national boundaries, we are squabbling about how to cooperate across departmental boundaries in the same institution, much less across university and state boundaries. Just as corporate America has restructured, so must academic America restructure.

CONCLUSIONS

In summary, I have focused on a number of changes that must occur for OR/MS to continue to exist, as well as changes that must occur for America's science and engineering enterprise to remain world-class. I have no misgivings concerning the time and commitment required to redesign the science and engineering product, to expand our portfolio of products and services, and to regain lost market share. A quick fix is not in the cards because we are really talking about changing the culture of academia, not just science and engineering education.

In their book *Corporate Cultures*, Terrence E. Deal and Allan A. Kennedy (1982, pp. 169–170) stated, "Changing the culture of an organization is a difficult, time-consuming, often gut-wrenching process. This is as true in public corporations as it is in the private domain. In fact, effecting such changes in a public institution is, if anything, more difficult because of the number of legitimate constituencies—the public, legislators, unions, employees, special-interest groups—that can raise barriers to change. But change can be accomplished if a sufficient level of commitment is applied to the process for a long enough time." Since changing an academic culture is surely more difficult than changing that of a corporation, you can see why a united effort on behalf of the scientific and engineering community will be required and a broader support base must be developed.

I suspect there are several who are truly "in search of excellence" (Peters and Waterman 1982); others are "managing for excellence" (Bradford and Cohen 1984); still others have as their objective "creating excellence" (Hickman and Silva 1984); finally, I suspect there are some who have developed "a passion for excellence." Regardless of which might apply to you, if we are to be excellent in OR/MS, I believe we must regain our emphasis on the roots of the origin of OR/MS.

Nearly 50 years ago, OR/MS contributed to the nation's success in a global military conflict. Having emerged in response to national needs, it is time for OR/MS to respond again. The nation is engaged in a global economic conflict that endangers our quality of life. Due to the nature of the competition, a high priority has been placed on cross-disciplinary, team-oriented research on complex problems that are hindering the nation's productivity and competitiveness. Will OR/MS respond again?

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