MANAGEMENT OF POST-INDUSTRIAL SYSTEMS:
ACADEMIC CHALLENGES AND THE STANFORD EXPERIENCE

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ABSTRACT

Recent worldwide trends include the information revolution, the explosion of bio-technologies, the globalization of markets, the acceleration of the transition from research to markets, increased awareness of ecological fragility, and growing aversion to technological risk. These create new needs, opportunities and constraints, both in the work place and higher education. The definition of old disciplines has become increasingly ill-adapted, and the need for interdisciplinary education more pressing. Yet students must be solidly anchored in specific domains to be able to address more complex problems and design new tools. Competition and globalization demand that students be prepared to operate in the changing world with sound bases, flexibility, financial savvy and an appreciation for cultural, ethnic and gender diversity.

This particularly affects departments of industrial engineering and operations research that focus on manufacturing, production, services, work organization, public policy analysis, economics of technology, decision and risk analysis, and engineering management. Within them, the lines between management science, social science and engineering are becoming increasingly blurred. They thus face challenges in constructing coherent and relevant academic programs. They must develop centers of excellence around existing disciplines and specific problems. This requires that all synergies be exploited to remain at the cutting edge of academic research and industrial needs.

This paper examines the trends shaping the needs for academic changes. It describes what they imply for universities, focusing on the specific needs of university departments that involve Industrial Engineering and Management, Management Science, Information Systems, Operations Research and Policy Analysis. It finally describes the model and innovations adopted by Stanford.

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Some of the global trends of the post-industrial era have profound implications for universities in general, and more specifically for academic departments, often located in schools of engineering, that focus on the management of engineered systems and technologies, both in industries and government. In this paper, I identify first some of these relevant trends (without pretending to be exhaustive) and examine their implications for universities in general, and more specifically, for these departments. I then describe the plans at Stanford University for a new department combining the strengths of its departments of Industrial Engineering and Engineering Management (IEEM), and of Engineering-Economic Systems and Operations Research (EES&OR).

1. SOME RELEVANT TRENDS OF THE POST-INDUSTRIAL ERA

The post-industrial era can be characterized by an explosion of information and communication technologies. This does not imply, of course, that manufacturing and services have become less important, but that they have been profoundly transformed, in the same way perhaps, as industry was transformed at the end of the nineteenth century by the emergence of electric power. Furthermore, at the present time and in large parts of the world, an economic movement towards less government intervention, unrestricted circulation of capital, and a more competitive atmosphere have led to a "faster-better-cheaper" mode of operations that has transformed the way product development is managed and funded, and the way production and work are located and organized.

The industries most affected by the high-technology trends are numerous and often interrelated. They include for example, electronic, computer and communication industries, but also biotechnology, biomedical and pharmaceutical industries. This emphasis on medical technologies (including, for example, medical imaging) is likely to continue, in particular in the United States, where the aging of the population will steadily increase the demand for advanced medical products.

In the electronics industry, one trend has been towards miniaturization of complex systems including for instance, sensors and actuators at the molecular scale. The challenge of miniaturization, however, may no longer be the key issue beyond a certain point. The objective is to design and integrate, within reasonable cost constraints, robust complex systems, involving hardware, software, and human operators or users. Given the current, intense focus on the *means* of communication, another challenge is to also ensure the *quality* of the information content. In the world of management science, for example, the role of mathematical models as core of decision support systems is essential provided that they accurately represent actual problems. In the same way, the role of empirical research, for example, in organizational behavior, is critical when it actually reveals the nature of the work environment. It provides, for instance, other means to approach decision making, and insights in the design of work and teams in the new technological context. It can also enhance the benefits of analytical models by clarifying the context in which decision support systems will be used. These are synergies that can be effectively fostered in academic departments.

The advent of the information and communication age, and in particular, of the Internet, has affected simultaneously two key aspects of the economy: the generation and dispersion of knowledge and the banking and investment system that supports the post-industrial development of technologies. The first implication of this coupling has been an acceleration of the research process, of the dispersion of research results, of the transformation of these research results into marketable products, and of the introduction of these products on the market. The second has been the fluidity of financial markets that can immediately spot and respond to opportunities. Venture capital, investments over the Internet and an often borderless financial system have made money available to inventors provided that they can quickly form competent and compatible management teams. In this respect, the role of venture capitalists, for example, in the Silicon Valley, has evolved from mere source of funds to management guides and mentors, a factor that has been critical to the success of many startups.

This acceleration of the globalization movement has lead to a dilemma in public policy. Government regulations and policies at the national scale are more and more difficult to formulate and enforce, even when called for by ethical and political considerations. They can scare away foreign investments and discourage innovation -- good or bad -- by putting barriers around national enterprises, but these obstacles can be easily avoided by moving the activity elsewhere. The legal systems have traditionally followed technical developments, but the speed of recent developments has not always provided the time necessary for the evolution and the maturation of the ethical system that is the basis of the law. For policy formulation, analysis and enforcement, some major problems, such as massive pollution issues or the possibility of global warming, have to be addressed at the world scale. This requires a delicate consensus, both in terms of scientific understanding and in terms of values and priorities.

The resulting atmosphere at this time, for example in the United States, is an unusual mix of prosperity and uneasiness. A feeling of uncertainty, for example about the sustainability of prosperity, has generated a new need and demand for security. This has led to an increasing demand for zero-risk technologies, and to a greater concern about potential instabilities of the climate and the ecology of the planet. Yet investments that could protect us against potential negative effects of global climate change or the decrease in the number of living species have to be considerable to be effective. These investments often, but not always, compete with those needed for technological development, manufacturing and services that are sources of job creation. Therefore, the cost-effectiveness of ecological and risk management policies matters.

The information revolution has also profoundly affected work and communications. This includes how industries set up and manage their supply chains, but also the way individuals within companies interact and generate products. A design team can be spread among several sites and collaborate in new ways to the creation, for instance, of a spacecraft. The question is then: how can this type of electronic interactions be organized to be as effective as direct ones, including casual encounters around water coolers? In addition, of course, there remains the issue of the quality of human interactions in such a distributed social setting, both within teams and among individuals.

The human interaction is still more complex when different nations and cultures are involved. One observes, for the moment, in large parts of the world, a domination of the US economic and political model. In that sense, for better or for worse, the United States has become *de facto* the leader of the globalization and democracy movements, and American consumption has been one of the main engines of the world economy. Yet, cultural differences need to be carefully accounted for -- and respected -- in the management of international operations. One problem, of course, is that the least well-off in society are for the moment left behind because the new technologies generally require a level of education and training that is often beyond their reach, and that they may not even perceive as necessary or desirable.

The current acceleration of economic evolution towards globalization and borderless markets may be temporary, and history does not allow prediction of how long it will last. Challenges to this model come for many sources, for example from Europe with its concerns for cultural identity, its preference for a more government-oriented system, a desire for reduced working hours and perhaps, a lesser enthusiasm for the benefits of technological products. A revealing debate has arisen for instance in Europe, around the question of risk in general and food safety in particular. Genetically modified agricultural products are generally accepted on the American continent while they are regarded with suspicion on the other side of the Atlantic. Whether the debate reflects a concern for a real risk or classic economic protectionism is a fundamental issue of policy analysis. Another challenge to the fluid-market model was the Asian financial crisis of the last few years. It has emphasized the instabilities inherent to the unrestricted circulation of capital, when there is a risk that some investments be locally misused, or that capital be withdrawn overnight by investors. It has also revealed the power of economies to recover quickly, provided that they can emerge as leaders in their fields and free themselves of undesirable local political constraints.

These factors, that is the globalization and acceleration of the cycle from fundamental research to introduction of new products on the market, affect the way universities must rethink their mission and structure their programs.

2. IMPLICATIONS FOR ACADEMIC STRUCTURES AND UNIVERSITY PROGRAMS

These profound changes imply that universities in general, and schools of engineering in particular, must now see themselves as global enterprises, competing as ever, but on a larger scale, for faculty, students and resources, without losing their core values and their sense of mission.

The first challenge that they face is that the classic definition of disciplines and schools, is poorly adapted to the resolution of practical, multi-faceted problems. This is not new, but recent advances, for example in computing and biology, have made the discipline borders increasingly cumbersome. Whereas deep scholarly work in specified areas is well served by the current structure, the Undergraduate and Masters students often need (and want) a spectrum of options that do not fit well into the school or college structure. For example, many business schools, because of their financial independence, are sometimes isolated from other programs and hardly accessible to other students. Conversely, their students may be isolated, for instance from engineering and technological education. In the same way, medical and law schools are often separated from their mother institutions. The creation of *ad hoc* centers (e.g., Bio-X at Stanford University) is one way of addressing a specific need, but such centers do not always solve the problem of “school walls” which is financial as well as intellectual, and needs to be addressed in those terms.

An implication of the fast pace of transfer from research to applications is a closer, more fruitful, but at times uneasy, relationship between academia and industry. Universities want to be able to perform fundamental research, preserve their intellectual independence and benefit from their findings. New legal, financial and ethical problems therefore arise. They have to be resolved through contracts, patents, licenses, and more generally, understandings that protect the researchers, those that fund them (industry as well as American tax payers), but also the students.

The international character and the diversity of the world in which our students will operate also require that they be prepared for it. To some degree, this will be naturally achieved through the diversity of the faculty and of the student body. It can also be enhanced by specific international courses, including for example, project courses than span several countries and continents. Already as of 1999 such a course was in place at Stanford and involved students from California, Singapore, Hong Kong, The Netherlands and Sweden in international projects and multicultural teams. Other possibilities are programs that involve language departments and engineering schools and couple the teachings of both.

Distance learning, for example through the Internet, is playing an increasing role. This poses a serious challenge to academic institutions at several levels. The first is technological: how to deliver, in an attractive and effective way the material that is taught, and make it relevant to an audience that is not immersed in the group of students who attend the live classes. A second and related challenge is the lack of face-to-face interaction between teachers and students, which especially affects teaching through case studies. Some of these problems can currently be addressed by e-mail, telephone and in some cases, teleconferences, but systems that permit audio-visual interaction during classes clearly need to be improved. Another challenge is institutional. Clearly, the distance-learning experience will be different because it will lack the quality of the current social interaction that campus life permits. Other types of interactions will take place, however, and what might be lost in homogeneity and class dynamics might be gained in the diversity of experiences of a distributed student body. Building an appropriate framework to deliver full degrees on-line thus remains an institutional, financial, technical and educational challenge.

Finally, executive education has become a central activity of many universities, in particular in the US. They bring additional resources to departments and schools, and fulfill an industry need to keep abreast of new knowledge and technological developments. They also facilitate interaction between educators and executives, which can enrich the experience of both sides and enhance the relevance of academic research. Yet, one potential downside of such executive programs is that they can also become a distraction from the educators' primary mission if these activities are allowed to infringe on their interaction with regular students or on their research activities.

3. CHALLENGES TO INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH DEPARTMENTS

Departments of Industrial Engineering (IE) have faced a challenge in recent years and have evolved considerably. These departments start from a variety of disciplines that include production systems, engineering economy and work design. They have generally chosen, for many years, to de-emphasize their traditional fields of time and motion studies and plant layout. Because, a few years ago, the United States seemed to lose ground in manufacturing, it is one focus that some IE departments have chosen, including for instance, robotics, sometimes in conjunction with mechanical engineering departments. Some IE departments have also decided that they needed to adapt to the development and use of information systems which has become the main focus of some of them, and to take a more global look at the management of supply chains and industrial marketing. Therefore, engineering and management aspects of production, distribution and finance have become more closely linked, especially with the advance of electronic commerce, and schools of engineering are ideally positioned to integrate management solutions that involve the development and use of technologies.

Changes in the world of work and the use of electronic communications has sometimes called for the complete re-design of workplaces, redefining teams and schedules, and providing more flexibility than before in the creation of international production systems. New courses and research programs have thus been created, for example, to guide the design of effective distributed teams. Finally, public concern about the safety of technological systems has led some of these departments to expand their traditional emphasis on quality control to the field of risk analysis and risk management. Courses were designed to provide students with methods to anticipate catastrophic system failures, compute their probabilities and find cost-effective ways to prevent them.

Some departments of Operations Research (OR) are also rethinking their role. Originally, the field started from a need to solve practical problems, for example in the Armed Forces, and for mathematical methods including optimization, linear, dynamic and integer programming and stochastic methods. These methods were also applied to industrial (e.g., production systems) and technical problems (e.g., design optimization). To the extent that the focus was on the mathematical solution of such problems, OR practitioners found themselves working in areas similar to those studied in computer science, applied mathematics, electrical engineering and statistics departments. As computers have become more powerful and problems have evolved, the need for optimization and approximation methods have expanded, and some OR departments are now developing new mathematical tools, for example, in the domains of communications and networks. For large-scale policy analyses, a main challenge remains problem formulation. Here again, powerful computers allow for more complex models. The question is how to formulate these models in such a way that they are both accurate and solvable when complexities, instabilities and non-linearities introduce serious difficulties.

Systems engineering has been spread for many years among the many engineering departments to which it is clearly relevant for the design and operations of complex systems, from water resources management, aeronautics and astronautics, to electrical engineering. At this time, however, systems engineering has taken different meanings, including, for example, the design of information systems and data bases, or the development of mathematical models that represent the evolution of more widely defined systems (e.g., “dynamic systems”).

4. STANFORD' NEW DEPARTMENT OF MANAGEMENT SCIENCE AND ENGINEERING

The Stanford department of IE-EM started as an Industrial Engineering department including an Operations Research group. It remained as an IE department following a split in the early sixties of this OR group. Subsequently, an Engineering Management focus was added to the IE department in response, in part, to a growing demand in the Silicon Valley for engineers with management skills. The result was a small (and original) department that covers a larger spectrum of topics and may have a stronger emphasis on management than most IE departments in the United Stated. It offered an ABET-accredited undergraduate program and includes three main areas of teaching and research (Stanford University, 1999). These groups include:

- a production group based on OR methods and centered on production operations and manufacturing,
- an organization behavior group based on social sciences focusing on work, technology management and entrepreneurship, and
- a risk analysis group focusing on probabilistic risk analysis and risk management for critical engineered systems, projects and programs.

The production group is particularly strong in the domain of supply-chain management, and runs the Supply Chain Forum with the support of industrial affiliates in conjunction with the Stanford Graduate School of Business, with which it also participates in the Alliance for Innovative Manufacturing at Stanford (AIMS). Other aspects of the production group’s work involve the service industry, focusing for example, on the health problems of the AIDS epidemics, information systems, and manufacturing problems.

The organizations and management group includes the center on Work, Technology and Organization that studies general issues of technology and work in the postindustrial society, for example, the creation and working of effective teams, focusing on the way new technologies have changed the workplace. Another emphasis of the organization group is on the management of technology, including strategic alliances and competition in a fast-changing world.

Entrepreneurship has become a centerpiece of the management group of the IE-EM department where it is located even though it belongs, organizationally, to the School of Engineering at large. The Stanford Technology Venture Program involves at this time a small number of students (in a co-terminal program) and includes both a set of courses and an internship in startup companies of the Silicon Valley. This program has been extremely successful and many of its graduates have been hired by the startups that employed them as interns. The challenge, at this time, is to develop the intellectual core and the academic backbone of such a program, including, for example, financial and marketing aspects of startups. This is a common problem at this point in the many schools that are starting entrepreneurship programs.

The risk analysis group has focused on the effects of human and management factors on the reliability of complex critical engineered systems. More recently, the emphasis has been on programmatic risk analysis involving management risks of exceeding schedule and budget, as well as on the risks of technical failures in critical design and development decisions. Recent applications have focused mainly marine, space and medical systems.

In addition, the IE-EM department ran several successful summer executive education programs (for example with the American Electronics Association) and broadcast some of its courses through the Stanford Instructional Television Network (SITN). These courses allows distance learning for companies that subscribe to SITN services, in real time in the Silicon Valley and with some delay for companies elsewhere in the United States.

The EES&OR department was born in 1996 from an earlier merger between the departments of Engineering-Economic Systems (EES) and Operations Research (OR). As mentioned earlier, the OR department was created in the early 1960's by a group of faculty members out of the existing Industrial Engineering department. The EES department was created in the late sixties to apply methods of systems and economic analysis to engineering problems involving policy and decision making, both in government and industry. The EES&OR department covered a large variety of topics of research and teaching (Stanford University, 1998): optimization (numerical optimization, stochastic optimization, network optimization, lattice programming), probability and stochastic processes, systems and simulation, economics, finance and investments, decisions (decisions analysis and dynamic programming), operations and services, strategy and policy. It ran successful executive education programs in theory of investments and in the use of spreadsheets for the solution of OR problems, an Affiliates program, and included an Energy Modeling Forum as well as a Decisions and Ethics Center.

As of 1996 the Stanford School of Engineering included three departments, now reduced to two, whose vocation was essentially the management of technological enterprises and systems, both by industry or by government. It seemed therefore that there were opportunities for synergies and that a merger made sense. A first merger, which occurred in 1996, involved the departments of EES and OR. During the academic year 1998-1999, the Dean of Engineering decided to create a new department that the faculty from IEEM and EESOR were given the opportunity to join, which they all eventually did.

Stanford University is thus creating a new department in its School of Engineering that will be *de facto* the result of a merger of the existing departments of IEEM and EES&OR. The faculty members of this new department recently chose and ratified by an approval rate of more than 90% the name: “Management Science and Engineering” (MS&E).

To address a number of problems that will have to be faced when the department is formed, the Dean of Engineering appointed a “vision committee” who defined as follows the new department’s mission:

> “The mission of the MS&E department will be research and education associated with the development of the knowledge, tools, and methods required to make decisions and shape policies, configure organizational structures, design engineering systems, and solve operational problems associated with the information-intensive, technology-based economy”.

The challenge, of course, is in the breadth of topics covered by the different groups that will constitute the new department, from the development of mathematical methods in the current group of Operations Research to the qualitative, interview-based methods used in some of the research of the organization and management group currently in IEEM. The different areas involved can be loosely described as:

- Operations Research and mathematical methods of systems analysis
- Production operations and manufacturing
- Decision analysis and risk analysis
- Economics, finance, public policy and strategy
- Organization behavior, management and entrepreneurship

As usual with such a diversity of fields of expertise, one challenge is to avoid the balkanization of the different groups and to resolve conflicts of cultures among them. Another is the construction of academic programs that give the students the benefits of different perspectives and a common culture, without distracting them from the focus of their main interest, whether in applied mathematics or in the social sciences.

The opportunity, of course, is in the power to combine the different disciplines, to understand the variety of problems involved in the management of systems and technologies, to find appropriate problem formulations and solutions, and to provide relevant decision support. The two old departments (IEEM and EES&OR) bring to the new one considerable assets to respond to the global challenges outlined earlier in this paper: a focus on high technology, production and manufacturing in a fast-changing world, information systems, supply-chain management, decision and policy making, work and technology, management of technologies and of technological risks, and the mathematical tools to address such problems, but also the cultural diversity of the faculty and the student body.

There are clearly risks associated to the fusion of two groups with such a breadth of interests and such different intellectual roots. Yet, the opportunities seem to outweigh these risks and to justify the effort that the institution and the faculty seem ready to put in this fusion.

5. REFERENCE

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