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Return to work: Toward post-industrial engineering

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Industrial engineering was originally founded as a discipline that focused on the study and design of work. Yet, today the field has largely distanced itself from this early concern. This paper tracks the decline of work studies in industrial engineering and explores the question of why the discipline lost its concern for work and, ultimately, its ability to speak to the kinds of social and economic changes that it was created to address. Our reading of historical documents and our analysis of data collected from nine industrial engineering departments from their founding to the present day reveal that changes in industrial engineering were tied to trends in society, to shifts in sources of funding, and to the field's concern with its own status. The decline of work studies in industrial engineering is especially problematic because the nature of work has dramatically changed over the past 50 years, as we outline in this paper. The upshot is that industrial engineering now finds itself unable to speak about the organization of work and the design of modern work systems. We explain why the time has come for the field to rekindle its interest in the nature of work and the particulars of the workplace and we suggest several paths for proceeding in this direction.

1. Introduction

If any discipline is rightfully the child of the second industrial revolution and the changes it wrought in the nature of work, that discipline is industrial engineering. Forged in mills and on shopfloors at the turn of the 20th century, industrial engineering sought to tame the social and economic turmoil that emerged as productive activity shifted from fields to cities, from hand tools to dedicated machines and from steam to electrical power. Whereas other thinkers of the day hoped to solve industry's problems by "Americanizing" an immigrant workforce and by peddling notions of leadership and self-reliance to captains of industry, industrial engineers recognized that the key to industrial order lay in the design of work systems and practices. They understood that adapting to the new economic regime would require philosophies and methods tailored to the forms of work that defined the new mode of production.

For the first half of the 20th century, industrial engineers articulated a philosophy of management and developed techniques for improving production systems by increasing the efficiency of work practices (Wren, 1972; Nelson, 1975). Beyond developing methods for studying motion and time, for which they are widely known, industrial engineers organized and streamlined procurement, inventory, quality and accounting systems. They redesigned machine tools to increase accuracy and efficiency. They also experimented with incentive plans, which they believed would enhance motivation and yield workers a fairer wage. For the most part, these early industrial engineers focused on factories and clerical bureaucracies where tasks were largely manual and repetitive and where output was tangible.

After World War II the study of work began to slip slowly into the background as industrial engineers turned their attention to more quantitative and analytical endeavors. Some engineers, still concerned with the factory, began to develop general models of efficient production and distribution. Others developed the mathematics of optimization in search of less contextualized models that they could apply not only to production but also to health care, transportation and military operations. Still other industrial engineers created the fields of risk and decision analysis in the hope of devising tools that any decision-maker could use. Engineering studies of work migrated toward controls, displays and human-machine interfaces: topics that could be investigated more rigorously in a laboratory than on the factory floor.

At about the same time, the nature of work began to change. Initially, the rate of change was sufficiently slow that it was not unreasonable for industrial engineers to assume that concepts and techniques developed for factories remained adequate for most other work settings. There is evidence, however, that work in contemporary society has now changed sufficiently to render such an assumption suspect (Anon, 1999). The occupational structure of the US has changed dramatically over the last 50 years. Blue-collar employment has fallen steadily whereas white-collar work has expanded. Employment in services now outranks employment in manufacturing. Professional and technical occupations employ more Americans today than any other occupational sector monitored by the Bureau of Labor Statistics (Hecker, 2001).

The dynamics of work are changing within occupational groups as well. Stable employment is declining and contingent work is on the rise, even among professionals and managers (Cohany, 1996; Kalleberg *et al.*, 1997). Computers and other digital technologies have eliminated some types of work, created others, and transformed a significant portion of what remains (Penn *et al.*, 1994). Work that formerly required direct operations on materials can increasingly be performed remotely. The ability to collaborate in distributed teams is more important than in the past (Hinds and Keisler, 2002). Under team systems, even factory workers may require interpersonal and analytical skills previously reserved for managers and engineers (Bailey, 1998).

For these reasons, industrial engineering once again faces great challenges and opportunities. Like the field's founders, who confronted the transformation associated with the rise of the modern factory, we face a shift in the nature of work occasioned by a changing technical infrastructure. This shift is marked by the spread of information technologies, microelectronic controls and biotechnological tools that are every bit as revolutionary as were dedicated machines and electric motors 100 years ago. Industrial engineers' varied attempts to grapple with these changes have been hampered by limited images of work and the workplace.

For example, ergonomics has changed considerably over the last several decades. Whereas in the 1950s most human factors research concerned "knobs and dials," today many ergonomists study the perceptual and cognitive loads that complex information systems create for white-collar, professional and military occupations. However, despite this change in focus, ergonomics' underlying model remains the relationship between a single individual and his or her machine (Chapanis, 1976). The model of the individual user has enabled ergonomists to champion many important modifications in design that have been crucial to the development of safer airplane cockpits, better computers and less taxing work spaces. However, focusing on human-machine interfaces and on problems that can be studied in the lab has left ergonomists with little to say about how technologies fit into and modify work processes outside of highly controlled and easily simulated environments. Focusing on the user as a biophysical perceiver has also directed attention away from interactions among individuals and their joint use of technology. Yet, studies by sociologists, anthropologists and computer scientists indicate that taking social dynamics into account is essential for successfully designing and deploying information technologies (Orlikowski, 1992; Thomas, 1994; Orr, 1997).

This paper begins by tracking the decline of work studies in industrial engineering over the past century. It explores the question of why industrial engineering lost its concern for work and, ultimately, its ability to speak to the kinds of social and economic changes that it was created to address. Our reading of historical documents and our analysis of data collected from nine industrial engineering departments reveal that changes in industrial engineering were tied to social trends, to shifts in sources of funding, and to the field's concern with its own status. We follow the analysis of how and why industrial engineering distanced itself from work with a discussion of how work has changed in the past 50 years to show that industrial engineering is now ill-positioned to address issues of modern work system design. We explain why the time has come for the field to rekindle its interest in the nature of work and the particulars of the workplace and suggest several paths for proceeding in this direction.

2. Methods

Because the question of what happened to the study of work in industrial engineering is a matter of history, its answer requires historical methods. Accordingly, we base our analysis on documents, on oral histories that we collected from long-tenured Industrial Engineering (IE) faculty and on data on course offerings from IE departments. Although course bulletins do not document the research that IE faculty may have actually conducted, they do provide a credible record of topics and approaches that the field saw as legitimate during particular historical eras. Moreover, though faculty may have done research on topics that had not yet entered the curriculum, it is reasonable to assume that when topics disappeared from the curriculum, faculty had ceased researching them.

We chose to study nine research-oriented IE departments whose foundings span the first and second halves of the 20th century. The four departments founded prior to World War II were Pennsylvania State University (1909), Columbia University (1921), University of Michigan (1924), and Ohio State University (1925). (These dates represent the first year that each department listed courses in its school's catalogue. In some instances, founding precedes listing by a year or two.) Those founded after the war were University of Southern California (1945), Georgia Institute of Technology (1946), Stanford University (1950), University of California, Berkeley (1955) and Purdue University (1956). This group includes the first IE department ever established (Penn State), the founder of the Institute of Industrial Engineers (Ohio State) and the founder of *IIE Transactions* (Georgia Tech).

The first step in developing our database on IE courses was to visit each of the nine campuses to photocopy relevant sections of yearly course catalogues. These photocopies contained course titles and descriptions for every undergraduate and graduate course offered by each department from its founding to the present day: a total of 26 000 courses spanning 92 years. (Our analysis would have been enhanced with information on syllabi, textbooks and instructors, but such information was rarely available. In addition, we excluded from our analysis courses that might have been required but that were offered outside the IE departments (e.g., industrial psychology or sociology). We did so because our concern is not with the courses deemed necessary for a complete education of an industrial engineer (one might as easily include calculus and physics), but rather with the courses whose inclusion in the curricula implies their centrality to the department's image and focus.) The second step in preparing our analysis was to develop a set of codes for categorizing the subject matter of these courses. Following accepted practices for qualitative data analysis (Miles and Huberman, 1984), we developed an initial set of codes for the courses offered by one IE department and wrote short descriptions defining each code. We then employed a research assistant, who was unfamiliar with the study's purpose, to code a second department's courses using the categories and descriptions that we developed. This procedure allowed us to assess the adequacy of our codes and to refine them without incurring the risk of informed bias. All three researchers discussed and resolved differences in interpretation. The assistant then used the refined set of categories to code the remaining departments' courses.

Fourteen content categories emerged from this process: (i) shop practices and factory methods; (ii) production systems; (iii) motion and time studies and work measurement; (iv) ergonomics; (v) job design; (vi) organizations and management; (vii) computers and information systems; (viii) accounting, finance and engineering economics; (ix) quality control; (x) optimization; (xi) simulation and stochastic processes; (xii) decision and risk analysis; (xiii) probability and statistics; and (xiv) miscellaneous courses (e.g., directed research, independent study, senior design projects and other courses with no specified content). On the basis of our coding we built an electronic database consisting of tables that recorded the annual number of courses taught by each department in each of these 14 areas.

We collected oral histories from senior faculty in eight of the nine departments. (No member of the ninth department was qualified to talk to us about the history of work studies and all relevant emeriti had passed away. In fact, a problem we faced in conducting this research was mortality among industrial engineers who were involved with work studies prior to the 1950s. Ten years from now oral histories of the type that we collected may be impossible to gather.) We identified these faculty from department Web sites and by asking younger faculty to refer us to colleagues whom they believed would be best positioned to speak on the history of work studies in their department. The interviews were structured around a small number of open-ended questions designed to elicit the informant's memories of events and attitudes that shaped the fate of work studies in his department.

We began the interviews by defining work studies for informants. We used the following definition: "Research and teaching that takes as its primary focus how humans work in organizations. We include in this term the following areas: motion and time studies, human factors, job design, ergonomics, and efficiency studies." The following were among the questions that we subsequently asked: how has the area of work studies developed over time at your school? What role did computerization and information play in the history of work studies? What were the research questions of interest among the work studies faculty and how or why did they change over time? We used the informants' responses to help us interpret trends in the course data.

3. The history of work studies in IE

Work studies encompasses four of our coding categories: (i) shop practices and factory methods; (ii) motion and time studies and work measurement; (iii) ergonomics; and (iv) job design. The history of work studies in IE can be divided into two periods roughly separated by World War II. The first period, beginning shortly after the turn of the century, was defined by an almost exclusive focus on actual shop practices. The post-war period saw a rise in the founding of IE departments, a decline of shopfloor studies, and the emergence of ergonomics and job design. Work studies dominated the curricula of IE departments in the first period, but in the second, it competed with and was quickly overshadowed by a move to more abstract mathematical and quantitative analyses.

3.1. *The pre-war era*

3.1.1. *The birth of IE*

In the 1880s engineers became increasingly interested in organizing the chaos of factory systems (Nelson, 1975; Shenhav, 1999). Mechanical engineers in that era were responsible for maintaining physical plant, overseeing production processes and designing equipment. Because these engineers were enmeshed in the everyday operation of the factory, some began to experiment with what we would today call organization design. During the last two decades of the 19th century, mechanical engineers wrote a number of books and papers outlining schemes for improving management's coordination and control (Metcalfe, 1885; Towne, 1886; Halsey, 1891; Taylor, 1895). Known as "systematic management", these schemes were of three types: (i) cost accounting systems; (ii) production control systems; and (iii) wage payment plans (Litterer, 1963). In 1886 Henry Towne, the president of the American Society of Mechanical Engineers, argued that because no management associations existed, the ASME should fill such a role (Towne, 1886). Towne's call was not heeded despite systematic management's growing influence in the engineering literature (Nelson, 1975).

Finding little support within their own discipline, mechanical engineers with managerial interests formed the first IE departments. They brought with them a craft-oriented expertise in machine design, plant layout, tooling and shop processes such as grinding, milling, polishing and welding. The earliest courses reflected this blend of interests. For example, when Penn State founded the first IE department in 1909, it offered courses entitled "Shop Methods," "Pattern Shop and Foundry Tools and Methods," "Manufacturing Accounts," "Shop Economics," "Factory Planning," "Shop Systems," "Accounting and Cost Keeping," and "Shop Time Study." To the degree that economics, accounting and management were taught, they were integrated with the study of physical processes, as the following description of "Shop Economics" shows:

> "Economic theory of factory location and of general arrangement of buildings and departments. Equipment of various shop departments and economical arrangements and operation of same. Power, light, heat, ventilation, sanitation, and transportation arrangements. General organization and management. Departments and departmental reports. Cost, time-study, labor-efficiency, wage-systems, and welfare methods." (Pennsylvania State College Bulletin, 1909–10, p. 169)

Between 1910 and 1912 a series of events transformed the systematic management movement almost overnight from the preoccupation of a handful of mechanical engineers into what became the first American business fad (Barley and Kunda, 1992). In 1910, the Eastern Railroad requested a rate increase from the Interstate Commerce Commission (ICC). On behalf of industrialists who felt that rates were already too high, Louis Brandeis argued before the ICC that had the railroad been managed more efficiently, it could have met its costs without raising prices (Nelson, 1980). Testimonies that Brandeis solicited from Frederick Taylor and other efficiency experts became the centerpiece of the hearings and the term "scientific management" was coined during the hearings (Haber, 1964). Taylor used the Eastern Railroad rate case to popularize his views and, shortly thereafter, wrote his most famous tract, *The Principles of Scientific Management* (Taylor, 1911). Harrington Emerson, a self-proclaimed spokesman for the movement, published two even more popular books lauding the benefits of efficiency (Emerson, 1912; 1914). These and other developments occasioned a public mania, known among historians as the "efficiency craze" (Haber, 1964).

Scientific management's ideas and rhetoric immediately filtered into the curricula at Penn State. In 1912 Penn State began a course entitled, "Principles of Industrial Engineering". The original description read: "The fundamental considerations as to materials, machines, and management which enter into the work of the Industrial Engineer." One year later, the description was amended to reflect Taylor's influence: "*The field and methods of the science of management* and the fundamental considerations as to *men*, materials, machines, methods, and *organization* which enter into the work of the '*efficiency*' *or* industrial engineer" (italics added). The text was Frank Gilbreth's *Primer of Scientific Management* (Gilbreth, 1912) whose preface was written by Brandeis. In the same year Penn State began a course entitled, "Scientific Management" for which the texts were Taylor's *Shop Management* (Taylor, 1903) and Frederic Parkhurst's *Applied Methods of Scientific Management* (Parkhurst, 1912).

3.1.2. *Scientific management's limited role*

Many people associate early IE with the study of work because they tie the field to Taylorism. But, in fact, scientific management had limited influence on IE's curricula beyond Penn State. The other departments in our sample founded in the pre-war era showed almost no interest in scientific management aside from motion and time studies. Ohio State's curriculum was nearly devoid of scientific management's rhetoric. Although Ohio State offered courses in "Work Analysis" and "Standardization and Simplification", the first course focused on machine speeds and fabrication and the second made no mention of efficiency, motion or time. Instead, "Standardization and Simplification" emphasized tools and equipment and defined standards as universal systems of measurement. The course description read:

> "The importance of standards of design, of processing, of performance, of tools and of equipment. The work of the national engineering societies, government bureaus, and progressive plants in standardization and simplification." (Ohio State University Bulletin, 1926–27, p. 97)

Ohio State did not launch a course in "Time and Motion Study" until 1935. The University of Michigan followed a similar pattern. In 1924 it began a course entitled "Standardization of Labor", whose description read, "The course treats on [*sic*] the employment of labor, wage payment in relation to standardized conditions and the position of labor in manufacture." (University of Michigan Catalogue and Register, 1924–25, p. 522). Conspicuously absent were references to efficiency, motion or time. Moreover, the course was dropped in 1928 leaving behind only courses in shop practice.

At Columbia the story was more complex. Although founded and chaired for 30 years by Walter Rautenstrauch, a self-proclaimed Taylorite, the department offered no courses that reflected Taylor's rhetoric (Emerson and Naehring, 1988). Four of the six courses that Columbia offered in 1921 had "manufacturing" in their title. One was an internship, one was about production planning and two covered shop practices. The description of "Manufacturing Processes" left no doubt about its shopfloor orientation:

> "Analysis of the operations performed in the cutting, sawing, stamping, milling, grinding, forging, moulding, and otherwise forming of metal products. Analysis of the

characteristics of machines commonly employed in metal working plants". (Columbia University Bulletin of Information, 1921–22, p. 75)

The other two courses revolved around finance and accounting. For example, "Specifications of Productive Methods" was an early course in engineering economics despite its title. The course was "intended to develop methods of analysis by which the machinery and equipment is selected for manufacturing a selected commodity at a given yearly rate as well as the preparation of a financial budget to cover its operations" (Columbia University Bulletin of Information, 1921–22, p. 76). Compared to similar courses at other schools, Columbia's language was unique: it couched shopfloor issues in the terminology of finance and economics. What it did not do was employ the rhetoric of scientific management. In fact, Columbia joined the Department of Sociology in teaching a course on "Contemporary Social Problems" before it launched its first course in motion and time studies in 1939.

The question that begs answering is why scientific management had so little influence on IE departments other than Penn State? The easy answer is that Taylor was personally involved in Penn State's development. In 1907 Taylor recommended Hugo Diemer for the chair of Penn State's mechanical engineering department (Emerson and Naehring, 1988). Diemer had taught the first IE course in the nation at the University of Kansas and founded Penn State's IE department a year after his arrival. Nevertheless, because Taylor's ideas were widely known, one would think that his influence would have extended beyond Penn State. To explain why it did not, we need to situate the founding of IE departments with respect to the intellectual history of the day.

By the end of World War II, enthusiasm for efficiency had cooled (Barley and Kunda, 1992). Industry had resisted the majority of Taylor's ideas with the exception of motion and time study. Industrialists saw Taylor's notion that engineers were the proper designers of organizations as an attack on ownership's prerogatives. Meanwhile, attempts to install motion and time studies had precipitated a number of labor strikes that attracted national attention (Edwards, 1979), and several widely publicized studies had discredited Taylor's notions of systemic change (Hoxie, 1915; Anon, 1921). Scientific management's inability to substantially reduce waste and lower costs, doubt about its ability to uncover laws of production, as well as its more obvious failure to bring about an industrial utopia, led many advocates to modify their stance. Even before World War I, a number of Taylor's devotees, including Lillian Gilbreth and Henry Gantt, had begun to admit that scientific management was no panacea for industry's ills (Barley and Kunda, 1992).

This was the social and intellectual climate into which most early IE departments were born. One must remember that only four IE departments were founded before 1920 (Emerson and Naehring, 1988). Aside from Penn State and Columbia, which we have discussed, departments existed at New York University and the University of Kansas. The latter had disbanded by the late 1930s. In short, scientific management was on the wane before most IE departments began. In general, motion and time studies and methods analysis were the only parts of scientific management that IE departments adopted, largely because they were popular in industry and because employers expected graduates to understand their use.

3.1.3. *The reign of the shop*

Notwithstanding scientific management's minimal influence, pre-war IE is rightfully regarded as a field centered on the study of work, especially the grounded study of work practices. Shop courses taught actual techniques for converting raw materials into products: forging, welding, cutting, stamping, sawing, milling, grinding, polishing, pulverizing, pattern making, jig making and so on. To study such processes was to study work. Figure 1 shows that the situated study of shop work continuously overshadowed scientific management's more analytic approach to work systems throughout the last century: even today shop courses still outnumber courses on motion, time, work measurement and other topics associated with scientific management. (Figure 1 displays the percentages of the total number of courses taught in all departments (rather than an average of departmental percentages) to avoid single departments skewing the data. The same is true for Figs. 4, 6, and 7.)

Figure 1 also leaves no doubt that work studies defined IE as a discipline in the pre-war era. Until 1932 work studies courses accounted for more than 50% of the curricula of the departments in our sample. Afterward, they hovered around 40% until the end of World War II. For evidence that industrial engineers of the day saw themselves primarily as students of shop work, one need look no further than the names of departments. From 1925 to 1935 the University of Michigan called its IE department, the Department of Shop Practice. In 1934 the name changed to Metal Processing. It was not until 1952 that Michigan introduced "industrial engineering" into the department's title. Likewise Ohio State's program was initially called "Shopwork". Today, Ohio State's Department of Industrial, Welding and Systems Engineering still acknowledges its shopfloor roots.

Although work studies and a shop culture clearly characterized IE in the pre-war years, Fig. 1 shows that shop courses steadily declined over the century as a percentage of the total courses taught and that the decline began before World War II. Figure 2 sheds light on what happened. As the figure shows, shop courses accounted for almost all IE courses until 1922. After that, the number of other courses exploded. Meanwhile, the number of shop courses remained roughly the same.

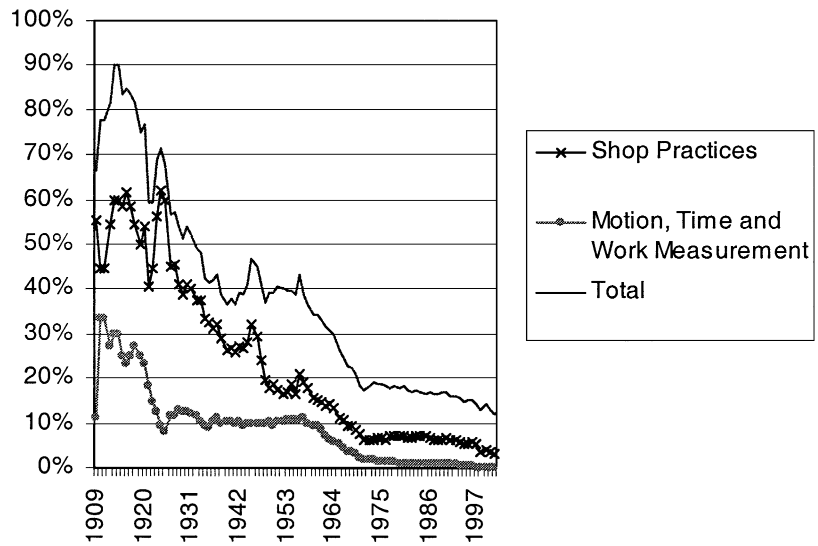

Fig. 1. Percent of IE courses on shop practices and on motion, time and work measurement.

3.2. *The post-war era*

3.2.1. *The changing face of IE*

Stinchcombe (1965) argued that organizations born in different eras exhibit different organizational structures. This was certainly true for IE departments. Figure 3 plots the average number of shop courses taught since 1909 in departments founded before and after World War II. The graph shows that departments founded after the war taught, and continue to teach, far fewer courses on shop work. Purdue and Berkeley initially taught a number of shop courses and account for the post-war peaks in 1956 and 1963 respectively. Berkeley eliminated these courses from its curriculum in 1966. One year after its founding Purdue moved all of its shop courses to a program intended primarily for supervisors and foremen. Interestingly enough, Columbia had done the same in 1947. In fact, Columbia and Michigan had eliminated almost all shop courses by the 1970s, leaving Penn State and Ohio State as the only schools in our sample that remain significantly invested in teaching shopfloor knowledge.

Although interest in shop practices declined after the war, interest in work did not disappear. Instead, the nature of the interest changed and evolved along two paths. The first path was job design and the second was ergonomics. As Fig. 4 indicates, job design began earlier and peaked soon thereafter, whereas ergonomics grew until 1975 when it began to plateau. The impetus behind IE's interest in job design lay in the rise of the human relations movement and attempts to institutionalize collective bargaining following the war. Ergonomics grew out of the military's wartime discovery that well-designed man-machine interfaces were crucial to a person's ability to operate complex technologies (Chapanis, 1976).

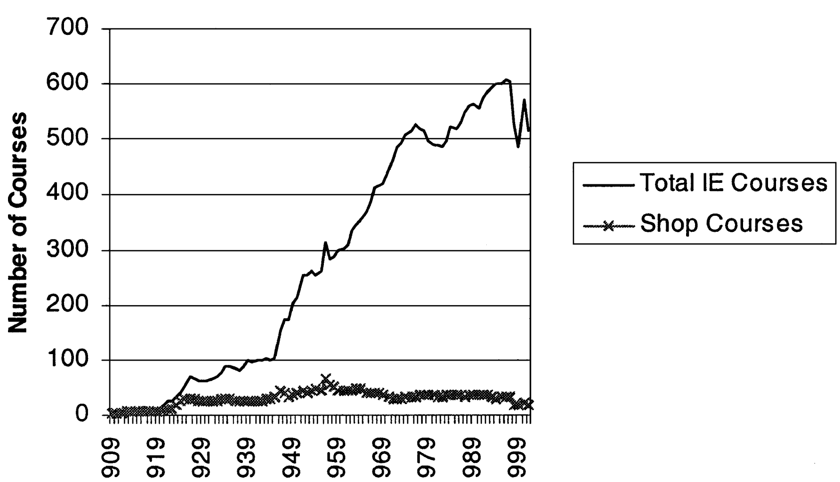

Fig. 2. Number of IE and shop courses taught annually.

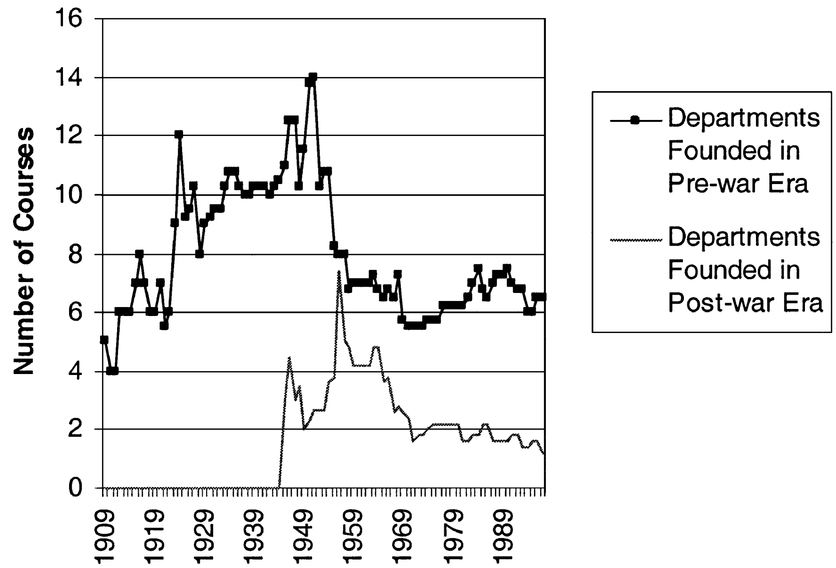

Fig. 3. Average number of shop courses taught by departments founded before and after World War II.

3.2.2. *Job design*

Although the human relations movement began in the late 1920s and 1930s with the Hawthorne studies (Roethlisberger and Dickson, 1934), it did not gain widespread support until after World War II, when corporate experimentation with techniques for enhancing loyalty, motivation and satisfaction blossomed almost overnight. Researchers and managers alike were convinced that improving morale and treating workers more fairly could enhance productivity. Shopfloor interventions included innovative compensation systems, schemes for participatory decision-making and job enrichment (Lewin, 1951; Lesieur, 1958; Hertzberg *et al.*, 1959). The philosophy of the human relations movement informed state and federal policies whose intent was to reduce hostility between labor and management and, hence, the odds of strikes. In the late 1940s a number of states founded schools of industrial and labor relations that were charged with institutionalizing the system of collective bargaining.

The tone of the human relations era quickly pervaded IE departments. Not only did industrial engineers become interested in designing work systems that enhanced morale and participation, but they began to teach courses on industrial and labor relations. (Although Penn State offered a course in "Industrial Relations" as early as 1920 and a course in "Personnel Relations" in 1921, the description and timing of these courses indicate that they were responsive to the surge of interest in welfare capitalism during the Progressive period.) Louis Davis, who taught at Berkeley in the 1950s, became a well-known advocate of job design. For a period of time, IE departments seemed to believe that their students needed to understand the role of labor in

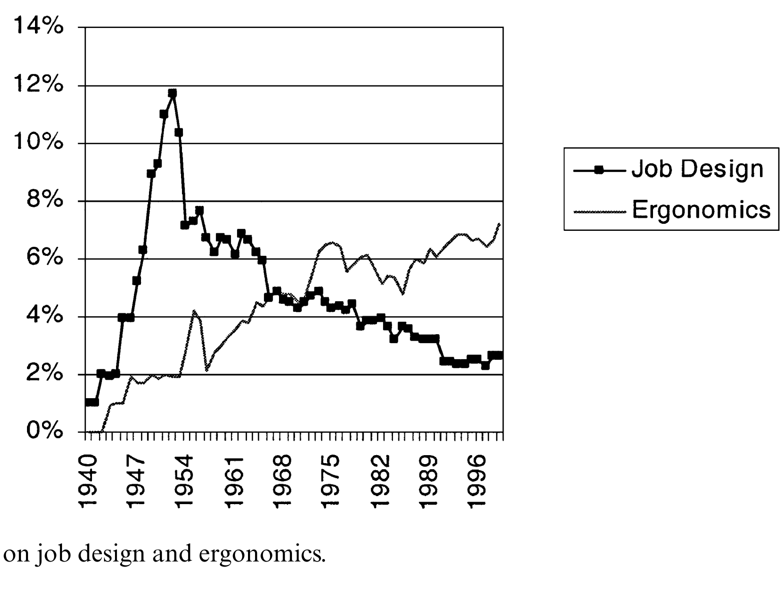

Fig. 4. Percent of IE courses on job design and ergonomics.

industry and the mechanics of collective bargaining. For example, Purdue's department was founded in 1955, just as the human relations movement was burgeoning. Tellingly, its new curriculum contained a course on "Industrial Relations" as well as a course on "Labor Relations". Although these courses were dropped a year later, the topics were taught in a number of other courses until 1963. Georgia Tech taught graduate courses in "Collective Bargaining" and "Job Evaluation". Among the schools in our sample, none was more heavily influenced by human relations than Columbia. In 1952 alone, it offered 11 courses in this area, including "Industrial Personnel and Labor Relations", "Industrial Relations for Engineers", "Job Evaluation", "Selection and Training", "Personnel Factors in the Design of Productive Operations", and "Personnel Techniques". Although courses in job design accounted for just over 10% of IE courses in the early 1950s (see Fig. 4), by the mid 1960s industrial engineers' interest in human relations waned and the number of courses steadily declined.

3.2.3. *Ergonomics*

More in tune with IE's identity was its embracing of ergonomics. At least philosophically, ergonomics was consistent with IE's interest in shop methods and motion. Like students of motion and time, ergonomists approached work as a biophysical process and focused on how humans interacted with machines. But whereas Taylorites attempted to change the worker's behavior, ergonomists redesigned tools and technologies. Moreover, ergonomics departed from early IE's worship of efficiency by championing effective use and human safety. Finally, whereas scientific management was field-based, ergonomics was situated in laboratories and often required sophisticated instruments.

In general, industrial engineers perceived ergonomics to be more "scientific" than scientific management. Our informants consistently contrasted the scientific aura of ergonomics with what one informant called the "hokiness" of scientific management. Informants at all schools told us that during the 1960s IE became increasingly concerned with its status as a technical discipline. "The issue", explained a USC professor, "was what constituted good engineering studies. How could IE be a 'basic' engineering field?" The emphasis was on becoming "academically respectable". Despite its name, scientific management could not provide the technical legitimacy that industrial engineers sought:

> "Taylor emphasized science because that was a big movement in those days. But what he labeled "science" is not what we would consider science. His studies were, at best, crude. What he was doing was a more systematic job at collecting data. Gilbreth's therbligs were an attempt to use the science model. It was great work in improving efficiency, but it certainly wasn't "scientific" as we use the term today. Time and motion became less important because there wasn't going to be much scientific progress in what was a subjective field." (USC professor)

A professor at Purdue added, "People perceived that work methods and measurement didn't have a scientific base and didn't provide the prestige that academics were looking for". A Penn State professor concurred:

> "Work measurement used field studies and was not mathematically sophisticated. In traditional work measurement they didn't get into modeling. They used numbers, but this is not the same thing as building models or trying to understand human behavior."

Ergonomics also brought industrial engineers new opportunities for funding. By the 1950s neither industry nor government was interested in research on motion, time or work methods, but both were anxious to fund research on human-machine interfaces and operator safety. The availability of funding facilitated the shift away from motion and time studies. A professor at Michigan explained, "We were picking up research grants in the area of ergonomics and we required faculty. The whole idea of safety, ergonomics, was heavily supported by the government. They didn't care about *productivity.* They cared about how long it took to learn things." Additionally, unlike motion and time studies, ergonomics garnered moral, and even financial, support from unions because it promised to make jobs safer and easier.

The shift to ergonomics changed the flavor of work studies in IE. Although job design bolstered IE's pre-war interest in studying work *in situ*, ergonomics encouraged industrial engineers to leave the field for the laboratory. As a result, work studies became increasingly distant from the actual work that people perform. Ergonomics also had the side effect of defining work primarily as the individual's relationship with tools and machines. Gone from the picture were the notion of a work system and an appreciation for the fact that work is embedded in a social context marked by dependencies and interactions.

Although the shift to ergonomics partially represented a changing epistemological paradigm, the move also reflected pragmatic concerns. As "publish or perish" became the watchword in American universities, industrial engineers could less easily afford fieldwork. In comparison to laboratory work, fieldwork yielded far fewer publications and at a slower pace. A professor at Purdue explained the problem:

> "Twenty years ago I had a large NSF grant: A million dollars. We monitored 60 workers eight hours a day. In the end, we got only two publications. I could do it because I was a full professor. If you do fieldwork, you can't produce the type of things you need to do to get promoted. It just doesn't seem to work. I had another one, a NIOSH study. I got one publication!"

Although all IE departments in our sample have, at one time or another, offered courses in job design and ergonomics, work studies never again dominated IE curricula as it did before World War II. Stanford and Berkeley eventually dropped ergonomics, albeit for different reasons. In Stanford's case, the cost of running an ergonomics program was simply too high for it to compete with other departments. When Stanford lost its last professor of ergonomics in the late 1970s the faculty

> "... had a long discussion about to do. Should we replace [him] with someone who could do ergonomics and time and motion? I was convinced that we should not, but that we should hire an organizations person because other departments had ergonomics covered. Michigan, Purdue, Virginia Tech would have about five people working in that area. They had labs. We didn't have a lab and we saw no hope of getting one". (Stanford professor.)

At Berkeley the move from ergonomics led to an emphasis on robotics. A Berkeley professor explained, "We had discussions of critical mass. We didn't think we'd be able to support [ergonomics] in a small department. We chose robotics because manual labor is a steadily decreasing proportion of GNP. Robotics brings ties to EE's and ME's. This is good for us."

Ergonomics' incomplete diffusion partially accounts for the diminished role of work studies in IE after the war, but the larger reason for its decline lay in a fundamental change of the field's intellectual orientation. As Fig. 5 shows, the percentage of work studies courses plateaued between 1936 and 1956. After this period an explosion of courses in other areas quickly dwarfed work studies of all kinds. Figure 6 reveals that this explosion occurred primarily because of a geometric increase in the number of courses relying on some form of mathematical analysis. Economics, finance and accounting, which had long been the quantitative staple of IE's curricula, actually declined during this period as did courses on organization and management. The field of computers and information systems entered IE after the war, but has never accounted for more than 5% of IE's total offerings. Figure 7 clearly shows that courses in optimization, production, simulation and stochastic processes drove the quantification of IE. As with ergonomics, the growth in these areas was tied to the events of World War II.

During the war, the British and American military employed teams of mathematicians, physicists, and statisticians to devise methods for solving logistical problems (Trefethen, 1954). Working with early computers, these "operations research teams" were so successful that after the war each of the services established its own operations research unit (Wren, 1972). Operations research quickly spread from the military to industry in the early 1950s. Hertz estimated that by 1954 at least 25 firms had established formal operations research groups and that as many as 300 analysts worked in industry (cited in Burack and Batlivala (1972)). By the mid-1960s queuing theory, decision analysis, network analysis, simulation techniques, and theories of linear and dynamic programming were sufficiently well developed to be used by large corporations, and a number of universities had already established programs leading to doctoral degrees in operations research (Anon, 1971).

IE embraced mathematically-oriented forms of analysis for much the same reasons that it turned to ergonomics. First, funding for optimization, production, decision analysis and similar fields became plentiful after the war. Not only were industry and the military willing to invest large amounts of money in the development of mathematical models and other tools for decision-making, but the National Science Foundation also made mathematical analysis a target of growth in the 1960s and 1970s. Second, like ergonomics, mathematical analysis played to the industrial engineers' desire for scientific legitimacy. In fact, having a vibrant operations research program quickly came to define what it meant to be a cutting edge department of IE:

> "When Lehrer came back as director of school of IE (after 1965), he put in a program that came out of operations

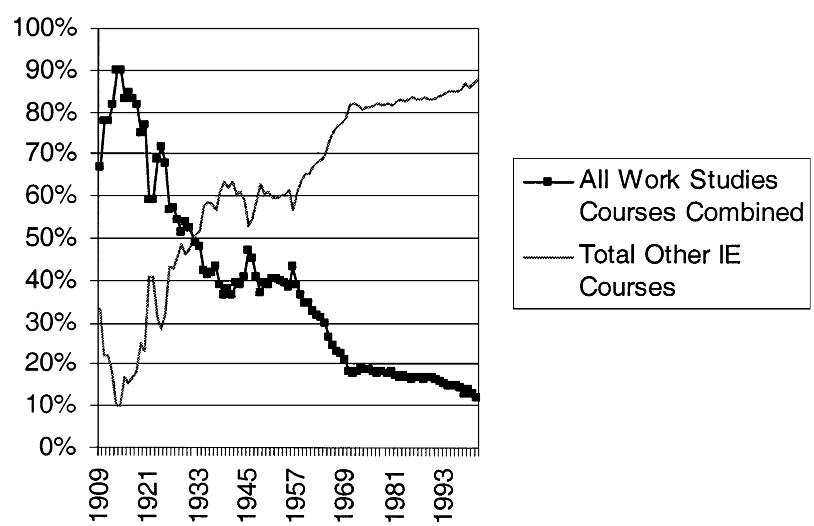

Fig. 5. The relative balance of work and non-work courses in IE curricula.

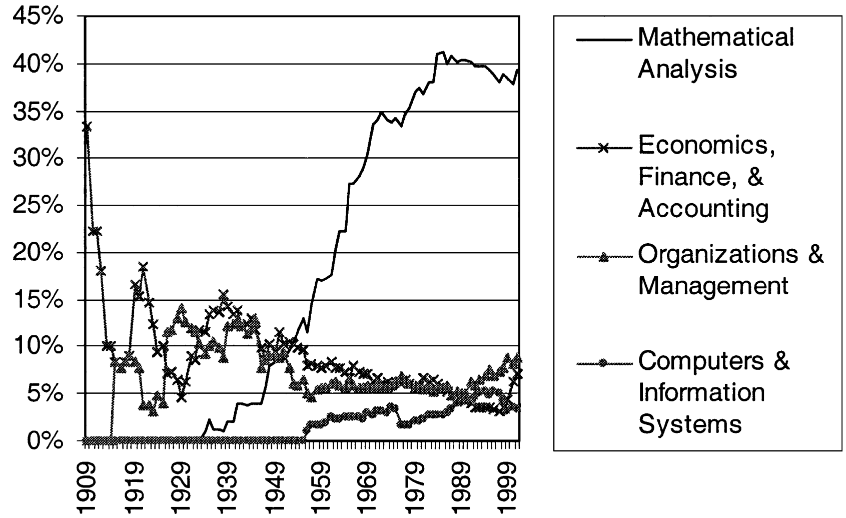

Fig. 6. Other IE domains as a percentage of total courses.

research. He didn't bring in more people so much as people changed their area of research. More math. More operations research. Probability theory. Game theory. The new things that were coming out then. This was the trend in the country. To be a progressive school you had to do this. Work studies was important, but never dominant (in the post war era.)" (Georgia Tech professor)

What Lehrer took to be a progressive department was explicitly defined in 1967 by the influential "Roy Report," an examination of IE curricula commissioned by the American Society for Engineering Education and the National Science Foundation. The committee consisted of Lehrer and representatives of five other major universities (Cornell, Stanford, Purdue, Oklahoma State, and Johns Hopkins). The report outlined an ideal curriculum matched to "current trends in education and professional practice". The committee strongly recommended that industrial engineers be exposed to the social sciences. Moreover, they advised IE departments to "develop special programs, focused more specifically upon behavior at the technological-sociological interface" (Anon, 1967, p. 512). But as we have seen, few departments heeded the call. What IE departments did notice was the committee's strong advocacy for mathematics, probability, statistics, numerical analysis and operations research. The committee also noted that motion and time study, wage incentives, job evaluation, tool design were among the topics that had long epitomized IE, but argued that they no longer defined the field:

"These skills no longer comprise . . . the frontiers of Industrial Engineering knowledge . . . Most work of this kind

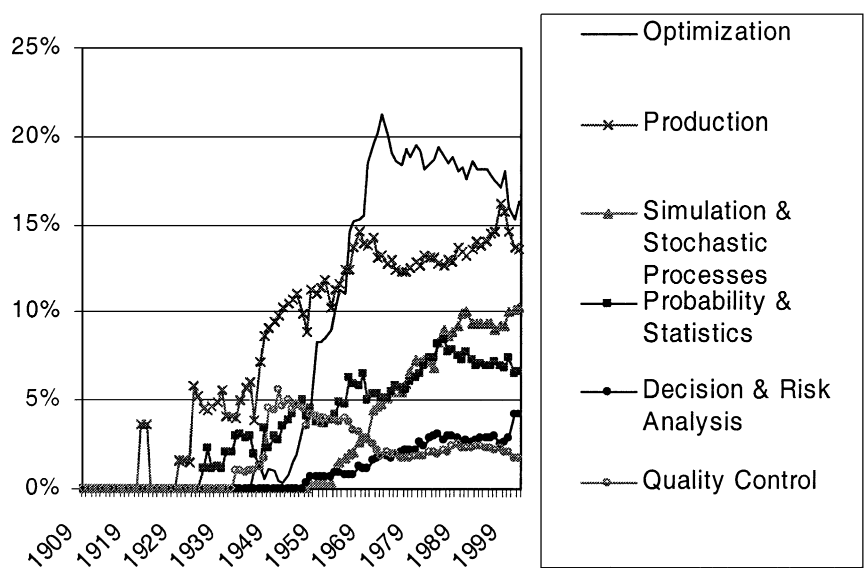

Fig. 7. Mathematical analysis courses as a percentage of total IE course by type.

> today is . . . in the hands of technicians, and the technical institutes seem best fitted to impart instruction in these important areas . . . We believe knowledge of these areas to be important to the professional Industrial Engineers of tomorrow (but that it) can be acquired by minimal exposure to courses with much greater emphasis upon engagement with unstructured, open-end design problems . . . (These techniques) deserve a place in Industrial Engineering but they no longer *are* Industrial Engineering. ((Anon, 1967, p. 515), emphasis in original.)

In short, the Roy Report marginalized all forms of work studies in favor of quantitative methods. The committee suggested that it was acceptable for instruction in human factors and ergonomics to be outsourced to psychologists (p. 512). They relegated job design and motion and time studies to the background of design courses (p. 515) and they deemed shop courses to be no longer "appropriate in programs directed toward the education of professionals" (p. 514).

Together, the post-war trends that we have been discussing led to the current state of affairs in IE. Although most IE departments still offer some work studies courses, these courses represent a small percentage of every department's curriculum. Moreover, as we saw in Fig. 4, ergonomics today comprises most of IE's work studies curricula. Ergonomics' contributions have been critical to improving the design of technologies and workspaces, and ergonomists have bettered the lives of large numbers of workers. Yet, of all the approaches to work studies that we have discussed, ergonomics is the most distant from work itself. This distancing is especially problematic because work has changed considerably over the last 50 years.

4. The changing nature of work

Although IE's retreat from the study of work and work systems undoubtedly helped the field build and sustain legitimacy in schools of engineering, what was a reasonable strategy in the 1960s and 1970s has today become an Achilles' heel. As Table 1 shows, over the last half-century changes in technology and the nature of the economy have slowly transformed the work that people do. Traditional factory jobs, as they were understood at mid-century, began to decline in the 1950s, just as industrial engineers began to jettison field-based studies of work (Barley, 1996a; Anon, 1999). Operatives and laborers fell from 26% of the workforce in 1950 to 13% in 1998. Moreover, many remaining production jobs have become more analytic and abstract as new technologies have transformed factory control systems (Zuboff, 1989). During the same period, professional and technical jobs expanded dramatically and now account for the largest percentage of all employed Americans. Their share of the labor force increased from 8% in 1950 to 18% in 1998. Since 1950 service jobs have increased by 5%, sales workers by 4% and managerial workers by 2%. As a result of these changes, our concepts for thinking about work are out of date: our systems for classifying occupations are obsolete; our cultural dichotomies for distinguishing types of work are antiquated and our occupational archetypes are outdated.

4.1. *Occupational classifications*

Occupational sociologists generally agree that the detailed categories by which the US government classifies jobs are outdated (Attewell, 1990). For instance, since 1939 the Department of Labor has only incrementally revised *The Dictionary of Occupational Titles (DOT)*, which still presents the best source of data on the content of jobs in the US economy. As a result, analysts can make much finer distinctions among blue-collar work than among managerial, clerical, service, sales, professional or technical work. For example, even though software development is divided into a large number of specialties, we have but one word for describing such work, computer programming. Cain and Treiman (1981) report that 76% of the listings in the most recent edition of the *DOT* (Anon, 1977) cover blue-collar jobs. Yet, only 26% of all employed Americans are blue-collar workers (a decline of 14% since 1940). Seventy-two

Table 1. Occupational categories as a percentage of the labor force: 1900–1991

	Percentage in											
Category	*1900*	*1910*	*1920*	*1930*	*1940*	*1950*	*1960*	*1970*	*1980*	*1988*	*1998*	*Net % change*
Farmworkers	38	31	27	21	17	12	6	3	3	4	3	−35
Professional/technical	4	5	5	7	8	8	10	14	15	16	18	14
Craft and kindred	11	12	13	13	12	14	14	14	12	11	11	0
Operatives/laborers	25	27	27	27	28	26	24	23	18	14	13	−12
Clerical and kindred	3	5	8	9	10	12	15	18	17	19	17	14
Service	9	10	8	10	12	11	12	13	13	16	16	7
Managerial/administrative	6	7	7	7	7	9	8	8	10	10	11	5
Sales workers	5	5	5	6	7	7	7	7	11	10	11	6

Note: Percentage employment by occupational category from 1900 to 1970 was calculated from employment data presented in Anon (1976, p. 139). Data for 1980 were taken from Klein (1984) and data for 1988 and 1998 are taken from Braddock (1999).

percent are employed in some form of white-collar or service work (an increase of 28% since 1940). Thus, our most systematic image of what work is like is based on categories developed for an economy that existed somewhere between a quarter and a half a century ago.

4.2. *Cultural dichotomies*

Our everyday concepts for talking about work are also relics of the industrial revolution. Dichotomies such as blue-collar and white-collar, mental and manual, and exempt and non-exempt are the legacy of a world in which one's standing rested, in large measure, on whether one's hands were clean or dirty at the end of the day. Although these distinctions are still important, their utility wanes with each passing year. For example, low-skilled service jobs may be just as unappealing and as routine as factory work, but they cannot be easily classified as blue-collar or even manual in the traditional sense of the term. The distinction between manager and worker also less adequately signals the nature of a person's work and status than it once did. Workers today are as likely to be engineers or programmers as they are machinists; managers and administrators are as likely to have no employees as they are hundreds. These changes fundamentally undermine the traditional notion that productivity gains are to be made primarily on the shopfloor. In fact, they challenge traditional notions of productivity altogether. For example, industrial engineers readily recognize that the length of the product development cycle directly affects market share. Yet, we know almost nothing about the actual work processes of product developers (for exceptions, see Kidder (1981), Bucciarelli (1994) and Hardagon and Sutton (1997)). As result we are restricted to the use of metrics such as "on time and under budget" to evaluate a complex process of innovation and creativity.

4.3. *Occupational archetypes*

Occupational archetypes or images that structure our theoretical and intuitive grasp of the division of labor are becoming anachronistic as well. As Weber (1978/1914) noted with respect to organizations, archetypes are useful not because they are descriptively accurate (actual instances rarely evince all of the attributes of an archetype) but because they serve as models that assist in thinking about social phenomena. "The-worker-on-the-assembly-line" is one such archetype used extensively by industrial engineers. It invokes the image of an individual, often in an automobile factory, standing beside a swiftly moving conveyor repeatedly performing the same operation on each assembly that flows by. Boredom, fatigue, routine, lack of autonomy and little need for thought or education are the hallmarks of such work. Although factory jobs have always been more variegated than this, the archetype nevertheless evokes a constellation of attributes that once captured a family resemblance among many factory jobs. The clerk, the professional, the secretary, the farmer, and the manager are other prominent archetypical occupations. Archetypical occupations are culturally and theoretically useful. By reducing the diversity of work to a few modal images, archetypes assist us both in comprehending how the division of labor is structured and in assigning status to individuals. They help parents shape their children's aspirations. They provide designers of technologies with images of users. It is not clear how we could think in general terms about worlds of work without such anchors.

The problem, however, is that archetypical occupations are temporally bounded and lose relevance as the nature of work changes. Consider, for example, the archetypical farmer, an independent businessman laboring in the fields from sunrise to sunset with the assistance of a tractor, a few hired hands, family members and little formal education, but extensive practical knowledge of crops, weather, animals, and soils. Modern farming bears little resemblance. Today, many farmers are subcontractors for agri-business, possess a college education, understand chemical properties of soils and fertilizers and manage their farms with the help of computers. Nor is farming the only archetypical occupation whose utility can be questioned. For example, Kern and Schumann (1992) have argued that information technologies in a number of industries have transformed the "worker-on-the-assembly-line" into a "systems controller". Systems controllers are a type of technician, and as Barley and colleagues have demonstrated, technicians' work in no way resembles traditional factory work (Barley and Bechky, 1994; Barley, 1996b; Zabusky and Barley, 1996). Specifically, it is not amenable to rationalization and routinization without sacrificing effectiveness and efficiency.

5. Bringing work back into IE

The historical and interview data provide a springboard for critiquing the current situation in IE and for proposing directions for reintegrating the study of work into the field. We argue that the study of work would benefit from the attention of industrial engineers and that the discipline, in turn, could gain by studying work. We conclude with ideas for how industrial engineers could equip themselves to be students of work in a post-industrial economy.

5.1. *Why does the study of work need industrial engineers?*

At present, most research on work is conducted by social scientists: typically, students of industrial relations, sociologists of work, industrial psychologists and a handful of renegade anthropologists. In comparison to engineers, researchers in these disciplines have greater expertise in the social dynamics of work ranging from power and politics to group behavior as well as the assessment of skills and social relationships. However, because most social scientists are not technically trained, they are less likely than engineers to understand the material properties of technologies and the complexities of modern production processes and to incorporate them into their analyses. It is here that industrial engineers can make an important contribution. Industrial engineers are trained in the physical sciences, computer science and engineering disciplines such as electrical engineering. They are also trained in formalized problem solving and model building, which teaches them, among other things, how to model system dynamics and how to break down system complexities via simplifying assumptions and modularization of system components. As a result, industrial engineers are well positioned to develop grounded assessments of technological aspects of work practices.

5.2. *What could industrial engineers gain from studying work?*

Because industrial engineers gradually distanced themselves from the study of work just as work dramatically changed, they now routinely find themselves addressing problems of the post-industrial workplace with outdated theories and methods. For example, cellular and lean manufacturing initiatives often espouse the use of teams among production operators. Yet, our models of work teams derive primarily from sociotechnical systems research conducted in coal mines in the 1950s, where autonomous teams made use of miners' deeply engrained craft knowledge as new technologies were introduced (Trist and Bamforth, 1951; Herbst, 1974). Today, many production systems are so complex that relevant knowledge has become differentiated and distributed across the organization. Under these conditions, advocating worker autonomy may cause unanticipated problems while not necessarily achieving productivity gains, as Bailey (1998) discovered among team programs in semiconductor manufacturing. She found that as production operators took on preventative maintenance and gained greater autonomy, they threatened the job security of equipment technicians. Engineers also became concerned when teams' statistical process control activities were at odds with their own improvement goals. Furthermore, in asserting their independence, teams also sometimes interfered with kanban systems, circumvented electronic monitoring and attempted to control lot processing. As this example illustrates, designers of modern work systems cannot apply generic work solutions, but rather must work from an intimate knowledge of specific practices, processes, technologies and workplace dynamics.

Thus, the field needs new theories and methods tailored to a highly educated workforce and to a variety of sophisticated workplaces. Engineers are unlikely to develop these tools unless they return to study work *in situ*. By doing so, industrial engineers should be able to speak more knowledgably about work systems whose products are knowledge and information as well as tangible goods, allowing the field to reclaim its legacy as the discipline that specializes in the design of work systems.

The spillover from studying work could also have a broad revitalizing effect within IE as a whole. It is worth remembering that the shopfloor culture that pervaded IE at mid-century provided operations researchers with an empirical understanding of work and production processes, which, in turn, served as a contextual background that informed their models. Operations researchers have noted that, to its detriment, the field subsequently distanced itself from real-world applications (Ackoff, 1979; Bertrand and Fransoo, 2002). Re-emphasizing close knowledge of work practices and processes could enhance the study of production systems, information systems, decisions, risk and other topics in IE in at least two ways.

First, knowledge of work practices can help researchers better specify their models. Consider, for example, the analysis of risk in complex technological systems. Although every craftsman knows that techniques affect quality, few risk analysts take work practices into account when making probabilistic estimates of failure. The value of doing so is nicely illustrated by Elisabeth Paté-Cornell's work on the risk of heat shielding tiles separating from space shuttles when they reenter the atmosphere (Paté-Cornell and Fischbeck, 1993). Unable to devise a satisfactory model on the basis of historical data and expert opinion, Paté-Cornell decided to observe the technicians who install the tiles at the Kennedy Space Flight Center. During her field visit, she discovered a technician who admitted to spitting in the glue to quicken the curing process as he installed tiles. The technician explained that the technique had been devised to help comply with management's relentless pressure for efficiency. Although the practice saved time, it had the unfortunate side effect of altering the glue's tensile strength. Taking spit and other work factors into account (e.g., that there was no notion of priority for applying and inspecting tiles in the most critical areas), Paté-Cornell's new models improved NASA's management of the orbiters' heat shield.

Second, with knowledge of work practices, industrial engineers could blend qualitative and quantitative approaches to yield exciting new approaches and insights. The work of Nelson Repenning at MIT is exemplary in this regard. Repenning routinely draws on fieldwork to build mathematical models that express the social dynamics of workplace systems (Repenning, 2000; Black and Repenning, 2001; Repenning, 2001; Rudolph and Repenning, 2002). Typically, these models sharpen the findings of field research, point to underlying processes whose complexities are difficult to observe, and extend theory in directions that would otherwise prove difficult. For example, Rudolph and Repenning (2002) use prior studies of the Tenerife air disaster and the U.S.S. Vincennes incident to build a model that shows how routine interruptions can build to the point where a self-regulating resilient system is transformed into a fragile, self-escalating one. Repenning (2001) draws on his fieldwork in the R&D division of a major manufacturer to build a model that shows how "fire-fighting" becomes a self-reinforcing phenomenon, especially in a multi-project environment. This paper calls into question the sufficiency of many current methods of resource and product portfolio planning.

Delving into the material aspects of technology and work may also forge stronger links between IE and other engineering disciplines. Knowledge of work and work practices is becoming increasingly important to mechanical engineers, computers scientists and others who design products and processes for users. Because designers generally know little about work systems, industrial engineers could well serve as content experts for the design process. Additionally, one cannot study complex technologies and production processes without learning something about the engineering and science on which they are based. As a result, industrial engineers who study work are likely to become more knowledgeable about the substantive domains of their engineering colleagues. Such knowledge should position them to engage in multi-disciplinary discourse and research. If industrial engineers could prove their ability to translate between work practices and the design of complex technologies, their credibility with members of other engineering disciplines can only grow.

5.3. *What does IE have to do to return to work?*

To recover the study of work, industrial engineers will need to make a number of changes. First and foremost, they will need to return to the field. This, in turn, will require them to recognize that empiricism is a scientific activity. As we have seen, IE turned to mathematical analyses and laboratory studies to assert its claim to scientific rigor. Ironically, however, no matter how important mathematics may be to scientific practice, by itself it is insufficient: all sciences are rooted in empirical observation. In fact, in advanced sciences empiricism usually complements and supports mathematical modeling. We contend that the same is true for IE. The strongest mathematical models of systems are based on a substantive understanding of the phenomena being modeled.

To take work seriously, industrial engineers must also become more knowledgeable about social science. Doing so will enable industrial engineers to serve as better bridges between the technical and the social. Embracing the social does not mean that industrial engineers need to be social scientists. However, it does mean that social science needs to be part of the industrial engineer's toolkit, just as that toolkit currently contains skills in simulation, computer programming, probability, database design and so on.

Achieving these objectives will require IE departments to reconfigure their degree requirements to train the next generation of researchers and practitioners. A single course in organizational behavior or industrial psychology is unlikely to provide the depth of knowledge that industrial engineers will require to study work. Rather, they will need broad exposure to relevant theories and methods drawn from sociology, psychology and anthropology. Courses that cover social and political processes in organizations, social networks, social interaction and group processes, organizational sociology, social conflict, technology and society, social psychology, social structure, organization theory, organizational culture, the division of labor, power and status, interpersonal relations, cognitive psychology, social influence and persuasion, and technology and law are indicative of the kind of exposure industrial engineers should gain.

Taking work studies seriously will also require transforming the study of work as it currently appears in IE's own curriculum. As many schools have recognized, motion and time studies are less important for a knowledge-based economy. Shop courses also offer little leverage for understanding and designing most modern work systems. Even a course on human-computer interaction does not, by itself, suffice. To cover the full range of changes in the workplace, IE departments must accept the challenge of developing new courses on topics that include knowledge work, service work, technical work, R&D management, and the relationship between technology and work across the entire occupational spectrum. Courses in human factors and information systems design should borrow significantly from research in computer-supported collaborative work, where an understanding of the social embeddedness of technologies and the inherent social relationships that shape and constrain technology use are considered crucial to effective system design. Finally, because field research will be crucial for gathering data on work systems, departments must also offer courses on observation, interviewing and qualitative data analysis tailored to the study of work.

To teach these courses and to further research in modern work systems, IE departments need to hire new faculty skilled in these domains. Granted, significant institutional barriers exist that may make hiring and promoting such individuals a daunting task at many engineering schools. Interest on the part of industry may prove helpful in convincing deans and department chairs of the benefits of this direction. Such interest can be found, for example, in the growing worldwide application of new human resources practices brought to light in MIT's lean manufacturing auto industry study (Kochan *et al.*, 1997) and in the growing corporate recognition, especially among software development firms, that distributed work teams pose unique management and organizational challenges (Hinds and Keisler, 2002).

In making these changes, however, IE departments must not abandon their technical roots. Changes in the nature of work over the past several decades clearly indicate that a broad education in the physical sciences and engineering is essential for designing work systems in high-technology environments. Ultimately, educators in IE should strive to integrate an understanding of social dynamics with substantive knowledge of engineering to produce students who can design more effective work systems. By doing so IE may not only recover its heritage, it should also be better positioned to assist society in adjusting to a post-industrial economy.

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