高等学校规划教材

工业工程专业英语

Professional English for Industrial Engineering

王爱虎 编

北京理工大学出版社
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内容简介

本书系统介绍了工业工程的专业概貌和发展。本书内容基本上涵盖了工业工程的知识体系，兼顾介绍了基础工业工程和现代工业工程的理论和方法，也介绍了各领域的最新发展动态。全书共分五篇（20 课），分别是：对工业工程的认识；基础工业工程；现代工业工程；工业工程前沿；工业工程展望。书末有专业词汇表。

本书既可作为本科生的专业英语课使用，也可作为硕士和博士研究生论文写作的参考用书。

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PREFACE 前言

尽管于将近一个世纪以前起源于美国的工业工程管理理念已经在工业发达地区如欧美和日本等得到深入普及和广泛发展,但其在中国真正受到重视却是最近几年的事情。从计划经济向市场经济的转变,20 余年的改革开放,国有、私营、合资和独资等多种经营方式的协调发展以及 2002 年末中国正式成为国际贸易组织(WTO)中的一员乃至十六大提出的新型工业化道路等为工业工程在中国的发展营造了良好的环境。与此相对应,工业工程专业的本科、工学硕士、工程硕士和博士的教育和培养也受到了国家教委和全国多所高等院校的重视。2002 年 9 月在北京举行的第九届工业工程和工程管理国际年会和工程硕士教学研讨会的不完全统计数据显示,全国有 90 多所高等院校已经开始了工业工程专业不同层次人才的培养。更可喜的是,2003 年 12 月在上海召开的第十届工业工程和工程管理国际年会和工业工程(院)系主任联席会议上校为准确的统计数据显示这个数据已经增长到 130 多。

国际竞争的加剧对工业工程专业人才的培养提出了更高的要求。未来的工业工程从业人员不仅需要掌握工业工程领域广博的专业知识,而且还应该具备同来自世界不同国家和地区、具有不同教育和文化背景的同行用英语进行专业沟通和交流的能力。而掌握大量的工业工程专业词汇无疑将对这种必要的沟通和交流起到巨大的促进作用。然而,目前国内关于工业工程专业的教材引进和编写正处于起步阶段,其中专业英语的教材尤为缺乏。这就是本教材的编写动机。

本书的目的可以简单概括为:为工业工程专业的学生(包括本科生、硕士生乃至博士生)、老师和从业人员提供一本系统介绍工业工程专业概貌和专业词汇的学习材料,以使其能够通过专业词汇的集中学习提高其专业英语阅读能力和专业沟通能力。

本书有如下特点:

- 突出了对专业词汇的介绍,与普通英语的教学有很好的衔接;
- 内容基本上涵盖了工业工程的知识体系;
- 兼顾了对基础和现代工业工程的理论和方法的介绍;
- 在对工业工程基本概念、理论和方法介绍的同时,强调了各领域的最新发展动态;

- 突出了工业发达国家的学者和从业人员对工业工程发展过程中经验的总结、思考和对未来的展望；
- 大部分内容选自高水平国外刊物，有很强的前瞻性，有利于高年级本科生、研究生乃至博士生的论文写作。

在本书的编写过程中得到了美国纽约州立大学布法罗大学工业工程系 Dr. Rakesh Nagi，Dr. Lilin，香港中文大学赵先德教授，华南理工大学工商管理学院徐学军教授，重庆大学易树平教授，河北科技大学李军教授、徐瑞园教授，北京交通大学鄂明成副教授，内蒙古工业大学陈红霞等的支持和帮助，在此表示谢意！

由于作者水平有限，书中难免有不妥和谬误之处，恳请读者批评和指正。

编　者

CONTENTS 目录

第一篇　对工业工程的认识

第二篇　基础工业工程

第三篇　现代工业工程

第四篇　工业工程前沿

第一篇

对工业工程的认识

1 Industrial Engineering Education for the 21st Century
21世纪的工业工程教育

The 21st century is just a few years away. Strategic planners all over the world are using the year 2000 as the focal point for future business activities. Are we all ready for that time? Is industrial engineering education ready for that time? As the industrial world prepares to meet the technological challenges of the 21st century, there is a need to focus on the people who will take it there. People will be the most important component of the "man-machine-material" systems competing in the next century. IEs should play a crucial role in preparing organizations for the 21st century through their roles as change initiators and facilitators. Improvements are needed in IE undergraduate education if that role is to be successfully carried out.

Undergraduate education is the foundation for professional practice. Undergraduate programs are the basis for entry into graduate schools and other professional fields. To facilitate this transition, urgent improvements are needed in education strategies. Several educators have recognized that the way engineering is practiced has changed dramatically over the years and an upgrade is needed in engineering education. Educators, employers and practitioners are calling for a better integration of science with the concepts of design and practice throughout the engineering curriculum. Such an integration should be a key component of any education reform in preparation for the 21st century.

Hurried attempts to improve education are being made in many areas. We now have terms like "total quality management for Academia," "just-in-time education," and "continuous education improvement." Unfortunately, many of these represent mere rhetorics that are not backed by practical implementation models. IE should take the lead in reforming its own curriculum so that it can help to develop practical implementation models that can be used by other disciplines. Many educators and administrators are searching for ways to transform improvement rhetorics and slogans into action. Models developed by IEs can provide the answers.

Quality in IE education

Incorporating quality concepts into education is a goal that should be pursued at national, state, local and institution levels. Existing models of total quality management (TQM) and continuous process improvement (CPI) can be adopted for curriculum improvement. However, because of the unique nature of academia, re-definition of TQM will be necessary so that the approach will be compatible with the academic process. For example, in industry, the idea of zero defects makes sense. But in academia, we cannot proclaim zero defects in our graduates since their success on the job cannot be guaranteed. Nonetheless, the basic concepts of improving product quality are applicable to improving any education process. Clynes, while reflecting on discussions he participated in at a National Research Council colloquium on engineering education, said "Teaching quality, like a company's customer service, can never be too good and always needs attention for improvement." This is true. A careful review of IE curriculum will reveal areas for improvement. This will help avoid stale curricula that may not meet the current needs of the society.

Theory and practice

Teaching determines the crux of research while research determines the crux of teaching. Integration of teaching and research is required for effective professional practice. The need to incorporate some aspect of practice into engineering education has been addressed widely in the literature. Pritsker recommends that professors must combine research interests with teaching responsibilities. The declining state of university education was described by Samuelson with respect to waste, lax academic standards and mediocre teaching and scholarship. These specific problems have been cited in the literature:

- Increasing undergraduate attrition despite falling academic standards at many schools. Decreasing teaching loads in favor of increasing dedication to research;
- Migration of full professors from undergraduate teaching in favor of graduate teaching and research;
- Watered down contents of undergraduate courses in the attempt to achieve retention goals;
- Decreasing relevance of undergraduate courses to real-world practice.

Curriculum integration

Curriculum integration (interdisciplinary approach) should be used to address the problems cited above. Curriculum integration should be a priority in reforming education programs. Students must understand the way the world around them works and be capable of becoming responsible contributors to the society. Interdisciplinary education offers a more holistic approach to achieving this goal. Interdisciplinary course and curriculum improvement should link separate but related subjects to provide students with comprehensive skills so they can adapt to the changing world. One form of interdisciplinary integration involves projects in which students from more than one academic department participate in joint industrial projects. This facilitates sharing of views from different angles.

Role of the IE

Enhanced IE education will prepare students to lead efforts to integrate entities in manufacturing and service organizations of the 21st century. The IE profession, as a whole, faces an important challenge in educating future IEs for this leadership role. The current IE curriculum provides good exposure to its many unique facets. Individual courses at both undergraduate and graduate levels in many institutions are comprehensive. Yet there are some fundamental deficiencies as discussed below.

The academic curriculum rarely emphasizes the fundamental philosophy of IE itself. That philosophy is a holistic approach to design, development and implementation of integrated systems of men, machines and materials. Students go through courses in operations research, manufacturing, human factors and so on without understanding the interrelationships between these areas and the synergistic impact this integrated approach has on man-machine systems.

IE is quickly losing its identity as a value-adding profession. The basic cause of this problem is that many IEs graduate without resolving the question of identity related to the following questions:

- What separates an IE from other engineers?
- What contribution does the profession make to an organization?

The root of this identity problem lies in the structured and isolated approach of various IE courses. This results in specialization that is too narrow. For example, graduates today tend to associate more with focused professional societies rather than the general IE. This is a disturbing drift that may destroy the identity of IE as we now know it.

There is a big difference between academic and industrial approaches to performance evaluation. The academic community evaluates its members by the number of publications and research grants. By contrast, industry measures performance in terms of real contributions to organizational goals. This has had a detrimental effect on the learning interaction that faculty and students must share for students to graduate with professional loyalty, technical competence and capability of integrating theoretical concepts and industrial practice effectively.

In the attempt to prepare students for graduate level education, the academic curriculum often has a strong mathematical orientation. Though a required approach, it develops a very structured approach to problem solving among students. Consequently, students expect all problems to have well-defined inputs, processing modules and outputs. Thus, when faced with complex, ill-defined, and unstructured problems that are common in the real world, many new graduates perform poorly. Chisman points out that the bulk of teaching should be done for undergraduate students since over 85 percent of them go into industry, not on to graduate school. Unfortunately, attempts to improve curriculum is often tilted in favor of research-oriented education, thereby depriving the majority of the students of the skills they need to survive in the business world.

Many young graduates mistakenly perceive their expected roles as being part of the management personnel, having little or no direct association with shop-floor activities. Such views impede hands-on experience and prevent the identification of root causes of industrial problems. Consequently, this leads to the development of solutions that are short-term, unrealistic, and/or inadequate. The growing reliance of simulation models that cannot be practically validated in real-world settings is one obvious symptom of this problem.

Like many other engineering curricula, IE is growing within an isolated shell. Students do not realize the importance of developing solutions beneficial to a system rather than for individual components. Many new graduates take a long time to become productive in developing solutions that require multidisciplinary approaches.

Ethics in education

Professional morality and responsibility should be introduced early to IE students. Lessons on ethics should be incorporated into curriculum improvement approaches. IE graduates should be familiar with engineering code of ethics so that they can uphold and advance the integrity, honor and dignity of their professions by:

- using their knowledge and skill for the enhancement of human welfare;
- being honest, loyal, and impartial in serving the public, their employers and clients;
- striving to increase the competence and prestige of their professions;
- supporting the professional and technical societies of their disciplines.

Some points to consider when developing curriculum improvement approaches are:

- Education should not just be a matter of taking courses, getting grades and moving on. Lifelong lessons should be a basic component of every education process. These lessons can only be achieved through a systems view of education. The politics of practice should be explained to students so that they are not shocked and frustrated when they go from the classroom to the boardroom.

- Universities face a variety of real-world multi-disciplinary problems that are often similar to industrial operations problems. These problems could be used as test cases for solution approaches. IE students could form consulting teams and develop effective solutions to such problems.
- Schools should increase their interaction with local industries when such industries are available. This will facilitate more realistic and relevant joint projects for students and industry professionals.
- The versatility of IEs in interacting with other groups in the industrial environment can be further enhanced by encouraging students to take more cross-disciplinary courses in disciplines such as mechanical engineering, computer science, business, etc.
- Students must keep in mind that the computer is just a tool and not the solution approach. For example, a word processor is a clerical tool that cannot compose a report by itself without the creative writing ability of the user. Likewise, a spreadsheet is an analytical tool that cannot perform accurate calculations without accurate inputs.

Curriculum assessment

Performance measures and benchmarks are needed for assessing the effectiveness of IE education. The effectiveness of curriculum can be measured in terms of the outgoing quality of students. This can be tracked by conducting surveys of employers to determine the relative performance of graduates.

The primary responsibility of a curriculum improvement team is to ensure proper forward and backward flow of information and knowledge between the academic institution and industry. The percentage of students passing the engineer-in-training (EIT) exam can also be used as a performance measure. The percentage of students going on to graduate programs and staying on to graduate will also be a valuable measure of performance. Entrance questionnaires and exit questionnaires can also be used to judge students' perception of the improved curriculum.

Conclusions

Significant changes are occurring in the world. These changes can come in terms of technological, economic, social and political developments. To adapt to these changes and still be productive contributors to the society, IE students must be prepared to be more versatile than their predecessors. This preparation requires significant changes in the contents and delivery of IE education. Educators and administrators institute plans immediately for reforming IE education in preparation for the landmark expectations of the 21st century. Efforts to improve IE education now will eventually lead to the development of leadership roles that other disciplines can emulate. This is a worthwhile service to the whole society that IE educators and professionals should not overlook.

Professional Words and Expressions

Industrial Engineering	工业工程
Total Quality Management	全面质量管理
Continuous Improvement	持续改进
Human Factors	人因学，功效学
Man-Machine Systems	人机系统
Shop-Floor Activities	车间活动
Simulation Model	仿真模型
Code of Ethics	道德标准，职业准则
Performance Measure	绩效测量
Benchmark	标杆

编者注

2003 年 12 月 6 日至 8 日于上海交通大学召开的中国机械工程学会第八次工业工程年会的相关资料显示：目前我国有 120 余所高校已经开始了工业工程专业的学士、工学硕士、工程硕士乃至博士的教育和培养。考虑到我国将成为 21 世纪的全球制造中心，市场对具有高水平工业工程素质的复合型人才将有较大的需求。有理由相信工业工程专业的教育将成为我国继 MBA 教育后的又一个亮点。然而，我国工业工程专业的教育体系还处在逐步建设和健全之中，培养方案的设计、实验室的建设、核心课程的确定和开发、教学环节的把握、论文研究的指导、教材的编写和师资队伍的建设等都是亟待解决的主要问题。而这篇短文则对美国教育界积累了将近一个世纪的工业工程专业办学经验进行了深入分析并就 21 世纪工业工程教学体系的建设予以了展望。相信文中的观点能够对正处于启蒙阶段的我国工业工程教育体系的建立起到指导和借鉴作用。

Real IE Value
工业工程的真正价值

Industrial engineers are great at solving problems. Ironically enough, there is still one age-old problem they are unable to solve — identity. And the problem is not getting any easier to solve. In fact, "identity" is just one of several challenges currently facing the IE profession.

Today's competitive global economy and tighter corporate budgets are forcing IEs to deal with issues that were barely mentioned a decade ago. Companies are flattening corporate structures; IE departments are being eliminated or renamed; and universities and colleges are under even greater pressure to provide industry with graduates who are better trained to handle a much wider variety of job responsibilities.

On the other hand, today's IE has at his or her disposal more technology and tools than the IE of 30 years ago could have ever imagined. New technologies have improved accuracy and speed and generally have increased the IEs' ability to cover a more diverse set of interests.

In addition, the IE now has a greater opportunity to concentrate on any one of a broad variety of areas that many companies now recognize as individual departments — including simulation, operations research, ergonomics, material handling and logistics.

The name game

What problems could possibly throw a shadow on such a bright array of opportunities? For starters, as new opportunities have developed for the IE, new questions have formed about what types of jobs the industrial engineer is qualified to perform.

At one time, it was easier to define what an IE did. "Industrial engineering was simple in those days when we dealt with methods, work standards and work simplification," says Carlos Cherubin, director of engineering for The Limited Co. "But there has to be some way to get past the old industrial engineering definition."

Even today, in many companies, IEs are still performing the traditional type of work that makes up what is now considered classical IE. "The big change is that the commercialization of a lot of these areas have turned them into 'niche thrusts,'" says John Powers, director of the management services department at Eastman Kodak Co. While IEs have always been very adaptable to these "thrusts" as a skill set, he says, they are now competing for the headlines.

Says Jerry Zollenberg, director of IE for United Parcel Service, "If a person loses sight of the total job and starts looking at the individual pieces, it comes out a little hairy." For example, Zollenberg says that he has an operations research (OR) group of 40 to 50 individuals who are working on the cutting edge of computer technology. At one time these people were designated as IEs. But Zollenberg says that even though they are not called IEs, the job they are doing is certainly IE-oriented and could be IE, depending on how you set up the organization.

Like it or not, the trend today is specialization, and companies are following suit. Tough economic times are forcing many companies to redefine corporate structures, with a primary goal of flattening their organization in an attempt to cut costs and speed the decision-making process. In the case of the IE department, that trend has moved departmental names from the generic "IE" to specific functions or areas that are being performed. Former IE departments have been decentralized or renamed and are now described using such terms as Quality Improvement Engineering, Management Services or Engineering Services, just to name a few.

"What I see is companies getting away from the IE name and trying to have names that are more descriptive of the broader set of skills," says Powers.

For many, including Rebecca Ray, IE manager at Glaxo Inc., it is a step in the right direction. Her department will soon carry the title Performance Improvement Engineering. "IE is probably the only engineering profession that insists on wearing its degree on its departmental door," she says. "We have focused too much on maintaining our degree, instead of identifying our function within our company."

Dr. Vinod Sahney, corporate vice president at Henry Ford Health Systems agrees. "One of our biggest difficulties is we equate industrial engineering with an IE department," he says, "I have never seen a mechanical engineering department, but yet they are hired and get a wide-range of jobs."

Tony Vieth, IE manager at Boeing Georgia Inc., believes that the individual persons, depending on how they are trained, can bring the right skills to the right job and they do not need to be in a department called industrial engineering. He also thinks IEs have gotten hung up on that over the years. On the other hand, the decentralized type of environment appears more threatening to others. "If we assume that decentralization will continue to the point of transferring IE responsibilities to others, as seen in the Volvo organization, we will see a profound impact upon the profession, namely unemployment," predicts Donald Barnes of Barnes Management Training Services.

But, a centralized IE department does not guarantee employment for the industrial engineer. Many large companies have "IE" departments where only a handful of industrial engineers can be found. An example is Boeing. Boeing has some very large IE departments, but often less than two or three people within the department have IE degrees. According to Vieth, it is because some of the functions within the department are so diverse.

Problems associated with renaming IE departments to describe their particular function may have more to do with appearance than with the actual job being performed. While IEs actually perform many of the specialized jobs, little credit is given to IE principles used in the approach. In fact, it often turns out that many of the individual functions and skills used by IEs are viewed by management as industrial engineering. As a result, individuals who can master one of those skills are mistakenly referred to by management as "industrial engineers."

Yet, those who understand the real value of industrial engineering still realize that the degreed IE brings to the job a unique way of thinking.

"There are things you can teach non-degreed people that are basic repetitive tasks," says Vieth. "But what you can't teach is how to take what you see, translate it, and recognize there is a problem, and then come up with a solution to that problem."

Erin Wallace, director of IE at Walt Disney World Co., would not hire anyone who was not a degreed IE. "I insist on it," she says. "When you've got a group of people who are distinctly IEs, they carry with them what we like to refer to as distinct competencies. Those distinct competencies for an IE at Walt Disney World include their ability to do quantitative analysis. You need an IE degree to be able to do that type of work."

Wallace says that when someone hires IE technology-type majors, they do not get some of the rudimentary problem solving skills acquired from taking engineering courses.

Curriculum

Since there is a favorable consensus about the technical qualifications of degreed IEs, universities and colleges must be doing all industry believes is necessary to prepare today's IE students. Appearances may be deceiving.

In fact, even though ABET accredits many IE and IET programs in the United States, there remains much variance and flexibility among each of the programs. Evidence of this fact can be found in a recent Australian study undertaken by the Industrial Engineering/Management (IE/M) group of the School of Mechanical and Manufacturing Engineering Swinburne Institute of Technology (SIT).

The school initiated a set of promotional activities to rejuvenate the industrial engineering name and status. One of the school's goals was to help convince managers and government to reconsider the role of industrial engineering.

In preparation for the events, the IE/M group surveyed more than 150 U. S. universities with accredited IE programs at the undergraduate and graduate level. Of those universities that answered, 37 were randomly drawn for analysis.

The main purpose was to analyze the quantity and quality of the IE subjects. According to Shayan and Hamadani at SIT, the most important point is that coverage of IE is not yet standardized.

Other steps

Two key projects currently working toward helping academia improve the overall IE curriculum include the Southeastern University and College Coalition for Engineering Education (SUCCEED) sponsored by the National Science Foundation (NSF), and IIE's joint effort between the Council on Industrial Engineering (CIE) and the Council of Industrial Engineering Academic Department Heads (CIEADH).

SUCCEED, which is aimed at all engineering disciplines, is an engineering education coalition established by NSF in March 1992. The coalition has proposed a new curriculum model, CURRICULUM 2 1, as a mechanism to focus its efforts on specific goals such as restructuring the engineering curriculum and improving the quality and quantity of graduates.

The second project, between CIE and CIEADH, has been ongoing since the Fall of 1990. Specifically, CIE (corporate-level directors whose span of control includes IE functions) meets with CIEADH (98 academic department heads from universities and colleges) at scheduled times during the year to better define what industry needs from academia. IIE acts as a facilitator between the two groups to help inform academia. The ultimate goal of these meetings is the development of a clearly defined set of output characteristics that will help academia design an improved undergraduate IE curriculum.

This is not to say that these organizations are attempting to standardize the IE curriculum, rather, they are trying to provide basic guidelines. The question of whether the IE curriculum should be standardized throughout every university is not an issue. Leaders in industry and academia readily agree that there is no possible way for every curriculum at every college to be identical.

"I don't think you can require every IE curriculum to be cookie cutter of each other," says Glaxo's Ray.

What appears to be a problem is the perceived gap between what type of students academia is providing compared with the types of students industry seeks. Most industry leaders acknowledge that the majority of universities and colleges should provide, and do provide, students who are technically competent. To expect that IE students be highly knowledgeable about every possible aspect of industrial engineering upon graduation may be unrealistic, says Zollenberg. Students are required to take a broad range of IE courses to help them understand the principles of IE and provide a solid academic foundation. A graduate student can then go on to specialize in a particular area if he or she desires to do so.

Zollenberg insists that it is impossible to expect students to learn everything they need to know about the jobs they will encounter. "I'm not sure anybody coming out is going to learn all of the required skills in four years of school. I don't think it's fair to the universities and I don't think it's fair to the kids," he says.

Expectations

What industry leaders do expect, however, are students who have the ability to operate in the environment in which they are placed. These areas where there appears to be a deficiency include interpersonal skills, knowledge of computers, nontechnical/business skills, quality management skills, and an appreciation for the plant floor. Depending upon what industry the new graduate is placed, the need for certain skills will vary.

Wallace, who works for a service-oriented company (Walt Disney World), thinks today's students are well-trained in most areas, with the exception of computer skills. She says she still sees a lot of students who come out of school without very good computer skills. "Nowadays, that should be a prerequisite."

In the manufacturing sector, Jack Broadway, director of corporate IE for Reynolds Metals, believes today's students are probably better educated than in the past, but they have some misconceptions about the types of jobs they will perform. "A lot of (students) coming out today want to sit behind a computer and they think that is their job. Well, a computer is just another tool. It's just something you use to do the job and then you go on and do something else," he says. He suggests that on-the job training while in school may be one of the best ways to prepare students.

On the healthcare side, Sahney (Henry Ford Health Systems) thinks that in general terms, schools are providing properly trained students, but they often are not given the opportunity to become well-rounded in other areas. Because what he says is the profession's "roots of accreditation," the curriculum is too tightly controlled. He does not think individual institutions have enough variety. In other words, he says, the electives are very limited by the time all of the required courses are finished. This problem is often exhibited as a lack of writing and presentation skills in many of the new graduates.

Most IEs eventually must sell their ideas and plans to management, which often requires above-average communication skills. For many IE graduates, this is a tough challenge. Russell Cartmill, IE director at The Coca-Cola Co., says he is frequently confronted with hiring recent graduates who lack basic communication skills. He says Coca-Cola ends up having to teach people things once they get in the areas of public speaking and report writing, "some of the basic things that you really need to have in industry in order to make a good presentation."

One way schools are combating this problem, which is also a problem with students in other engineering disciplines, is semester-long undergraduate and graduate-level courses directed at familiarizing engineering students from all disciplines with the non-technical aspects of engineering. These courses focus on topics such as financial management, project management, business planning and business development.

Other schools have even gone as far as offering graduate degrees that are a combination of an IE degree and business degree in an attempt to target students seeking manufacturing engineering jobs.

But Vieth is not sure that the business route is the best path for the industrial engineering curriculum to follow. "I think if we lose track of the technical knowledge, we're just going to look like a high-priced business graduate," he says.

Another option IE departments at universities and colleges might consider is specializing in a particular function of IE (i.e. operations research, material handling, ergonomics, human factors, etc.), and market their program accordingly. For example, says Cherubin, if a college student wants to be an IE and has a particular interest in material handling, that student should be able to choose certain schools whose charter is very specific. In addition to helping the student, he says, it provides an important service to a potential employer. "Don't put students out in the work environment and, at that point, let them start defining their career," says Cherubin.

Vieth has similar views. "Maybe the IEs that our universities train today should be trained to be part of a specific department," he says.

Ray thinks that the problem might not be what is taught, but the way it is taught. IE classes and departments at universities are structured in a way that teaches students to work alone, she says.

Students model themselves after the people they admire, Ray states. "While students are in college, they are looking at their professors. If they see their professors operating autonomously — on their own island — and not interrelating across other disciplines, the IE is going to come out of that program thinking they don't need anybody's help to solve a problem," she says.

She says it takes her up to 18 months to put a newly hired graduate through "boot camp" to make them realize that they have to work as a member of a team to facilitate the flow of information within her organization.

Future directions

With all of these challenges facing the IE profession, there may be some who doubt the IEs' future. But if the individual IE will assume the role as a change implementor — not a change follower — broad opportunities are on the horizon.

Some see a renewed interest in traditional IE functions, specifically, cost estimation and analysis. E. Franklin Livingston, senior industrial engineer at Weber USA Inc., a manufacturer of carburetors and fuel injectors, cites a recent request from General Motor's vice president of world-wide purchasing, J. Ignacio Lopez de Amortua, as proof. "He is expecting drastic cost reductions from suppliers over the next five years," says Livingston.

Livingston points out that Chrysler and Ford will probably follow suit and make similar demands on their suppliers. If that is true, Livingston foresees in the next 10 years that probably more emphasis will be placed on conventional industrial engineering. "But I don't think it will ever go back to the way it was 25 years ago," Livingston says.

Others see the IE heading in the direction of large processes and systems. Process thinking has become widespread in recent years, due largely to the quality movement. Industrial engineers seeking to expand their opportunities and improve the quality of operations are now looking at the entire process, rather than just a particular task or business function.

Two areas that may be of special importance to IEs in the coming years include information technology (IT) and business process redesign/reengineering (BPR). As IT continues to evolve, technological advancements will have a big impact on how companies (IEs) look at business processes of the next decade. Working together, IT and BPR has the potential to create a new type of industrial engineering, changing the way the discipline is practiced and the skills necessary to practice it.

This whole area of business process re-engineering offers a great opportunity that many IEs have been unwilling to explore. As a result, managers have been reluctant to look to the IE to carry the banner, Powers says. "If we've got a problem, it's of our own doing and our own unwillingness to take the lead in a lot of these major improvement activities," he states.

One area where IEs have not been so reluctant to get involved is the systems integration arena. If the systems integration function continues to develop at its current rate, this particular role — that of systems integrator — will most likely get so sophisticated that it will requite someone with technical knowledge who can look at the bigger picture. "This is a function for which industrial engineers are uniquely trained," says Thomas Hodgson, with the Design and Manufacturing Division at NSF.

As a result, many of the traditional IE functions could be handled by IE technology individuals, while degreed IEs would serve in the consultant role. In this scenario, IEs could have the responsibility of training others, who would then apply it.

However, many of those opportunities in systems integration are already opening up and if IEs do not step up to the current challenge of systems integration, others may step in and take that function from the IE, says Hodgson.

"We need to grow in our understanding of the other engineering disciplines so as to better do our job. We need to grow in our capability to make use of the rapidly improving computational capabilities that are available," he says.

More challenges

Whatever the future holds, the biggest threat to IE may be what people do not know about the profession. In an economy where every company is cutting costs and looking for ways to trim excess "fat," one might think CEOs and managers would be snatching up every available IE. Instead, many corporate executives and human resource managers are turning to other disciplines to fill jobs ideally suited for IEs. "It's really quite silly, since IEs are the people who save you money," says Wallace.

Why is this happening? Because IEs need to do a better job of showing management all of their abilities and talents. While TQM and business process reengineering may pose big challenges, the IE's broad, fundamental background has provided them with the training and education found in no other profession. Sadly, the specialized tasks that companies are asking individuals from other disciplines to perform are tasks that IEs have always been trained to perform! It is time for IEs to market those abilities accordingly.

"We have not done a good job of demonstrating and selling ourselves in a way that we truly get recognized for what our mission and our capabilities and our supposed demonstrative performance really is," says Powers.

IEs must take the proactive approach and position themselves as leaders of changes occurring in all sectors of industry. In fact, IEs must create the changes. Says Zollenberg, "I think we have to step up to the front and take a leadership role, rather than just sit back and wait for somebody to ask us to do a study."

And what about the identity problem? Rudy Herrmann, president of Rotary Lift, sums it up well when he says, "The 'name game' goes away if we can learn how to be effective functional professionals, and be respected and understand all of our contributions."

The key is "we." If every industrial engineer, in industry and academia, will work together to tackle these challenges and make other companies and individuals aware of the IE's many talents, the age-old identity problem just might be on the brink of fading away.

Professional Words and Expressions

Industrial Engineering (IE)	工业工程
Industrial Engineer	工业工程师
Simulation	仿真
Operations Research	运筹学
Quality Improvement Engineering	质量改善工程
Management Services	管理服务
Engineering Services	工程服务
Performance Improvement Engineering	绩效改善工程
Ergonomics	人因学,功效学
Material Handling	物料搬运
Logistics	物流
Financial Management	金融/财务管理
Project Management	项目管理
Business Planning and Development	商业规划与开发
Information Technology (IT)	信息技术
Business Process Redesign/ Reengineering (BPR)	业务流程再设计/再造
Human Resource Management	人力资源管理
Quality Movement	质量运动

Notes

1. On the other hand, today's IE has at his or her disposal more technology and tools than the IE of 30 years ago could have ever imagined.
可翻译为:另一方面,现在的工业工程师可以使用许多30年前的同行想都不可能想到的技术和工具。
2. If a person loses sight of the total job and starts looking at the individual pieces, it comes out a little hairy.
可翻译为:如果一个人不能对整项工作做全面把握而只是将注意力放在个别的方面,则结果将不会令人满意。
3. Problems associated with renaming IE departments to describe their particular function may have more to do with appearance than with the actual job being performed.
可翻译为:将工业工程部重新命名以明确描述其具体职能,其间所出现的问题与其说与实际完成的工作有关倒不如说与问题的表象有关。
4. In fact, even though ABET accredits many IE and IET programs in the United States, there remains much variance and flexibility among each of the programs.
ABET是工程与技术鉴定委员会(The Accreditation Board for Engineering and Technology)的简写 。该委员会是美国用来检查和评价各工程类大学全部课程的官方机构,ABET鉴定目的是向公众和工程类毕业生的雇主保证学校的课程满足了规定的最低标准。该句可翻译为:实际上,尽管工程与技术鉴定委员会鉴定了美国的许多工业工程和工业工程与技术项目,但这些项目之间仍然存在很大的区别和灵活性。
5. Two key projects currently working toward ... and the Council of Industrial Engineering Academic Department Heads (CIEADH).
该句中提到了如下几个机构:
    - 美国东南地区大学和学院工程教育联合会(SUCCEED):1992年美国自然科学基金委员会资助东南地区的8所工程类学院而成立的教育联合会,旨在提高工程类本科的教育水平。(详见 http://www.succeed.ufl.edu)
    - 自然科学基金委员会(National Science Foundation)
    - 工业工程师学会 (Institute of Industrial Engineers, IIE):世界上最大的专门支持工业工程领域和个人从事质量和生产率改善活动的非赢利性行业协会。成立于1948年,现有会员15 000余人,在全球范围内有280个分会。文中提到的工业工程理事会(Council on Industrial Engineering, CIE)和工业工程系主任理事会(Council of Industrial Engineering Academic Department Heads, CIEADH)为工业工程师学会的下属机构。(详见 http://www.iienet.org)
6. But if the individual IE will assume the role as a change implementor — not a change follower — broad opportunities are on the horizon.
可翻译为:然而,如果每个工业工程师都承担起变化的实施者而不是变化的追随者的角色,则广泛的机会就会出现。

7. If we've got a problem, it's of our own doing and our own unwillingness to take the lead in a lot of these major improvement activities.

可翻译为:如果我们遇到了问题,这些问题也是由于我们自己的所作所为和不愿意在一些重大的改进活动中承担领导角色所造成的。

第二篇

基础工业工程

3 Operations Research
运筹学

Brief history

Operations research is a relatively young discipline, being organized as a separate professional field of study only since the end of World War II. The Operational Research Society of the United Kingdom (ORS), the Operations Research Society of America (ORSA), and the Institute of Management Sciences (TIMS) were founded in 1948, 1952, and 1953, respectively. However, the methods and practices of operations research were being applied just prior to the war by British scientists working for the Air Ministry. In fact, two of these scientists are credited with first coining the phrase "operational research".

The earliest application of operations research involved improving the early warning system of the RAF's Fighter Command. This system was quickly put to the test during the Battle of Britain. Throughout the remainder of the war, the methods of operations research were used by all branches of the British military to improve the results of their operations. As might be expected, the armed forces of the United States began to apply similar techniques soon after Pearl Harbor.

After WWII, the use of operations research continued in the military and was greatly expanded. In addition, businesses on both sides of the Atlantic began to apply operations research to a broad range of management problems, such as accident prevention, production planning, inventory control, and personnel planning.

The first formal university courses and curricula also began to be developed during the immediate postwar period. MIT, Case Institute of Technology (now Case Western Reserve University), and the University of Pennsylvania were among the first universities to offer formal degree programs in the United States in the early fifties. It is interesting to note that similar academic programs did not develop in the United Kingdom until later, although lectures and courses were offered at a few universities. University programs in operations research in the United States and Canada are located in a wide variety of colleges, schools, and departments, reflecting the field's highly interdisciplinary nature. Programs are found in departments of mathematical sciences, decision sciences, statistics, industrial engineering, computer science, management science, engineering management, mechanical engineering, and operations research. These departments are located in schools or colleges of engineering, business, management, industrial engineering, and applied science.

Operations research, as defined by the Operations Research Society of America, "is concerned with scientifically deciding how to best design and operate man-machine systems, usually under conditions requiring the allocation of scarce resources." Important to the field is the development, testing, and use of models to predict various outcomes under differing conditions or to optimize the outcome for a given condition. This gives decision makers the ability either to choose the "best" outcome or to enhance the likelihood of a given set of desired outcomes. The application of quantitative methods is also very important.

Some OR accomplishments

Some important breakthroughs of the 1970s and 1980s are highlighted below, with descriptions of how they have been employed and the resulting economic impact.

Integrative OR systems

In 1983 and 1984, Citgo Petroleum Corporation, the nation's largest independent refining and marketing company, with 1985 sales in excess of $4 billion, invested in a unique set of comprehensive and integrative systems that combine such OR disciplines as mathematical programming, forecasting, and expert systems, with statistics and organizational theory. Citgo applied the OR systems to such operations as crude and product acquisition, refining, supply and distribution, strategic and operational market planning, accounts receivable and payable, inventory control, and setting individual performance objectives, and now credits these OR systems with turning a 1984 operating loss that exceeded $50 million into a 1985 operating profit in excess of $70 million.

Network flow problems

The 1970s were marked by a number of breakthroughs in the modeling and solution of network flow problems. Initial developments created specialized primal simplex algorithms for problems of transportation and transshipment. Later, algorithms were developed for generalized networks and linear programs with large embedded networks. These algorithms demonstrated unprecedented efficiency, having speeds that ranged from 10 to 200 times faster on network problems than the best general purpose linear programming systems — efficiencies entirely above and beyond any afforded by changes in computer hardware or compilers.

It is now possible to solve huge network flow problems routinely, and as a result, important new applications are emerging. Companies such as Agrico, Ciba-Geigy, W. R. Grace, International Paper, Kelly-Springfield, Owens-Corning Fiberglass, Quaker Oats, and R. G. Sloan have successfully coupled their data gathering systems with network flow models to improve the cost effectiveness and service effectiveness of logistics decisions. For instance, Agrico reported a decrease in net working capital requirements of 13% and 5-year savings of \$43 million, Kelly-Springfield reported savings of over \$8 million annually, and Cahil May Roberts credits OR with a 20% reduction in delivery and transportation costs.

The hypercube queueing model

A computer implemented, multiserver queueing model resulting from National Science Foundation supported research is now routinely used for deploying heterogeneous servers in cities in both hemispheres. The hypercube model is the basis for emergency services deployment in New York, San Diego, Sacramento, Dallas, Portland (Oregon), Caracas, and Rotterdam. Typical reported productivity improvements are on the order of 10% ~ 15%.

Lagrangian relaxation

Lagrange multipliers, used to relax complicating constraints in hard combinatorial optimization problems, facilitate the use of polynomial algorithms for computing bounds. In the last decade, this approach has grown from a successful theory to a proven tool that is the backbone of a number of large-scale applications. Used to schedule the distribution of industrial gases at Air Products and Chemicals, Inc., this technique has been credited with saving 6% ~ 10% of the operating costs, amounting to annual benefits of about \$2 million for the company.

Network queueing models

Networks of queues can represent situations such as the flow of messages through a communication network, jobs through a computer system, or products through work centers in a factory. A typical application may have hundreds of customer types and work centers. Traditionally, realistic queueing models have proven intractable, even for one work center; however, recent technical breakthroughs in the analysis of such networks involve the creative use of approximations to solve large networks. IBM used this approach to analyze and justify a major factory of the future, thereby gaining a competitive edge of several months in bringing a new product to the market.

Mathematical programming models

Enormous progress has been made by using large-scale mathematical programming models to route raw materials, components, and finished goods optimally among production plants and warehouses. One such technical achievement is the use of approximation methods to analyze models with nonconvex cost curves representing the economies of scale that typically arise in trucking operations, an approach General Motors used in more than 40 plants to achieve a 26% logistics cost savings, for an annual saving of \$2.9 million.

Simulation modeling

With the development of numerous interactive simulation languages, simulation continues to be an important tool. Simulation models were recently used to describe the water distribution system in the Netherlands. These models were part of a broad analysis focused on building new facilities and changing operating rules to improve water supply, as well as on the adjustment of prices and regulations to reduce demands. The analysis is credited with saving hundreds of millions of dollars in capital expenditures and reducing agricultural damage by about \$15 million per year. The Dutch government adopted the methodology and uses it in train water resource planners from many nations.

Stochastic network analysis

Headway has been made in incorporating stochastic effects into mathematical programming models. A stochastic network analysis was used by North American Van Lines to dispatch thousands of trucks daily from customer origins to customer destinations. This analysis reduced the cost of their operations by an estimated \$2.5 million annually.

Inventory control

Progress continues in the control of inventories, a domain of important application since the earliest days of OR. For example, a model controls inventories of blood at blood banks in Long Island, schedules blood deliveries according to statistical estimates of the needs of each bank, and uses actual requirements to adjust deliveries. It forecasts short-term shortages and surpluses to control movement of blood from adjoining regions. As a result, reductions of blood wastage of 80% and of delivery costs by 64% have been realized.

Markov decision processes

Our ability to analyze large-scale constrained Markov decision processes is continually expanding. This approach was used to develop optimal maintenance policies for each mile of the 7,400 mile network of highways in Arizona. The model integrates management policy decisions, budgetary policies, environmental factors, and engineering decisions. During the first year of implementation the model saved \$14 million, almost one-third of Arizona's highway preservation budget. The forecast for future annual savings is about \$25 million.

Stochastic service systems

Using the Defense Communications Engineering Center's queueing based circuit switch integration and analysis model, the Defense Communications Agency saved $150 million over the past 10 years by a yearly reconfiguration of the CONUS AUTOVON network, a Department of Defense telephone network in the United States which handles military communications and has a precedence and preemption capability.

An outlook on a research agenda

Operations research is a rich field possessing deep intellectual content. It has many varied subfields and numerous applications in engineering, physical sciences, economics, management, and social sciences. A dynamic field, it has successfully renewed itself through new lines of inquiry and application. No brief assessment of a research agenda could do the field justice.

What follows highlights five major OR areas. They are not meant to be all inclusive — many areas are not covered. Two are theoretical (optimization and stochastic processes), one is applied (manufacturing and logistics), one has major elements of both theory and practice (the OR/AI interface), and one studies underlying processes (operational and modeling science).

Optimization

Optimizing — determining how to get an objective function or performance index to its maximum within the limits of available resources and technology — is a fundamental goal of decision making and, moreover, an important tool in engineering design. For more than three decades, research in optimization — a considerable fraction of which has been funded by the STOR program of NSF — has been active and fruitful, with payoffs accumulating through a multitude of applications.

Linear programming is widely used throughout the world. Optimization also involves techniques for solving large-scale, discrete, nonlinear, multiobjective, and global problems. Some recent advances in the field have such great potential that they have been cited prominently in popular publications, including the New York Times and the Wall Street Journal. Moreover, optimization is in a new stage of proliferation because its techniques are now accessible to microcomputers. Since optimization has achieved a degree of maturity, it is natural to take a hard look at what can be expected from further research.

In the more mature areas such as linear programming and unconstrained optimization, and in those of intermediate maturity such as integer and constrained convex optimization, emphasis will be placed on rapid, large-scale computation. This will be driven both by the need to solve large problems in manufacturing and logistics, and by the opportunities created in new computer technologies such as parallel processing. Research in such newer and lesser understood areas as global, multicriteria, and qualitative optimization, will necessarily deal with basic issues.

Stochastic processes

We live in a world in which we have limited knowledge and an inability to predict the future with certainty. A telecommunications network may suddenly be flooded by calls; a vital machine in a manufacturing plant may fail unexpectedly; a firefighting service may be called into action without warning. The study of stochastic processes provides us with a systematic way to model, design and control service systems characterized by such uncertainty. Operations research will continue to provide an observational framework for such studies through fundamental research into foundations of probabilistic phenomena.

Flexible manufacturing systems (FMS) and computer/communication networks exemplify complex systems that fall into a class called discrete event stochastic systems (DESS). The efficient design and operation of these systems is extremely important to economic competitiveness, yet system behavior is not completely understood. Present methods of analysis and design of DESS focus on their behavior in the steady state, a conceptualization that requires performance measures to be made "in the long run" or "averaged over time." Yet, most systems exhibit dynamic behavior on their way to (or sometimes even during) the steady state that may produce a deviation in performance from that computed by steady state analysis. Design and control of such systems (for example, multiechelon spare parts inventories, integrated manufacturing cells, or computer/communication nets) involving explicit consideration of the cost or impact of transient behavior, is now a real possibility.

Similarly, most current analyses presume time stationary of input parameters (arrival rates, processing time, movements, linkages) when, in fact, the actual parameters often vary with time, perhaps with some degree of regularity or even control. Errors introduced into existing design and analysis models by "average" or "typical" parameter values need to be addressed and the resultant understanding utilized. Some relatively new methodology already incorporates time varying system parameters; more must be developed.

There are two major problems in modeling and analyzing stochastic service systems: design and control. System design is concerned with finding answers to strategic questions of resource allocation, such as how many machine maintenance repair stations should be built in a manufacturing facility, or what the capacity of data links incorporated into a telecommunications system should be. System control deals with day-to-day operations or tactics; for example, when to activate additional repair crews, or when to temporarily prevent new messages from entering a system.

The OR/AI interface

The primary objective shared by OR and artificial intelligence (AI) is to provide methods and procedures that support effective problem solving and decision making. The two disciplines approach this common objective in fundamentally different but complementary ways: AI problem solving techniques tend to be inferential and to rely on expert knowledge and heuristics; OR uses algorithmic, mathematically based approaches. Artificial intelligence emphasizes qualitative aspects of problems; OR emphasizes the quantitative. A careful integration of these two approaches to problem solving shows significant promise for improving the capability and, notably, the acceptability of problem solving systems.

Operational science and modeling science

Most current research in OR focuses on the development and improvement of its technological methodologies for passing from a formalized model of the phenomena and preferences arising in some problem of design or decision, to a "solution" of a problem using the model (a recommended design or operating policy, for example). This natural focus has scored notable successes, and remains rich in intellectual promise. But the narrowing of emphasis from problem solving to model utilization has limited the development of two equally fundamental research areas underlying problem solving.

One of these is operational science, which may be defined as the systematic study — empirical and analytical — of the major generic processes, such as routing or maintenance, arising in OR. Whereas other branches of engineering may turn to well established sciences for basic data and theory, OR must often develop on its own much of the descriptive and predictive "science" of the phenomena it treats.

The other area is modeling science, the application of OR methodology, to the identification of fundamental principles and concepts for guiding the construction, use, and evaluation of OR models. The process of model building — considering parameters such as resources available and time pressures — is a fertile area for further research.

While enhancement of OR model utilization technology must continue, it needs to be reinforced and balanced through intensive research into both operational science and modeling science.

Manufacturing and logistics

The design, evaluation, and control of production and distribution systems have been, and will continue to be, vital focuses of OR. The scope of research here includes all activities by which labor, raw materials, and capital are mobilized to bring goods to market. While this discussion focuses on physical production, the provision of services involves similar issues of resource allocation and management.

To compete effectively in the markets of today and tomorrow, the entire production and distribution stages of the product realization process must act in concert, so as ultimately to deliver the right products at the right prices to the right places at the right times. Failure to do so predictably results in waste: excess inventory, poor quality, poor customer service, and unnecessary cost. The globalization of markets and the compression of product life cycles have only increased the urgency of this issue. The powerful impact of coordination has become widely recognized in recent years because of the success of the just-in-time (JIT) system, first used in Japanese companies, and now in several firms in the United States. This approach only works in certain settings, however; for example, supply and production lead-times must be regular and predictable. Attempts to impose the JIT system on inappropriate settings have resulted in spectacular and well publicized failures. The best features of the method must be adapted to designs for realistic, integrated approaches to coordination.

Professional Words and Expressions

Operations Research	运筹学
Mathematical Programming	数学规划
Forecasting	预测
Expert System	专家系统
Statistics	统计学
Organizational Theory	组织理论
Simplex Algorithm	单纯形(算)法
Transportation Problem	运输问题
Network Problem	网络问题
Linear Programming	线性规划
Hypercube Queueing Model	超立方排队模型
Lagrangian Relaxation	拉格朗日松弛法
Lagrange Multiplier	拉格朗日乘数
Combinatorial Optimization Problem	组合优化问题
Polynomial Algorithm	多项式算法
Constraints	约束
Bound	界限
Network Queueing Model	网络排队模型
Nonconvex	非凸的
Simulation Modeling	仿真建模
Stochastic Network Analysis	随机网络分析
Markov Decision Process	马尔可夫决策过程
Stochastic Service System	随机服务系统
Objective Function	目标函数,目标方程
Discrete Optimization	离散优化

Nonlinear Optimization	非线性优化
Multiobjective Optimization	多目标优化
Unconstrained Optimization	无约束优化
Integer Optimization	整数优化
Flexible Manufacturing System (FMS)	柔性制造系统
Discrete Event Stochastic System (DESS)	离散事件随机系统
Artificial Intelligence (AI)	人工智能

Notes

Operations research, as defined by the Operations Research Society of America, "is concerned with scientifically deciding how to best design and operate man-machine systems, usually under conditions requiring the allocation of scarce resources."
美国运筹学学会将运筹学定义为:在需要对紧缺资源进行分配的前提下决定如何最好地设计和运作人－机系统的决策科学。

4 Work-Measured Labor Standards
基于作业测量的劳动标准

Work-measured labor standards have been around for about a century, and they will continue to be around for the foreseeable future. They are useful tools applicable to many areas of business. Perhaps the only thing wrong with these tools is their lack of a buzz word or catchy acronym. Maybe they should be called WMLS to keep up with the times.

For many years, work-measured labor standards were recognized as being very helpful in identifying remedies for those companies ailing from productivity problems. Dr. W. Edwards Deming was one of the first persons to down-grade labor standards. Point 11b of his famous 14 points states: "Eliminate numerical quotas for the work force."

Using labor standards to determine workers' pay has generally proven to be demoralizing and adversarial and ineffective in the long run. Workers end up achieving 150-200 percent of the old standards, or perhaps they simply loaf around once the standard is met. Stock holders are unhappy; management is unhappy; and workers end up losing respect for management. It's a demoralizing situation for everyone. Labor standards are not really useful for whipping workers into being productive. Dr. Deming's point makes sense.

But have you ever had to cost out a product or service, or cost estimate a proposed new product or service? Have you ever had to schedule a job and give a customer an estimated delivery date, and then organize workers to produce the product? Have you done any simulation? What did you use to determine the labor times? Was it just magic? Of course not. You used some form of standard times, even if they were only quick estimates on a napkin over lunch.

If you're a manufacturer, chances are you have a bill-of-materials (BOM) system to determine standard parts cost. Do you also have an equivalent bill-of-labor system to determine standard labor costs?

Basically, you need to formalize your labor times, and your labor costs. If your standard labor times are realistic, your costing is more accurate, and your delivery times are also more accurate. The complaint "I can't afford to set standard times" should be followed by the question "Can you afford not to?"

Let's be realistic about it. There is no such thing as an "accurate" labor standard time. Human workers come in at least a billion models with varying physical, mental, and emotional specifications and work under varying environmental conditions. This variety makes "average" or standard times extremely difficult to determine. Standard times are standard times only because all parties involved agree they are standard times. This is an important point.

The key is to quickly and economically develop and maintain standard times that are as close to real life as possible.

Developing standard times

Five techniques are commonly used to develop standard times: motion analysis, time study, activity sampling, historical data, and estimates.

Motion analysis — This technique involves dividing a task into its component motions, then looking up the motion times on a chart or data card of a pre-determined motion times system (PMTS). PMTSs currently in use include Methods Time Measurement (MTM), Maynard Operation Sequence Technique (MOST), Modular Arrangement of Predetermined Time Standards (MODAPTS), Master Standard Data (MSD), Motion Standard Times (MST), and Work Factor.

Motion analysis is applicable to short-cycle, highly-repetitive tasks. Most PMTSs have been computerized by one or more vendors. Computerization ranges from rapid code validation and automatic calculation, to question and answer scenarios, to interactive expert systems. Choosing a PMTS is basically a matter of finding one you like, then selecting the computer implementation that is appropriate and affordable. Computerized PMTSs are typically part of larger, often expensive, standards management software. Applying a PMTS can be time-consuming, whether it's computerized or not. However, a PMTS forces you to look at the method you use to accomplish a particular job, which promotes methods improvement. But, remember, a PMTS is best for short-cycle, highly-repetitive tasks.

Time study — The most widely used tool to develop standard times is still time study. Time study reflects what is happening in your job or project. It is also easy to learn and use. Now, the PC has made summarization of time study data a matter of seconds instead of hours.

A computerized study is taken on an electronic hand-held data collector by assigning a code number to each element. Element codes are entered into the data collector as they occur. A time key is pressed at the end of each element, at the breakpoints. The data becomes a series of code, time, code, time, etc. Rating or leveling factors are also entered into the data collector. Data are then sent to the PC for almost instant summarization. Statistical error figures and graphical histograms can quickly point out any highly variable elements, possibly indicating a bad method.

The real key in computerized time study is actually the data collector, not the software. For example, many firms have used spreadsheet software for summarization. However, taking the study by stopwatch and typing the values into the spreadsheet saves little if any time. But it does invite entry errors. It's far better to use a data collector or hand-held computer — even a laptop computer — for conducting the study. This applies no matter what software you use for summarization.

Activity sampling — An often overlooked tool is activity sampling, usually called work sampling by North American IEs. In this technique, a group of workers are observed at random times and their individual activities noted each tour. After a week or two, the average time spent on each activity can be calculated, and statistically justified. The average time per piece can then be determined.

Activity sampling can quickly establish standard times on highly variable or long-duration tasks. The key to fast and easy activity sampling is an electronic data collector and PC software. Subject or activity codes are entered into the data collector. The data are then sent to the PC on a daily basis. This allows for almost instant summarization at any time during the course of a study. Activity sampling can also uncover bottlenecks and determine reasonable allowances.

Historical data — This really is not a tool as much as it is a good shop practice. Keep accurate job records. If you have an electronic jobclock system, historical times from past jobs offer an excellent source for standard times. As methods change, the standard times gradually change, using a moving average approach. This can be especially beneficial on long tasks that might change from job to job as methods improve.

Estimates — A well-reasoned estimate is what makes a standard a good standard, especially for seldom-performed, highly variable tasks. Be sure to get estimates from at least three people who do the task. Then average them, and discuss the average with all three individuals. Put it in your computerized standards system.

Let's quickly review the techniques, and put them into perspective according to the tasks for which they apply:

- Motion analysis: very short, repetitive tasks;
- Time study: short, repetitive and variable tasks;
- Activity sampling: longer, variable tasks;
- Historical data: long, repetitive and variable tasks;
- Estimates: seldom performed, variable tasks.

The main point is this: Use the tool that develops the standard time consistent with the type of task involved. Use a computer program if a large amount of data is involved, such as time study and activity sampling data.

Maintaining standard times

Far too many U. S. companies have developed — or had a consultant develop — standard times and then stopped there. One of the biggest problems in American industry is "creeping methods changes." Methods improve, but acceptable standard times are not updated to reflect the newer standards. It is as important to update your standard times as it is to develop them in the first place.

How can you do that economically? A computer can help a great deal. Although you can use spreadsheet and database software, programs are available specifically for maintaining standard times. The programs typically store measured times, then use them to develop and maintain worker and product standards. Such programs feature several "levels" of standard times, but they can usually be characterized as having three major levels: elements, operations and routers.

Elements — Individual work-measured times are often referred to as standard elements or standard data. Some companies maintain standard data in ring binders, but most don't even bother cataloging individual work-measured time elements. A PC-based system encourages standard data development and application because it simplifies the process and eliminates extra paperwork. Most software programs offer integrated motion-level standard data in the form of an integrated PMTS. But your time study, activity sampling, historical data, and estimate elements are also legitimate standard data elements. Such elements can be cataloged in a computerized standards system for rapid application to worker standards. This is much faster than looking them up in a ring binder.

Operations — Worker standards are often referred to as operation or process standards, and are typically paper systems just begging for computerization. The operations or process level is the core level in any PC-based standards system, and it often offers side benefits such as manufacturing line balancing. Frequencies, allowances, internal elements, setup elements, workplace layouts, assembly sketches, operator instructions, and other worker-oriented aspects are also handled at this level.

Routers — Product standards are usually called routers or routings, and then summarize setup and run times from several operations. Costing and scheduling are accomplished at this level. Routers are typically computerized as parts of an MRP II or other mainframe costing system. However, routers can also be part of a PC-based standards system, offering automatic updates as operation times change.

Like any standards system, a computerized standards system won't help — and can be counterproductive — if it is not kept up-to-date. If you expect to continue to produce accurate labor costs and cost estimates, and meet promised delivery dates, keep your labor standards current. Actual time spent updating isn't burdensome, especially when your standards are computerized.

Most computerized standards systems feature an integrated PMTS to help the user develop standards. But don't let that be your primary purpose for "buying into" computerized standards. Maintaining your standards comes first. Look upon an integrated PMTS as a bonus, but just for those highly-repetitive short-cycle tasks. The primary purpose of a computerized standards system should be to manage standards, not create them.

Summary

Since practically everyone is already using standard times in one form or another, using work measurement to develop these times is simply an improvement on what you are already doing. (You're using times from some source, even if they are simply educated guesses.) Computerization not only speeds development, but fosters maintenance of standards. The following 6 points will help clarify some points regarding standard times:

1. Standard times are necessary for costing and cost-estimating, and for scheduling and manpower allocation.
2. a. A standard time is not a standard time unless all parties involved agree it is a standard time.
   b. Never use the word "accurate" when discussing standard times.
3. The more realistic your standard times, the more realistic your costing and scheduling.
4. Use the fastest, easiest work measurement technique that is consistent with the task being measured: motion analysis, time study, activity sampling, historical data, or estimates.
5. a. Constantly check to be sure the method being used is the same as the standard-time method.
   b. Change a standard time as more data becomes available for the task (such as historical data).
   c. Change a standard time whenever the method changes.
6. Use a computer.

Professional Words and Expressions

Work-Measured Labor Standards	作业测量的劳动力标准
Motion Analysis	动作分析
Time Study	时间研究

Activity/Work Sampling	活动/工作抽样
Historical Data	历史数据
Estimate	估算
Pre-determined Motion Times System (PMTS)	预定动作时间系统
Methods Time Measurement (MTM)	方法时间测量法
Maynard Operation Sequence Technique (MOST)	梅纳德操作排序技术
Modular Arrangement	模块化安排法
Predetermined Time Standards (PTS)	预定时间标准法
Master Standard Data (MSD)	主时间数据法
Motion Standard Times (MST)	动作标准时间法
Work Factor	工作要素法
Interactive Expert System	交互式专家系统
Data Collector	数据收集器
Rating or Leveling Factor	评比因子
Histogram	直方图
Moving Average Approach	移动平均法
Manufacturing Line Balancing	生产线平衡

Notes

1. Perhaps the only thing wrong with these tools is their lack of a buzz word or catchy acronym.
   也许这些工具的惟一缺点是它们没有一个能够反映其内涵的响亮的词组或引人的字母缩写。
2. Human workers come in at least a billion models with varying physical, mental, and emotional specifications and work under varying environmental conditions.
   由于物理、精神和感情等方面以及工作环境的不断变化,工人至少可以被分为十亿种不同的类型。
3. Standard times are standard times only because all parties involved agree they are standard times.
   标准时间之所以是标准的仅仅是因为相关的所有部门都承认其是标准时间。
4. Like any standards system, a computerized standards system won't help — and can be counter-productive — if it is not kept up-to-date.
   同其他的任何标准系统一样,如果不能做到与时俱进,计算机化的标准系统将起不到相应的作用并且可能会降低生产率。

5 Ergonomics
人因学

The origin of ergonomics

Ergonomics is the scientific discipline that is concerned with the interaction between humans and artifacts and the design of systems where people participate. It deals with the design of systems that people use at work and leisure, tools that are used to perform tasks, and procedures and practices that organize human activity. The purpose of the design activities is to match systems, jobs, products and environments to the physical and mental abilities and limitations of people. A complementary way to make a system function is to train and educate the operator or the user of the system. Ideally, however, systems should be designed so that they are intuitive to use and do not require special training or education.

The word ergonomics comes from the Greek ergo (work) and nomos (rules, law). It was first used by Wojciech Jastrzebowski in a Polish newspaper in 1857. One may argue that ergonomics is nothing new. Hand tools, for example, have been used since the beginning of mankind, and ergonomics was always a concern. Tools concentrate and deliver power, and aid the human in tasks such as cutting, smashing, scraping and piercing. Various hand tools have been developed since the Stone Age, and the interest in ergonomic design can be traced back in history.

Ramazzini, in the eighteenth century, published a book, The Diseases of Workers, where he documented links between many occupational hazards and the type of work performed. He described, for example, the development of cumulative trauma disorder and believed that these events were caused by repetitive motions of the hand, by constrained body posture, and by excessive mental stress.

LaMettrie's controversial book L'homme Machine was published in 1748, at the beginning of the Industrial Revolution. Two things can be learned from LaMettrie's writings. First, the comparison of human capabilities and machine capabilities was already a sensitive issue in the eighteenth century. Second, by considering how machines operate, one can also learn much about human behavior. Both issues are still debated in ergonomics today. For example, the comparison of robots and humans has made us understand how industrial tasks should be designed to better fit humans.

Rosenbrock pointed out that during the Industrial Revolution there were efforts to apply the concepts of a 'human centered design' to tools such as the spinning-jenny and the spinning-mule. The concern was to allocate interesting tasks to the human operator, but to let the machine do repetitive tasks.

At the beginning of the twentieth century, Frederick Taylor introduced the 'scientific' study of work. This was followed by Frank and Lillian Gilbreth who developed the time-and-motion study and the concept of dividing ordinary jobs into several small micro-elements called 'therbligs'. Today there are sometimes objections to Taylorism, which has been seen as a tool for exploiting workers. Nonetheless, these methods are useful for measuring and predicting work activities. Time-and-motion study is a valuable tool if used for the right purpose!

Industrial psychology in the beginning of the twentieth century emphasized how one could select, classify and train operators who were suitable to perform the task. The research on accident proneness is typical of this era. Accident proneness implies that there are certain individuals with enduring personality characteristics, who incur a majority of accidents. If one can understand how these individuals differ from 'normal' people, one can exclude them from activities where they incur accidents. This approach, which dominated research for about 20 years, was not fruitful, since accident proneness and many personality features are not stable features, but change with age and experience. In current ergonomics there is a realization that human error is mostly caused by poor design, and the emphasis is to design environments and artifacts that are safe for all users.

In Europe, ergonomics started with industrial applications in the 1950s, and used information from work physiology, biomechanics and anthropometry for design of workstations and industrial processes. The focus was on the well-being of workers and manufacturing productivity. In the USA, human factors engineering, human factors and engineering psychology developed from military problems, and had their origin in experimental psychology and systems engineering. The purpose was to enhance systems performance. Today these two traditions have fused. It is indicative that the Human Factors Society in the USA recently changed its name to the Human Factors and Ergonomics Society.

Since the 1950s ergonomics and human factors have proliferated in Asia, Africa, Latin America and Australia. In many industrially developing countries (IDCs) ergonomic problems have manifested themselves, and have become more obvious in the era of rapid industrialization. The transformation from a rural, agrarian to an urban, industrialized life has come at a cost, and workers are 'paying' in terms of a tremendous increase in industrial injuries and in terms of worker stress. Many of these problems remain hidden, because official statistics that can illuminate the true state of affairs are not usually available. Industrialization has come about too quickly, and many societies have difficulties in coping with the changes in infrastructure.

In the transition to the new industrial world IDCs are bypassing several stages of development and are immediately immersed in the computerized global environment. What took the western world 200 years, may be accomplished in 20 years. Associated with this development is a new ergonomics problem that deals with the globalization of communication, integration of resources and global management. This problem is shared by the IDCs and the Western countries. The 'Asian tigers' are well positioned to take the lead in this area, but at the present time they lack some of the necessary infrastructure in terms of experience and trained personnel. There is tremendous economic potential in designing usable systems for global communication and customized markets. Technology transfer from the Western world is important, but must be concerned not only with the adaptation and use of machines but also with the entire infrastructure of training local users to develop independent capabilities so that they can act freely on the global market. Ergonomists who understand these problems will have a significant role to play.

A systems description of ergonomics

The purpose of this section is to describe the evolving science of ergonomics in a systematic context. Most ergonomics problems are well described by a systems approach. In Figure 1, an environment-operator-machine system is considered. The operator (or user) is the central focus in ergonomics and should be described in an organizational context, which is the purpose of Figure 1. The Figure illustrates only the most important operator concepts. In reality, human perception, information processing, and response are much more complex with many feedback loops and variables that are not detailed in Figure 1.

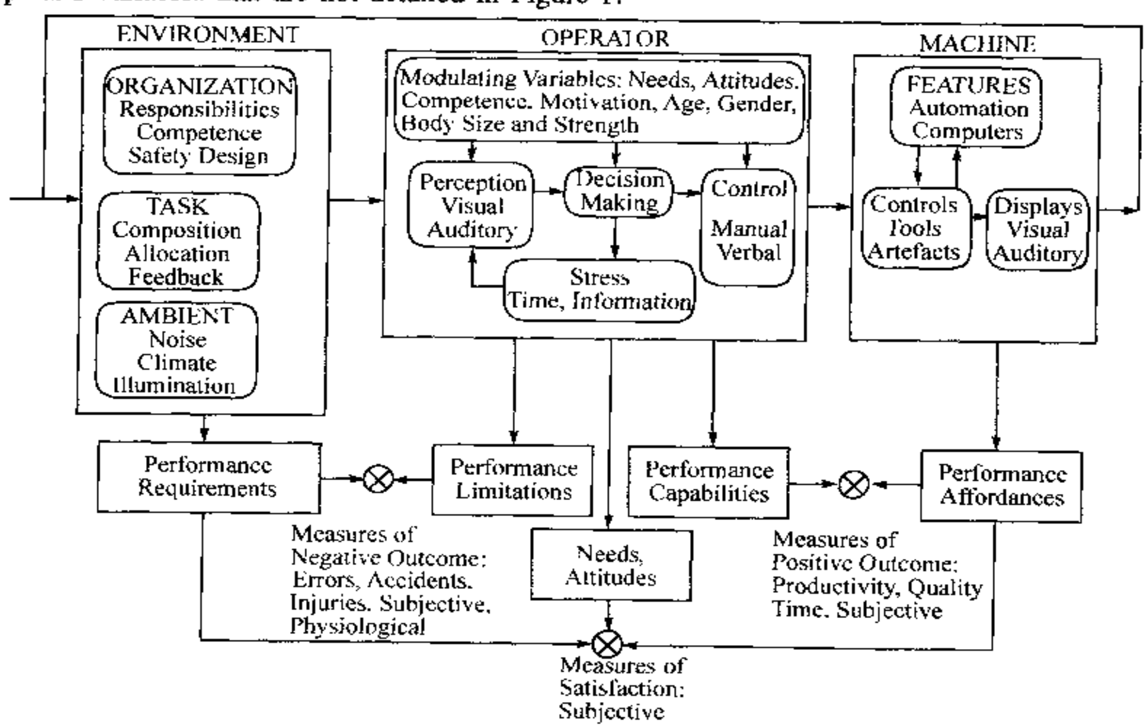


Figure 1. Ergonomics systems model for measurement of safety, productivity and satisfaction

In scientific studies, a classification of independent and dependent variables is often used to analyze a problem. Since ergonomics studies the effect of environmental and machine design features on the operator, the dependent variables are associated with the operator sub-system. These are detailed in Figure 1, and include measures of negative and positive outcome and satisfaction. The independent variables are associated with design parameters of the environment and the machine (such as alternative task allocation, different controls and displays).

The operator perceives the environment — mainly through the visual and auditory senses, then considers the information, makes a decision and finally produces a control response. Perception is guided by the operator's attention. From the millions of bits of information available, the operator is forced to choose the information most relevant to the task. Some attentional processes are automatic and subconscious (pre-attentive) and are executed instantaneously. Some processes become automatic with training, while some are deliberate and slow strategies that provide more time for analysis of the situation.

For new or unusual tasks decision-making can be time consuming. The operator will have to interpret the information, the alternatives for action, and to what extent those actions are relevant to achieve the goals of the task. For routine tasks, decisions are more or less automatic and much quicker to accomplish. In this context researchers question whether 'decision making' is an appropriate term. 'Situated action' may be more appropriate to describe the automaticity in response.

The purpose of the operator's response is to convey information through either manual response, such as control of a machine (e. g. computer) or a tool (e. g. hammer) or an artifact (e. g. football) or verbal response such as computer voice control of a machine or verbal message to a co-worker.

There are several modulating variables that affect task performance including: operator needs, attitudes, competence, expertise, motivation, age, gender, body size and strength. These are idiosyncratic variables and they are different for different individuals. For example, an experienced, competent operator will perceive a task differently than a novice operator. She/He will focus on details of importance, filter irrelevant information and 'chunk' the information into larger milts so that it is possible to make faster and more efficient decisions. Body size is an example of another modulating variable, and the purpose of anthropometry is to design the physical workspace to fit operators with different body size.

Stress is an important variable that affects perception, decision-making and response selection. High psychological stress levels are normal when the time to perform a task is limited or when there is too much information to process. Under such conditions the bandwidth of attention may narrow, and operators develop 'tunnel vision'. Thus the probability of operator error increases.

In general, high stress levels lead to increased physiological arousal and can be monitored by using various physiological measures (e.g. heart rate, EEG, blink rate, and excretion of catecholamines).

The sub-system environment is used to conceptualize the task as well as the context in which it is performed. It could be a steel-worker monitoring an oven. Here organization of work determines the task allocation; some tasks may be allocated to fellow workers, or supervisors, or computers. Task-allocation is a central problem in ergonomics: how can one best allocate work tasks among machines and operators so as to realize both company goals and individual goals? Task allocation affects how information is communicated between employees and computers, and it also affects systems performance.

The operator receives various forms of feedback from his/her actions. There may be feedback from task performance, from co-workers, from management and so forth. To enhance task performance, communication, and job satisfaction, such feedback must be informative. This means that individuals must receive feedback on how well or poorly they are doing, as well as feedback through communication.

The ambient environment describes the influence of environmental variables on the operator. For example, a steel-worker is exposed to high levels of noise and heat. This increases physiological arousal and stress, thereby affecting task performance, safety and satisfaction.

The importance of the organizational environment has been increasingly emphasized during the last few years. This movement in ergonomics is referred to as 'macroergonomics'. Ergonomics is undertaken in an organizational context, which deeply affects the appropriateness of alternative design measures. Company policies with respect to communication patterns, decentralization of responsibilities, and task allocation have an impact on ergonomics design. One should first decide who should do what and how people should communicate. Following this analysis individual tasks, machines, displays and controls can be designed.

Macroergonomics is a much neglected area, and until recently there had not been much research. One exception is the socio-technical research developed in the UK in the 1950s (e.g. the Tavistock group). It may be because the human factors research in the military setting was so dominating in the USA that the importance of organizational context was deemphasized.

For the purpose of completeness of description it is noted that organizational considerations are important in the work context, but are less important for design of leisure systems and consumer products. These are typically used by individuals who do not have to consider collaboration and task delegation.

The machine sub-system is broadly conceptualized in Figure 1. The term 'machine' is in a sense misleading, since it symbolizes any artifact. The 'machine' could be a computer, a VCR, or a football. The term 'controls' denotes machine controls that are used by the operator. Note that machine control may be taken over by automation and computers through allocation and delegation of tasks to autonomous processes.

As a result of machine control, there is a changing state that is 'displayed' — it can be seen or heard; a pocket calculator will show the results of a calculation, the melting iron in a steel plant will change temperature and color, a computer will produce a sound, and the toaster will 'pop' the bread. All of these are examples of displays. They convey visual or auditory information, and they can be designed to optimize systems performance.

It is important to note that the system in Figure 1 has feedback. Machine information is fed back to the environment sub-system and becomes integrated with the task. Ergonomics is concerned with dynamic systems. It is necessary to go around the loop and incorporate the effect of feedback. Ergonomics is in this matter different from other disciplines. In experimental psychology, for example, there is no requirement for study of dynamic systems.

The system in Figure 1 will be used to discuss three major system goals in ergonomics: safety, productivity, and operator satisfaction.

The goal of safety

Ergonomics is rarely a goal by itself. Safety, operator (user) satisfaction and productivity are common goals. Ergonomics is rather a design methodology that is used to arrive at safety, productivity and satisfaction.

The safety status of a system can be assessed by comparing the performance requirements of the environment with the performance limitations of the operator (Figure 1). A task will impose a demand for operator attention, and this demand varies over time. For example, a car driver must sometimes look constantly at the traffic and at other times the traffic situation is less demanding. At the same time operator attention varies over time. A sleepy driver has a low level of attention, while a driver of a racing car has a high level of attention. If the task demands are greater than the available attention, there is an increased risk of accidents or errors. Hence it is important to understand how the limitations imposed by operator perception, decision-making and control action can be taken into consideration in design, so as to create systems with low and stable performance requirements.

Injuries and accidents are relatively rare in the workplace. Rather than waiting the accidents to happen it may be necessary to predict safety problems by analyzing other indicators (or dependent variables) such as operator errors, subjective assessments and physiological response variables. These measures are indicated in Figure 1 under the heading of 'Measures of negative outcome'.

In the case where the system must be redesigned to make it safer, there may be several different options, including:

(1) The allocation of tasks between workers and machines/computers. Workers may be moved from a hazardous area and automation could take over the job.

(2) Work processes and workstations can be redesigned to optimize worker posture, comfort and convenience.

(3) The exposure to ambient parameters including illumination, noise and heat stress can be reduced.

(4) Organizational factors such as allocation of responsibility and autonomy as well as policies for communication can be changed.

(5) Design features of a machine can be improved, including changes of controls and displays.

These and other options for redesign can be derived from Figure 1.

The goal of productivity

As mentioned, systems design has three goals: safety, productivity and operator satisfaction. Their relative importance varies depending on the system. In a nuclear power plant, safety and production of electricity are two self-evident goals, and together they determine the design of the plant.

To enhance system performance one can design a system that improves performance affordances. This means that through efficient design of the system the operator can excel in exercising his/her skills. Such system design makes it possible to perceive quickly, make fast decisions, and exercise efficient control.

To improve system performance an ergonomist could, for example, design system affordances so that they enhance important skill parameters: handling of machine controls becomes intuitive (e.g. through control-response compatibility), interpretation of displays becomes instantaneous (e.g. through use of ecological displays).

In Figure 1 several measures of positive outcome are indicated. One can measure productivity, quality, time to perform a task, and one can ask the operator how well the system works (subjective assessments). These measures are the common dependent variables used to measure the productivity of a system.

The trade-off between productivity and safety

Ergonomics improvements may focus on reducing operator errors as well as increasing efficiency or speed of operation. It may, however, be difficult to simultaneously improve both safety and productivity. In general, the greater the speed (of vehicles, production machinery, etc.) the less will be the time available for the operator to react. A shorter time for operator reaction will compromise safety but increase productivity. Operators have a choice between increased speed or increased accuracy, which is referred to as speed-accuracy trade-off or SATO. Industrial managers often encourage employees to increase both speed and accuracy (productivity and quality). This is contrary to the concept of SATO and hence difficult or impossible to achieve.

In industrial production systems it will, however, be possible to improve safety and quality of production at the same time. A reduction of operator errors will typically lead to improved safety as well as improved production quality. An emphasis on quality of production may therefore be more appropriate and more effective than the traditional approach in industry to stress on quantity of production.

The goal of operator satisfaction

Operator satisfaction is conceived in a broad sense: from worker satisfaction to user satisfaction. Various aspects of dissatisfaction such as job dissatisfaction or consumer dissatisfaction are also considered. The main point in Figure 1 is that (dis) satisfaction may be predicted by comparing operator needs and attitudes with the performance requirements of the environment and the performance affordances of the machine.

Satisfaction and dissatisfaction are mediated through the operators' needs and attitudes. Since needs and attitudes are different among different individuals, some users can be satisfied with a system while others are dissatisfied. Needs and attitudes vary substantially between countries and cultures. What are considered workers' rights in Sweden (e.g. to have a window in your office) are less important in other countries. In Sweden, a lack of window would cause great dissatisfaction, since office workers have 'acquired' a need, but workers in the USA may not think twice about this.

For safety and productivity, it was noted above that there is a trade-off: improved safety leads to lower speed of production and vice versa. For job satisfaction or dissatisfaction there does not seem to be any similar trade-offs. One would think that a satisfied worker would produce more and a dissatisfied worker would produce less. One would also think that a satisfied worker would be safer and a dissatisfied worker not so safe. However, extensive research on these issues has not been able to demonstrate that there is a connection.

Conclusion

Owing to the diffusion of computer technology and complex machinery new interests have emerged in ergonomics. Cognitive ergonomics, usability studies, human reliability, and human-computer interaction are current top priorities. Organizational design and the study of industrial change processes and continuous improvements are also important. Biomechanics and work physiology are less dominating than they were in the past, except that there is a renewed interest in biomechanics due to musculoskeletal disorders.

It is interesting to note that this trend is valid not only for industrialized countries but also for industrially developing countries. Since the beginning of the history of ergonomics around 1950, society and technology have developed tremendously. Brian Shackel characterized the development as follows:

1950s — military ergonomics
1960s — industrial ergonomics
1970s — consumer products ergonomics
1980s — human-computer interaction and software ergonomics
1990s — cognitive ergonomics and organizational ergonomics

The interest in the 2000s will be on global communication. This type of ergonomics is driven by the global markets and its main purpose is to enhance global trade and interaction. It is facilitated by Internet communication, and it makes it feasible to start virtual organizations.

There is also an ergonomics interest in dealing with global environmental and social problems, such as the pollution of the big cities, crime, the trend of unemployment, and so forth. Moray (1991) suggested that ergonomics methodology could be used for solving these types of problems, since they are based on behavior of the individual and may be solved by giving forceful feedback to the individual.

Ergonomics is a science of design. The design methodology as illustrated in the systems approach in Figure 1, is well suited to solving problems outside the traditional sphere of interest. Ergonomics will continue to evolve and professional ergonomists must extend their knowledge to deal with a rapidly changing scenario. This will require increasing interaction with other disciplines to solve problems of an interdisciplinary nature. There is also a need for communication and collaboration between ergonomists in proposing ergonomics design measures. Activities in research and development may be based on local information, but the design solution may be supported by many ergonomists working in synergy around the world.

Clearly the profession is driven by design requirements from users, markets, industries, organizations and governments. Ergonomics must be able to quickly respond to the changing needs of society.

Professional Words and Expressions

Ergonomics	功效学,人因学
Occupational Hazards	职业危险
Human Centered Design	面向人类的设计
Time-and-Motion Study	时间和动作研究
Industrial Psychology	工业心理学
Accident Proneness	事故倾向性
Work Physiology	工作生理学
Biomechanics	生物力学
Anthropometry	人体测量学
Human Factors Engineering	人因工程
Engineering Psychology	工程心理学
Experimental Psychology	实验心理学
Systems Engineering	系统工程
Human Perception	人类感知
Information Processing	信息处理
Response	响应,反应
Feedback Loops	反馈回路
Independent Variable	独立变量
Dependent Variable	非独立变量
Visual Sense	视觉
Auditory Sense	听觉
Manual Response	手动响应
Verbal Response	语音响应
Idiosyncratic Variable	(人类的)特征变量
Physiological Arousal	生理干扰
Macroergonomics	宏观功效学
Speed-Accuracy Trade-Off (SATO)	速度和精度的平衡
Cognitive Ergonomics	认知功效学
Usability Study	使用性研究
Human Reliability	人类可靠性
Human-Computer Interaction	人机交互
Musculoskeletal Disorder	肌骨失调,肌骨紊乱

Notes

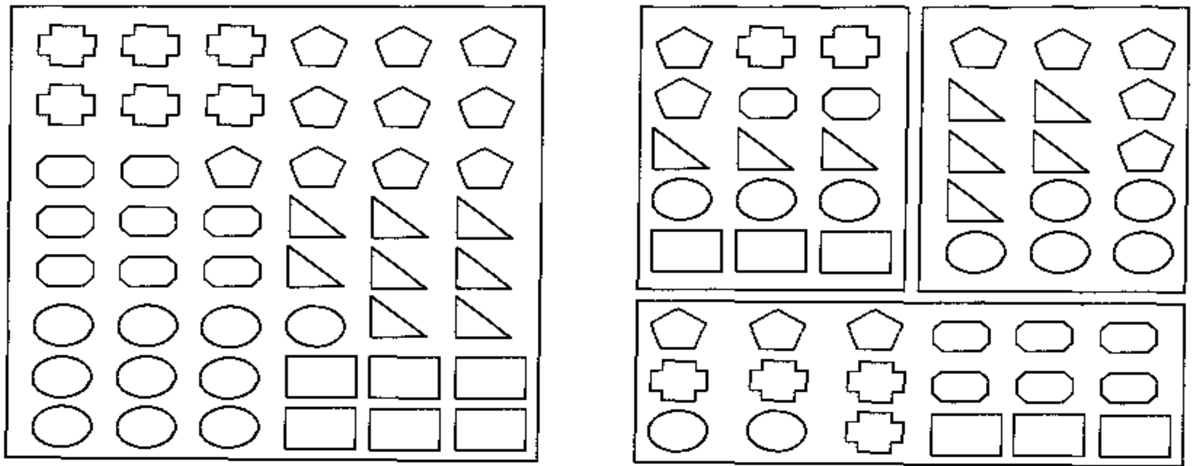
1. Accident proneness implies that there are certain individuals with enduring personality characteristics, who incur a majority of accidents.
   事故倾向性指具有某类特性的个体导致主要事故的发生。
2. The transformation from a rural, agrarian to an urban, industrialized life has come at a cost, and workers are 'paying' in terms of a tremendous increase in industrial injuries and in terms of worker stress.
   从以田园式为主的农业经济向以城市化为主的工业经济的转变付出了一定的代价,这些代价是工人以显著增加的工业伤害和工作压力的形式付出的。
3. Technology transfer from the Western world is important, but must be concerned not only with the adaptation and use of machines but also with the entire infrastructure of training local users to develop independent capabilities so that they can act freely on the global market.
   尽管从西方引进技术很重要,但技术转让的过程不仅要考虑如何使本土使用者适应和使用机器,而且还要考虑如何建设能够培训这些本土使用者的独立能力以便其能够在全球化的市场中运用自如的整个基础设施。
4. Ergonomics is rather a design methodology that is used to arrive at safety, productivity and satisfaction.
   应该说功效学是一种用来实现系统安全性、生产率和操纵者满意度的设计方法。

6 Next Generation Factory Layouts
21 世纪的工厂布局

There is an emerging consensus that existing layout configurations do not meet the needs of multiproduct enterprises and there is a need for a new generation of factory layouts that are more flexible, modular, and easy to reconfigure. With increased flexibility, modularity, and reconfigurability, factories could avoid redesigning their layouts each time their production requirements changed. Creating new layouts can be expensive and disruptive, especially when factories must shut down. Because factories that operate in volatile environments or introduce new products regularly cannot afford frequent disruptions, plant managers often prefer to live with the inefficiencies of existing layouts rather than suffer through costly redesigns, which may quickly become obsolete.

Conventional layouts, such as product, process, and cellular layouts, do not meet these needs. They are typically designed for a specific product mix and production volume that are assumed to continue for a sufficiently long period (usually, three to five years). The evaluation criterion used in most layout design procedures — long-term material-handling efficiency — fails to capture the priorities of the flexible factory (for example, scope is more important than scale, responsiveness is more important than cost, and reconfigurability is more important than efficiency). Consequently, layout performance deteriorates as product volumes, mix, or routings fluctuate. A static measure of material-handling efficiency also fails to capture the impact of layout configuration on aspects of operational performance, such as work-in-process accumulation, queue times at processing departments, and throughput rates. Consequently, layouts that improve material handling often cause inefficiencies elsewhere in the form of long lead times or large in-process inventories.

When product variety is high or production volumes are small, a functional layout, with all resources of the same type in one location, is often thought to provide the greatest flexibility (Figure 1). However, a functional layout is notorious for its material-handling inefficiency and scheduling complexity, which can lead to long lead times, large work-in-process inventories, and inefficient material handling. While grouping resources based on function provides some economies of scale and simplicity in allocating workloads, it makes the layout susceptible to manufacturing inefficiencies when there are changes in product mix or routings. Such changes often require a costly redesign of the plant layout or the material-handling system.



(a)Functional layout (b)Cellular layout

Figure 1. In a functional layout, resources of the same type are placed in the same location, while in a cellular layout, resources are partitioned into cells, each dedicated to a family of products

An alternative to a functional layout is a cellular configuration, in which the factory is partitioned into cells (Figure 1), each dedicated to a family of products with similar processing requirements. Although cellular factories can simplify work flow and reduce material handling, they are generally designed to produce a specific set of products whose demand levels are assumed to be stable and product life cycles sufficiently long. In fact, cells are usually dedicated to single product families with little allowance for intercell flows. Cellular factories are inefficient when demand for existing products fluctuates or new products are introduced often. Some authors have proposed alternative cellular structures to overcome these problems, such as overlapping cells, cells with machine sharing, and fractal cells. Although an improvement, these alternatives remain bounded by their cellular structure.

Layout design procedures, whether for functional or cellular layouts, have been largely based on a deterministic paradigm. Such design parameters as product mix, product demands, and product routings are assumed to be known with certainty. The design criterion is often a static measure of material-handling efficiency (a total adjacency score, total material-handling cost, or a combination of both), which does not capture the need for flexibility and reconfigurability. In fact, the relationship between layout flexibility and layout performance is poorly understood and analytical models for its evaluation are lacking. The structural properties of layouts that affect their flexibility are also not well understood. Current design criteria do not capture the effect of layout on such performance measures as congestion, cycle time, and throughput rate. They also ignore the impact of such operational parameters as setup, batching, and loading and unloading at work centers. More important, they measure only average performance and in so doing cannot guarantee effectiveness under all operating scenarios. Clearly, we need a new class of layouts, new evaluation criteria, and new design models and solution procedures.

Emerging trends in industry

Several important trends are emerging in industry that could transform the layout design problem or even eliminate it. We focus on five of these trends to highlight the interaction between new business practices, new technologies, and layout design.

Contract Manufacturing

In many industries, outside suppliers are increasingly doing most of the manufacturing and assembly for original equipment manufacturers (OEMs). Along with just-in-time deliveries, outsourcing has led to firms reconfiguring their final assembly facilities to accommodate closer coupling between suppliers and OEMs. For example, many automobile manufacturers allow suppliers to deliver components directly to points of use on their assembly lines. They have designed multiple loading docks and multiple inventory drop-off points throughout their factories. To support modular plants, designers are using spine layouts (Figure 2), with the product moving along a main artery, or spine, through the plant. Linked to the spine are mini-assembly lines owned by the suppliers, each attaching its own module to the moving product. The hybrid layout has features of a flow line and multiple, autonomous cells. The configuration allows the plant to add and remove suppliers without changing the main layout. It also gracefully accommodates the growth and contraction of supplier operations. Facility planners had to choose layouts that make material handling efficient not only in each individual plant but throughout the complex. The challenge for facility planners is then to develop a layout and a material-handling system to permit high efficiency at the core and flexibility and reconfigurability at the periphery. The design metrics should certainly be different depending on the area of the plant, but the design tools should also support a variety of layout types within the same facility. The modular layouts we discuss later address in part the challenges of constructing such hybrid layouts.

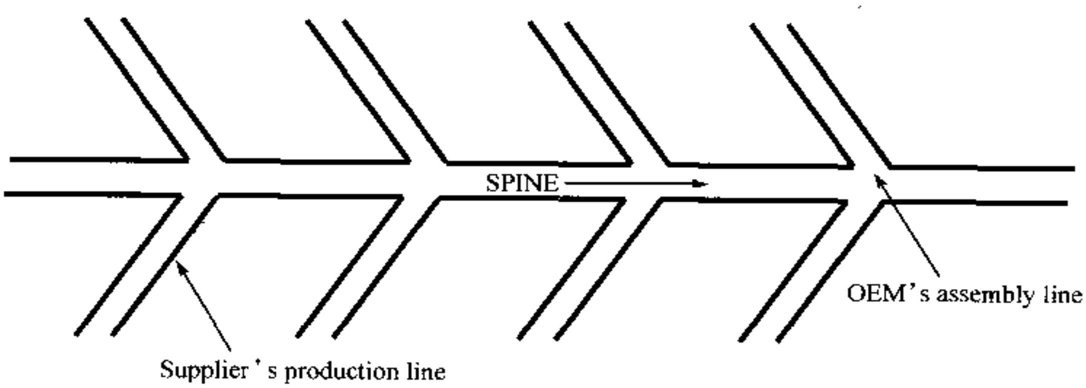


Figure 2. In a spine layout, products move along a main artery through the plant. Linked to the spine are mini-assembly lines owned by independent suppliers who attach additional modules as needed

Delayed Product Differentiation

Increased product variety and the need for mass customization has led many companies to delay product differentiation, postponing the point in the manufacturing process when products are assigned individual features. Companies do this, for example, by building a platform common to all products and differentiating it by assigning to it certain product-specific features and components only after actual demand becomes known. They create hybrid facilities consisting of flow-line-like components where they build the common platforms and job shop-like components where they customize the products. If final products are easily grouped into families, the job-shop structure could be replaced by cells, each dedicated to one of the product families (Figure 3). Taken to the extreme, delayed differentiation can eliminate the problem of designing layouts altogether. For example, if customization takes place at the point of sale or in distribution warehouses, as is increasingly the case for computers, the factory becomes a single high-volume, low-variety production line. Hewlett-Packard has implemented such a strategy by carrying out the localization steps for its computers and printers in its overseas distribution centers (for example, its distribution warehouses install country-specific power supplies and power cords). The blurring of the lines between warehousing and manufacturing raises interesting questions. How does transforming warehouses from pure storage facilities to facilities that also do light assembly affect their design? How should the layout of warehouses change to accommodate both the needs of efficient storage and efficient manufacturing and assembly? In industries where the differentiation steps are carried out inside the factory, there is clearly a need for design tools that support hybrid layouts that may have the features of product, cellular, and functional layouts all under one roof. The modular layouts we discuss later could be a step in that direction.

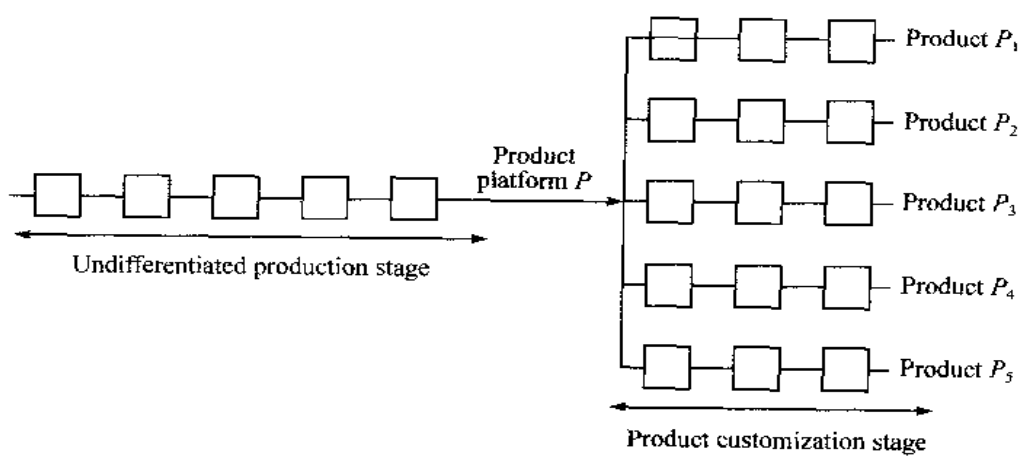


Figure 3. A plant with delayed differentiation has a hybrid layout consisting of two stages. In the first stage, the plant makes undifferentiated products in a make-to-stock fashion. In the second stage, it customizes the products based on actual demand (make-to-order production)

Multichannel Manufacturing

The increased emphasis on quick-response manufacturing and minimum finished-goods inventory has led many manufacturers and suppliers to invest in additional capacity, often by running parallel production lines. By having duplicate flexible production lines shared across products, companies hope to ensure a seamless flow of material. Depending on downstream congestion, products can move in and out of neighboring production lines, creating multiple paths, or channels, minimizing queueing and congestion. Designers of multichannel systems face such challenges as determining how many duplicate paths to have and how to organize the resource duplicates on the plant floor.

Scalable Machines

In the last few years, there has been a concerted effort in the metal cutting industry to develop machines that are highly flexible and scalable and that can perform many functions and be adjusted for various capacities. The functionality and efficiency of the machines can easily be upgraded by plugging in additional modules or acquiring additional software. If successful, such efforts could lead to facilities that use one machine for most processing with little material handling and movement. Because a machine can be rapidly configured for different mixes and volumes, changes in production requirements would have little effect on layout.

Such scalable machines could transform layout design. If material movement became minimal, factory layouts would be greatly simplified and their design would be less important. Emphasis in factory design would then likely shift from the detailed design of each processing department to the higher level integration of these departments (for example, integrating machining with assembly or assembly with inspection and packaging).

Portable Machines

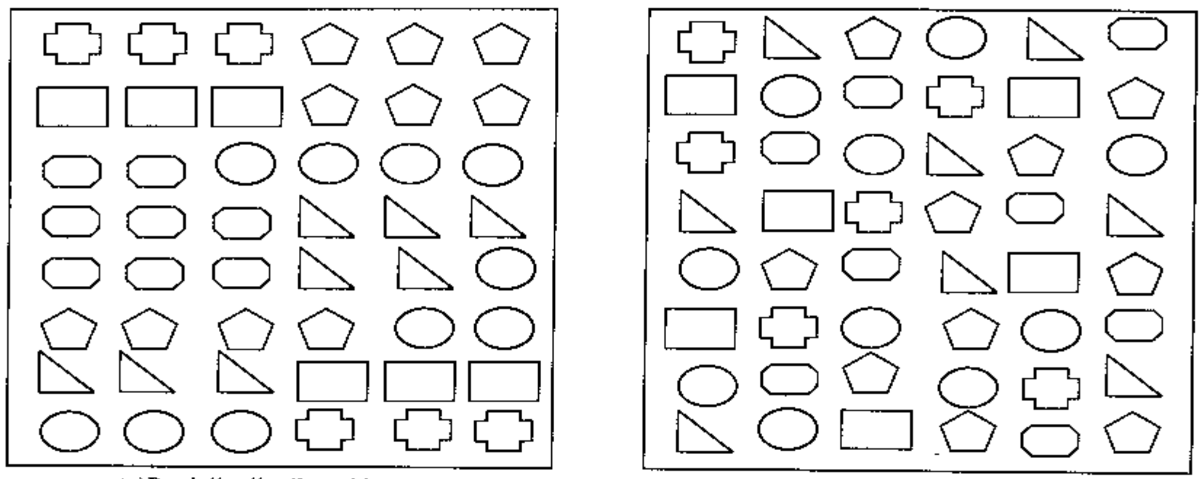
Several equipment manufacturers are marketing portable machines that are easily and dynamically deployed in different areas of the factory as production requirements change. The portable machines go to the workplace and mount on the workpieces — instead of the other way around (that is, workpieces are stationary and movement is incurred by the machines). Hence, factories would have to be laid out to facilitate the flow of machines instead of parts.

Next generation factory layouts

Three approaches to layout design address three distinct needs of the flexible factory. The first two approaches present novel layout configurations, namely distributed and modular layouts. In the third approach, we use operational performance as a design criterion to generate what we term agile layouts.

Distributed Layouts

Distributed layouts disaggregate large functional departments into subdepartments distributed throughout the plant floor (Figure 4). Duplicate departments strategically located throughout the factory allow the facility to hedge against future fluctuations in job-flow patterns and volumes. In turn, disaggregated and distributed subdepartments reduce material-travel distances for many production flow sequences. Planners can easily find efficient flows for a wide range of product mixes and volumes. Such layouts are especially appealing when demand fluctuates too frequently to make reconfiguring the plant cost effective. In these settings, a fixed layout that performs well for many demand scenarios is desirable.



(a)Partially distributed layout　　(b)Maximally distributed layout

Figure 4. In a distributed layout, not all equipment of the same type (represented by a particular shape in the figure) is placed in adjoining locations. Instead, equipment of the same type is either grouped in multiple clusters (partial distribution) or placed individually throughout the plant (maximal distribution)

In designing a distributed layout, a firm faces several challenges. How should it create subdepartments, and how many should it have of each type? How much capacity should it assign to each subdepartment? Where should it place the subdepartments? How should it allocate workload among similar subdepartments? How will department disaggregation and distribution affect operational performance (for example, material-handling times, work in process, and queueing times)? How should the firm manage material flow, now that there is greater routing flexibility? How should it coordinate the competing needs for material handling of similar subdepartments? What performance measure should the firm use when designing distributed layouts? Should it measure expected material-handling cost over possible demand scenarios, or should it seek a measure of robustness that guarantees a minimum level of performance for all scenarios? More important, how sensitive are the final layouts to the adopted performance measure? Although duplicating departments might increase flexibility, it could also increase and diminish economies of scale (for example, operators and auxiliary resources must be duplicated). The firm must trade off the material-handling benefits of disaggregation and duplication against cost increases in other areas.

Modular Layouts

Modular layouts are hybrid layouts for systems with complex material flows that cannot be described as functional, flow line, or cellular. Several of the emerging trends in industry are leading to such configurations. For example, the automobile industry builds modular factories around flow-line-like cores with connected supplier production lines in various forms. Firms that delay product differentiation also use layouts that combine product, process, and cellular features. With such modular layouts, manufacturers can scale their activities up or down quickly. In their research on modular layouts, Irani and Huang (2000) sought to answer the following fundamental questions. Could a layout other than the three traditional layouts better fit the material flows of multiproduct manufacturers? Perhaps a combination of the three traditional layouts? Could a network of layout modules provide a metastructure for designing multiproduct manufacturing facilities in general? Would grouping and arranging resources into modules corresponding to specific traditional layouts minimize total flow distances or costs?

Agile Layouts

In facilities that permit frequent reconfiguration, layouts could be designed to maximize operational performance rather than to minimize material-handling cost. As production-planning periods shrink, factories shift their focus from long-run cost efficiency to short term responsiveness and agility. Such performance measures as cycle time, work-in-process (WIP) accumulation, and throughput become especially important. Unfortunately, capturing the relationship between layout configuration and operational performance is difficult. Meller and Gau (1996) reviewed over 150 papers on factory layout and found only one paper on the subject. Recently Benjaafar (2002) introduced an analytical model capable of capturing the relationship between layout configuration and operational performance. He embedded the model in a layout-design procedure in which the design criterion can be one of several measures of operational performance. Heragu *et al.* (2000) expanded Benjaafar's (2002) model to include set-up time, transfer, and process batch size and developed a method that can estimate operational performance measures of functional and cellular manufacturing systems.

Research challenges

Several research challenges remain. In designing distributed layouts, designers of the current models assume that the number of department duplicates and the capacity of each duplicate are known. In practice, facility designers must make these decisions before developing a layout. Current models do not account for the cost of disaggregating and distributing departments nor do they capture the economies of scale associated with operating consolidated departments. The infrastructure typical of a single consolidated department in a job shop (for example, operators, computer control systems, loading and unloading areas, and waste-disposal facilities) must be duplicated in a distributed layout across all department duplicates. Thus, while department disaggregation and distribution may yield material-handling benefits, a firm must trade off these benefits against the advantages of operating consolidated facilities. We need an integrated model that combines department duplication and capacity assignment with layout design and flow allocation. In our initial flow-allocation model, we assumed full flexibility in assigning workload among duplicates of the same department. In practice, this could mean splitting orders for a single product among several duplicates, smaller batches, and longer and more frequent setups. Order splitting could also delay shipping completed orders because batches of the same order were not synchronized. To address this problem, one would need to capture setup minimization in the objective function or place additional constraints on flow allocation to prevent order splitting.

For modular layouts, several important issues need to be addressed: (1) After identifying all common substrings, one would need to aggregate several of the substrings into a single module to minimize machine duplication costs based on a measure of substring dissimilarity and a threshold value for aggregating similar substrings. This is related to the problem of determining the optimal number of modules in the final layout. One idea is to develop measures of connectivity and transitivity of the directed graph we obtain from aggregating a set of common substrings. (2) We need to establish feasibility criteria for allocating machines to several modules subject to machine availability and criteria for minimum machine utilization. An iterative loop should be incorporated in the design to absorb any module rejected because of these criteria. (3) The current approach treats each residual substring as a sequence of operations performed on machines located in process departments. It seems logical to cluster these substrings and aggregate their machines into cell modules based on user-defined thresholds for string clustering. (4) We must compare the performance of this new layout with those of flow line, cellular, and functional layouts for the same facility.

For agile layouts, we need models that account for different routing and dispatching policies of the material-handling system. These models could then be used to study the effects of different policies on layout performance. Furthermore, we could use the queueing model to evaluate and compare the performance of classical layout configurations under varying conditions. We might identify new configurations that are more effective in achieving small WIP levels. In particular, identifying configurations that reduce distance variance without affecting average distance can be valuable. Such configurations might include the star layout, where departments are equidistant from each other, or the hub-and-spoke layout, in which each hub consists of several equidistant departments and is served by a dedicated transporter. In many applications, differentiating between WIP at different departments or different stages of the production process is useful. WIP tends to appreciate in value as it progresses through the production process. We should favor layouts that reduce the most expensive WIP first, for example, those in which departments that carry out the last production steps are centrally located. Another important avenue of research is to integrate layout design with the design of the material-handling system. For example, we could simultaneously decide on material-handling capacity (number of transporters or transporter carrying capacity) and department placement, with the objective of minimizing both WIP-holding cost and capital investment costs. We could then examine the trade-offs between capacity and WIP.

Professional Words and Expressions

Factory Layout	工厂布局
Product Layout	产品式布局
Process Layout	工艺式布局
Functional Layout	功能式布局
Cellular Layout	单元式布局
Modular Layout	模块式布局
Layout/Facility Design	布局/设施设计
Work-In-Process (WIP)	半制品
Material Handling	物料搬运
Cell	制造单元
Throughput	生产量,生产率
Reconfigurability	(布局的)可重组性,可重塑性
Work Center	工作中心
Contract Manufacturing	契约制造
Original Equipment Manufacturer (OEM)	原始设备制造商
Delayed Product Differentiation	产品延迟差异化
Multichannel Manufacturing	多通道制造
Scalable Machine	可扩展的机器
Portable Machine	便携式机器
Workpiece	工件
Distributed Layout	分布式布局
Agile Layout	敏捷布局
Waste-Disposal Facility	废物处理设施
Capacity Assignment	能力分配
Threshold Value	阀值
Directed Graph	有向图
Machine Utilization	设备利用率
Routing and Dispatching	路径规划和调度
Consolidated Facility	联合设施,公用设施
Star Layout	星型布局
Hub-and-Spoke Layout	轮辐式布局

Notes

1. While grouping resources based on function provides some economies of scale and simplicity in allocating workloads, it makes the layout susceptible to manufacturing inefficiencies when there are changes in product mix or routings.
   尽管根据能够实现的功能将资源分组能够获得一定的规模效应并能简化工作量的分配，但当产品的组合或工艺路径发生变化时很容易造成功能式布局的制造效率低下。
2. Layout design procedures, whether for functional or cellular layouts, have been largely based on a deterministic paradigm.
   无论是功能式布局还是单元式布局，其设计过程大体上都是基于确定性假设的。
3. In fact, the relationship between layout flexibility and layout performance is poorly understood and analytical models for its evaluation are lacking.
   实际上，人们对于布局灵活性与布局绩效之间关系的理解很有限而且缺乏用来评价这些关系的分析模型。
4. Facility planners had to choose layouts that make material handling efficient not only in each individual plant but throughout the complex. The challenge for facility planners is then to develop a layout and a material-handling system to permit high efficiency at the core and flexibility and reconfigurability at the periphery.
   设施规划者必须选择那些不仅在每个工厂内部而且在整个综合企业中就物料搬运来说都是有效的布局。因而，这里的挑战在于如何开发布局和物料搬运系统使得每个工厂在内部都很高效而在其与其他工厂的交界处则具有很高的灵活性和可重组性。
5. They create hybrid facilities consisting of flow-line-like components where they build the common platforms and job shop-like components where they customize the products.
   他们建设由通用和个性化平台组成的混合型设施，前者以流水线方式生产通用零部件而后者则用专业化车间的方式生产体现产品个性化的零部件。
6. Depending on downstream congestion, products can move in and out of neighboring production lines, creating multiple paths, or channels, minimizing queueing and congestion.
   根据生产线下游的阻塞情况，产品可以在相邻的生产线之间相互调配，这样就产生了多个生产路径或通道，同时可以最小化排队等待和阻塞(时间)。

7 Operations Management
运作管理

What is operations management?

Production is the creation of goods and services. Operations management (OM) is the set of activities that creates value in the form of goods and services by transforming inputs into outputs. Activities creating goods and services take place in all organizations. In manufacturing firms, the production activities that create goods are usually quite obvious. In them, we can see the creation of a tangible product such as a Sony TV or a Harley Davidson motorcycle.

In organizations that do not create physical products, the production function may be less obvious. It may be "hidden" from the public and even from the customer. Examples are the transformations that take place at a bank, hospital, airline office, or college.

Often when services are performed, no tangible goods are produced. Instead, the product may take such forms as the transfer of funds from a savings account to a checking account, the transplant of a liver, the filling of an empty seat on an airline, or the education of a student. Regardless of whether the end product is a good or service, the production activities that go on in the organization are often referred to as operations or operations management.

Organizing to produce goods and services

To create goods and services, all organizations perform three functions (see Figure 1 to 3). These functions are the necessary ingredients not only for production but also for an organization's survival. They are:

- Marketing, which generates the demand, or at least takes the order for a product or service (nothing happens until there is a sale);
- Production/operations, which creates the product;
- Finance/accounting, which tracks how well the organization is doing, pays the bills, and collects the money.

Universities, churches or synagogues, and businesses all perform these functions. Even a volunteer group such as the Boy Scouts of America is organized to perform these three basic functions. Figures 1 to 3 show how a bank, an airline, and a manufacturing firm organize themselves to perform these functions. The blue-shaded areas of the figures show the operations functions in these firms.

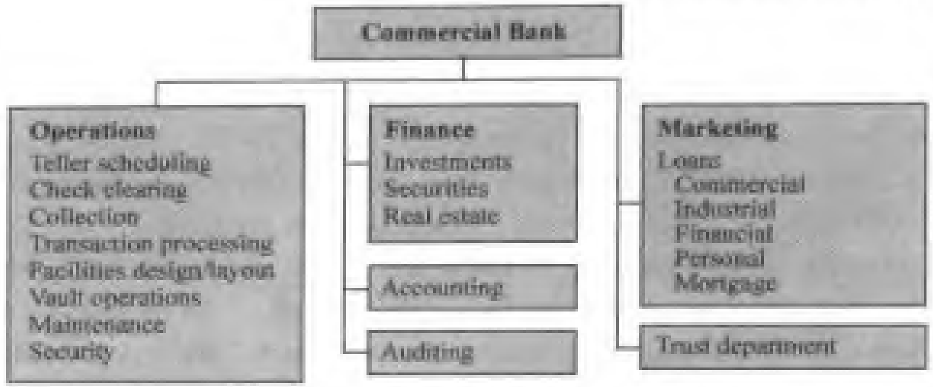


Figure 1. Organization chart for a commercial bank

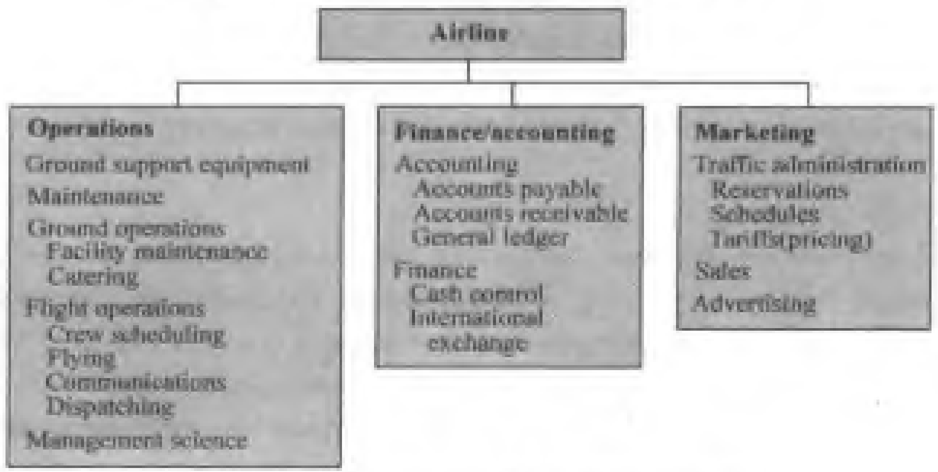


Figure 2. Organization chart for an airline company

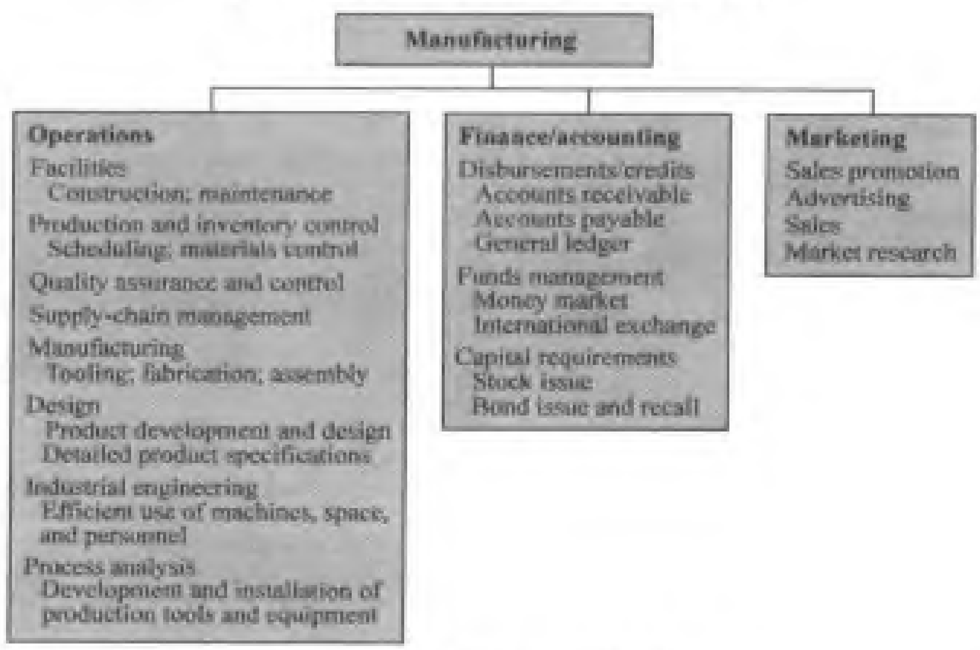


Figure 3. Organization chart for a manufacturing company

Why study OM?

We study OM for four reasons:

- OM is one of the three major functions of any organization, and it is integrally related to all the other business functions. All organizations market (sell), finance (account), and produce (operate) and it is important to know how the OM activity functions. Therefore, we study how people organize themselves for productive enterprise;
- We study OM because we want to know how goods and services are produced. The production function is the segment of our society that creates the products we use;
- We study OM to understand what operations managers do. By understanding what these managers do, you can develop the skills necessary to become such a manager. This will help you explore the numerous and lucrative career opportunities in OM;
- We study OM because it is such a costly part of an organization. A large percentage of the revenue of most firms is spent in the OM function. Indeed, OM provides a major opportunity for an organization to improve its profitability and enhance its service to society.

What operations managers do?

All good managers perform the basic functions of the management process. The management process consists of planning, organizing, staffing, leading, and controlling. Operations managers apply this management process to the decisions they make in the OM function. The 10 major decisions of OM are shown in Table 1. Successfully addressing each of these decisions requires planning, organizing, staffing, leading and controlling. Typical issues relevant to these decisions are also shown.

Table 1. Ten critical decisions of operations management

Ten Decision Areas	Issues
Service and product design	What good or service should we offer? How should we design these products?
Quality management	Who is responsible for quality? How do we define the quality?
Process and capacity design	What process and what capacity will these products require? What equipment and technology is necessary for these processes?
Location	Where should we put the facility? On what criteria should we base the location decision?
Layout design	How should we arrange the facility? How large must the facility be to meet our plan?
Human resources and job design	How do we provide a reasonable work environment? How much can we expect our employees to produce?

续表

Ten Decision Areas	Issues
Supply-chain management	Should we make or buy this component? Who are our suppliers and who can integrate into our e-commerce program?
Inventory, material requirements planning, and JIT (Just-in-time)	How much inventory of each item should we have? When do we reorder?
Intermediate and short-term scheduling	Are we better off keeping people on the payroll during slowdowns? Which job do we perform next?
Maintenance	Who is responsible for maintenance? When do we do maintenance?

The heritage of operations management

The field of OM is relatively young, but its history is rich and interesting. Our lives and the OM discipline have been enhanced by the innovations and contributions of numerous individuals. We now introduce a few of these people, and we provide a summary of significant events in operations management in Figure 4.

Eli Whitney (1800) is credited for the early popularization of interchangeable parts, which was achieved through standardization and quality control. Through a contract he signed with the U. S. government for 10,000 muskets, he was able to command a premium price because of their interchangeable parts.

Frederick W. Taylor (1881), known as the father of scientific management, contributed to personnel selection, planning and scheduling, motion study, and the now popular field of ergonomics. One of his major contributions was his belief that management should be much more resourceful and aggressive in the improvement of work methods. Taylor and his colleagues, Henry L. Gantt and Frank and Lillian Gilbreth, were among the first to systematically seek the best way to produce.

Another of Taylor's contributions was the belief that management should assume more responsibility for:

- Matching employees to the right job;
- Providing the proper training;
- Providing proper work methods and tools;
- Establishing legitimate incentives for work to be accomplished.

Customization Focus

Mass Customization Era
1995 — 2005
Globalization
Internet
Enterprise Resource Planning
Learning Organization
International Quality Standards
Finite Scheduling
Supply Chain Management
Agile Manufacturing

Cost Focus

Early Concepts
1776 — 1880
Labor Specialization (Smith, Babbage)
Standardized Parts(Whitney)

Scientific Management Era
1880 — 1910
Gantt Charts (Gantt)
Motion & Time Studies (Gilbreth)
Process Analysis (Taylor)
Queuing Theory (Erlang)

Mass Production Era
1910 — 1980
Moving Assembly Line (Ford/Sorensen)
Statistical Sampling (Shewhart)
Economic Order Quantity (Harris)
Linear Programming (Dantzig) PERT/CPM (DuPont)
Material Requirements Planning

Quality Focus

Lean Production Era
1980 — 1995
Just-In-Time
Computer Aided Design
Electronic Data Interchange
Total Quality Management
Baldrige Award
Empowerment
Kanbans

Figure 4. Significant events in operations management

By 1913, Henry Ford and Charles Sorensen combined what they knew about standardized parts with the quasi-assembly lines of the meatpacking and mail-order industries and added the revolutionary concept of the assembly line where men stood still and material moved.

Quality control is another historically significant contribution to the field of OM. Walter Shewhart (1924) combined his knowledge of statistics with the need for quality control and provided the foundations for statistical sampling in quality control. W. Edwards Deming (1950) believed, as did Frederick Taylor, that management must do more to improve the work environment and processes so that quality can be improved.

Operations management will continue to progress with contributions from other disciplines, including industrial engineering and management science. These disciplines, along with statistics, management, and economics, have contributed substantially to greater productivity.

Innovations from the physical sciences (biology, anatomy, chemistry, physics) have also contributed to advances in OM. These innovations include new adhesives, chemical processes for printed circuit boards, gamma rays to sanitize food products, and molten tin tables on which to float higher-quality molten glass as it cools. The design of products and processes often depends on the biological and physical sciences.

Especially important contributions to OM have come from the information sciences, which we define as the systematic processing of data to yield information. The information sciences, the Internet, and e-commerce are contributing in a major way toward improved productivity while providing society with a greater diversity of goods and services.

Decisions in operations management require individuals who are well versed in management science, in information science, and often in one of the biological or physical sciences.

Operations in the service sector

Manufacturers produce a tangible product, and service products are often intangible. But many products are a combination of a good and a service, which complicates the definition of a service. Even the U. S. government has trouble generating a consistent definition. Because definitions vary, much of the data and statistics generated about the service sector are inconsistent. However, we will define services as including repair and maintenance, government, food and lodging, transportation, insurance, trade, financial, real estate, education, legal, medical, entertainment, and other professional occupations.

Exciting new trends in operations management

One of the reasons OM is such an exciting discipline is that the operations manager is confronted with an ever-changing world. Both the approach to and the results of the 10 OM decisions are subject to change. These dynamics are the result of a variety of forces, from globalization of world trade to the transfer of ideas, products, and money at electronic speeds. The direction now being taken by OM — where it has been and where it is going — is outlined as follows.

- Global focus: The rapid decline in communication and transportation costs has made markets global. But at the same time, resources in the form of materials, talent, and labor have also become global. Contributing to this rapid globalization are countries throughout the world that are vying for economic growth and industrialization. Operations managers are responding with innovations that generate and move ideas, parts, and finished goods rapidly, wherever and whenever needed.
- Just-in-time performance: Vast financial resources are committed to inventory, making it costly. Inventory also impedes response to rapid changes in the marketplace. Operations managers are viciously cutting inventories at every level, from raw materials to finished goods.
- Supply-chain partnering: Shorter product life cycles, as well as rapid changes in material and process technology, require more participation by suppliers. Suppliers usually supply over half of the value of products. Consequently, operations managers are building long-term partnerships with critical players in the supply chain.
- Rapid product development: Rapid international communication of news, entertainment,

and lifestyles is dramatically chopping away at the life span of products. Operations managers are responding with technology and alliances (partners) that are faster and management that is more effective.

- Mass customization: Once we begin to consider the world as the marketplace, then the individual differences become quite obvious. Cultural differences, compounded by individual differences, in a world where consumers are increasingly aware of options, places substantial pressure on firms to respond. Operations managers are responding with production processes that are flexible enough to cater to individual whims of consumers. The goal is to produce individual products, whenever and wherever needed.
- Empowered employees: The knowledge explosion and a more technical workplace have combined to require more competence at the workplace. Operations managers are responding by moving more decision making to the individual worker.
- Environmentally sensitive production: The operation manager's continuing battle to improve productivity is increasingly concerned with designing products and processes that are environmentally friendly. That means designing products that are biodegradable, or automobile components that can be reused or recycled, or more efficient packaging.

The productivity challenge

The creation of goods and services requires changing resources into goods and services. The more efficiently we make this change, the more productive we are and the more value is added to the good or service provided. Productivity is the ratio of outputs (goods and services) divided by the inputs (resources, such as labor and capital). The operations manager's job is to enhance (improve) this ratio of outputs to inputs. Improving productivity means improving efficiency.

This improvement can be achieved in two ways: a reduction in inputs while output remains constant, or an increase in output while inputs remain constant. Both represent an improvement in productivity. In an economic sense, inputs are labor, capital, and management, which are integrated into a production system. Management creates this production system, which provides the conversion of inputs to outputs. Ontputs are goods and services, including such diverse items as guns, butter, education, improved judicial systems, and ski resorts. Production is the making of goods and services. High production may imply only that more people are working and that employment levels are high (low unemployment), but it does not imply high productivity.

The challenge of social responsibility

Operations managers function in a system where they are subjected to constant changes and challenges. These come from stakeholders such as customers, suppliers, owners, lenders, and employees. These stakeholders and government agencies require that managers respond in a socially responsible way in maintaining a clean environment, a safe workplace, and ethical behavior. If operations managers focus on increasing productivity in an open system in which all stakeholders have a voice, then many of these challenges are mitigated. The company will use fewer resources, the employees will be committed, and the ethical climate will be enhanced.

Professional Words and Expressions

Operations Management	运作管理
Service/Product Design	服务/产品设计
Quality Management	质量管理
Process Design	工艺设计
Capacity Design	能力(产能)设计
Location	选址
Layout Design	(设施)布局设计
Human Resources	人力资源
Job Design	作业设计
Supply-Chain Management	供应链管理
Inventory Management	库存管理
Material Requirements Planning	物料需求规划
JIT (Just-in-time)	准时制造
Intermediate/Short-Term Scheduling	中/短期规划,调度
Maintenance	维护
Interchangeable Part	可互换零件
Standardization	标准化
Quality Control	质量控制
Personnel Selection	职员甄选
Planning and Scheduling	规划和调度
Motion Study	动作研究
Ergonomics	人因学,功效学
Assembly Line	装配线
Supply-Chain Partnering	供应链结盟
Mass Customization	大规模订制
Empowered Employee	被授权的员工

Notes

Operations managers are responding with production processes that are flexible enough to cater to individual whims of consumers.

运作经理们用具有足够灵活性的生产过程来迎合每个客户的多变的需求。

8 The Role of IE in Engineering Economics
工业工程在工程经济学中的作用

As we are now in a global economy with ever-increasing competition, the need for world-class performance cannot be ignored. This need implies, among other things, the continued emergence of world-class quality, information systems, ergonomics, and manufacturing systems. It also means that more firms are likely to invest in such areas to reach their strategic objectives. Of course, this brings us to a very specific topic — project justification.

It may seem trivial to state that an industrial project must be evaluated in order to justify it. However, the kinds of projects that are needed today to survive in our competitive environment are quite different from their counterparts 20 or 30 years ago. They differ in terms of their technological content and in terms of their strategic implications for the firm. Whereas yesterday we were dealing with single machine replacement problems, we are now confronted with overall systems, programs, and processes.

The consequence of such complexity is that the traditional investment justification process fails to measure the proper value of projects such as computer-integrated manufacturing systems, information systems, and even ergonomics projects. It is well known that such a failure may result in wrong decisions. Poor investment justification processes may lead to poor decision making with respect to today's projects: good projects might be rejected, and bad ones might be accepted. This seems to be the fate of several new technologies (including industrial ergonomics) that are not implemented because their prospective return is not satisfactory. Among the causes of such poor ratings is the inability to properly estimate the benefits and costs of today's proposal.

As a result, management must resort to the "leap of faith" approach to justify new systems that are intuitively sound from a strategic point of view but that are not convincing economically. From such considerations it may seem that firms don't have any other choices other than to spend their capital, whatever the cost, and go ahead with implementing the resulting changes that come with these projects. Such a strategy would be dangerous.

If it is true that firms that do not invest in strategic projects due to poor investment analyses may be in a serious predicament in the future, it also would be risky for them to systematically go ahead with such projects when their rate of return is not acceptable. It may also be true that under certain conditions strategic projects may not be the right thing to do. After all, investments such as information technology or computer-integrated manufacturing systems are only as good as their contributions to the overall strategy of the firm.

Engineering economics

The role of engineering economics is to correctly assess the appropriateness of a given project, estimate its value, and justify it from an economic standpoint. If projects are not acceptable, then the evaluation process that has been used to reach this conclusion should also explain their poor returns. That same process should also indicate ways to improve the investment proposal to make it more attractive to management.

Engineering economy has been part of engineers' training (and of IE curricula, of course) for a long time. Historically, it was used for projects that had only operational implications for the firm. However, as noted above, today's projects may have strategic implications as well. As a consequence, engineering economy is likely to be important for both engineers and management.

However, engineering economy can not do it alone. It must be part of a process that includes not only engineers but management accountants; marketing, quality, and health and safety specialists; and others within the firm. Such a process should foster interdisciplinary thinking, not unlike parallel or concurrent engineering used in product design.

At this point it is certainly worthwhile to emphasize the role of IEs in this process. As industrial engineers are trained in both technology and engineering economy, they are able to bridge the gap between mechanical, electrical, and computer engineering and ergonomics, on the one hand, and management accounting on the other. Highly qualified engineers designing equipment for flexible manufacturing systems (FMS) or information systems, while aware of the technology with which they are dealing, are not necessarily trained to translate technological characteristics into economic and strategic terms.

At the other end of the spectrum, management accountants may be well aware of the business needs, strategic aims, and their organization's financial position, but cannot understand the capabilities of new technologies. Not surprisingly, communication barriers occur. Industrial engineering's main contribution to the economic evaluation process is linking technology to economics. That is where engineering economy comes into the picture. The background of IEs in engineering economy provides them with cost models that link technology with the economics of accounting (Figure 1).

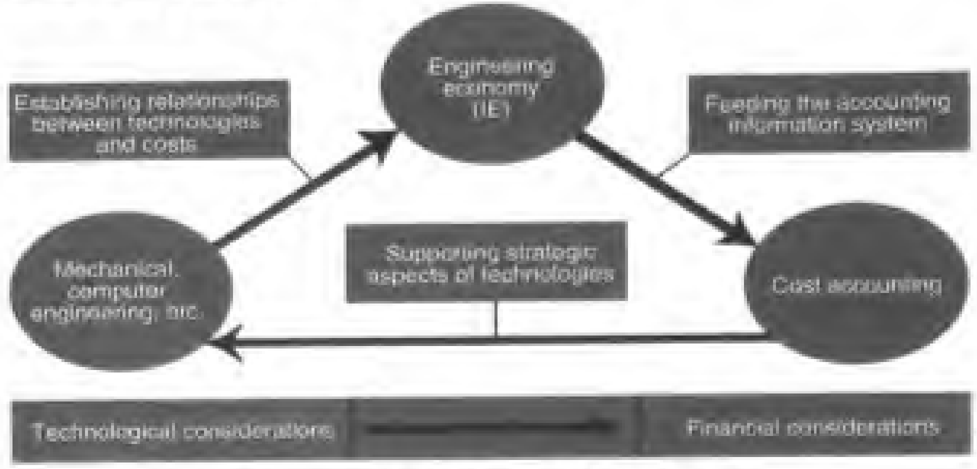


Figure 1. The role of IE in project evaluation

As the industrial environment has changed drastically, engineering economy has evolved accordingly. Indeed, its aim is not only to compute net present values (NPVs) or internal rates of return (IRRs), but also to design cost models and evaluation processes that can be used within decision support systems for a variety of technological projects.

Armed with economic models tailored to specific technologies, industrial engineers are able to measure, for instance, the cost of flexibility and, in turn, help integrate this figure in accounting cost systems and financial justification models. By including engineering economy in the justification process, firms are therefore better equipped for solving complex justification problems that involve technical and financial specialists working together in an interdisciplinary group.

Such a successful group is likely to shed light on such questions as: What is the rate of return of ergonomics? What is the payback of a six-sigma program? What are the benefits of this new information technology? What is the value of flexibility associated with this FMS? It is unreasonable to think that one person would be able to answer such difficult questions satisfactorily. The need for a project evaluation group thus seems more appropriate in the face of the competitive environment within which firms must compete, on the one hand, and the complexity of the projects involved, on the other.

Such a concept is certainly compatible with open accounting, which is implemented by firms and aimed at sharing financial information inside the organization. There is another practical advantage of starting a group that has diversity: the persons involved agree to have a unified vision of costs and benefits related to a new technology (if they want to work effectively). Lack of agreement on the nature of costs and benefits may lead to controversies over the project and failure of the justification effort.

A project evaluation group, like any group or task force in the firm, should follow a process. In a way, economic justification itself is a process. This may not be obvious, but to evaluate a project, especially one of those proposed today, a great deal of analysis must be done. The justification process can be defined in terms of steps as illustrated in Figure 2.

Steps in the evaluation process	Associated analytical problems	Analytical tools used in each step
(1) Cost and benefit identification	Costs and benefits are not properly identified. Economic repercussions of new technologies are not identified. Hidden costs are not identified. Irreducible and intangible benefits are not identified.	Cost classification Cost typology
(2) Cost behavior assessment	What drives costs is not well understood. Cost variability is difficult to assess. Proper cost relationships are not easily developed.	Cost model: Activity-based cost (ABC) modeling Technology-specific cost modeling
(3) Cost behavior procedure	Indirect costs or overhead are not properly allocated (in terms of quantity and location) to cost objects such as a process workstation, department, or product. How much to allocate? Where to allocate? What is the allocation error?	Application of cost model (ABC...)to cost allocation Location analysis Allocation error analysis
(4) Cash flow profile estimation of investment	Cash flows may not be easily estimated as all alternatives are not fully determined. Cash flows that are far in the future are more uncertain. The proper rate of introduction of new technologies is difficult to determine.	Application of cost model (ABC...)to cash flow estimation Cost reduction analysis (for real costs) Cost avoidance analysis (for opportunity costs)
(5) Investment economic return evaluation	Discount rate (cost of capital) may not be appropriate (typically too high) economic risk is not well assessed.	Short-term analysis (pay back...) Long term analysis (NPV, IRR...) Economic risk analysis (sensitivity analysis, expected return analysis, simulation, scenario approach)
(6) Investment audit		

Figure 2. Evaluation process for technological investments

Steps in the evaluation process

An important advantage of such a process is that the overall evaluation problem is divided into smaller subproblems that can be tackled more easily. Moreover, this process is able to give a sense of direction to engineering economy analysts and to nonspecialists who are confronted with justifying their proposals and have nowhere to start. Such a process is needed for the kinds of projects that are found in today's proposals (e.g. new manufacturing technologies, new computer/information systems, total quality programs, and ergonomics projects).

Ideally, all of the steps in Figure 2 should be performed; however, depending on the specific situation, some of these steps may require more or less effort. But implicit or explicit in any justification procedure is the fact that the nature of costs and benefits be identified. Then their behavior is modeled in one way or another (engineering economists, cost estimators, and traditional and management accountants all use some cost models). Afterward, costs are allocated to specific cost objects such as a production/assembly line, department, workstation, or product. Then, an estimate of future benefits resulting from the project is performed. The evaluation of the project is done in terms of both short- and long-term standpoints along with a risk analysis (which should be done, if possible).

These steps result in an estimate of the return of a project. Another step is sometimes done after project implementation, namely a project audit. This last step is not part of project evaluations *per se*, but it is wise to include it. The correctness of future cash flow estimations depends on the reliability of the evaluation process. Improvements in this area come from recognizing and avoiding past errors in cash flow estimation. This is the main purpose of a project audit.

Analytical problems encountered

Not surprisingly, the steps described here represent a challenge for analysts confronted with a thorough evaluation of a strategic investment. Each of these steps helps define the particular problems that must be solved within the justification process. These problems are common to several kinds of projects. They have been found in justifying investments in new manufacturing technologies, new computer/information systems, total quality programs, and ergonomic interventions — the very projects with which IEs and other engineers are typically confronted.

Take, for instance, the problem of identifying the costs and benefits of a project. Many studies have been done to identify, describe, classify, and quantify the economic value of flexibility of new manufacturing systems such as FMS. Flexibility is one of the main economic advantages (or strategic benefits) of such systems; yet its definition is multidimensional and covers many aspects of organizations. It is a classic example of cost identification that requires special analysis. Another example of difficult cost identification is that of quality, especially costs related to poor quality. Classifying certain quality costs is not straightforward. Also, it is not obvious to show that some overhead or so-called indirect quality costs are due to quality problems.

But the most challenging experience associated with cost and benefit identification is probably with information technology (IT). This class of investment has proved to be complex and somewhat elusive, even for IT specialists. There are several reasons for this. Without going into detail, let's say that IT has far-reaching implications for firms in general, as its enabling capabilities can significantly modify business processes. This step of cost identification is far from trivial and should not be taken lightly.

The same can be said for the other steps of the process. In the second step, cost behavior analysis, the main problem is how to correctly model specific costs in terms of their drivers. In the area of new manufacturing systems (e.g. FMS), special models and approaches need to be used if the cost of flexibility is going to be modeled. Information technology is another example that shows the importance of performing this step. Take programming costs, for instance. The drivers of this cost are likely to be the programming language, quality of the software tools, complexity and size of the system, and number of functions to be programmed.

In the third step, cost allocation, much has been said on properly allocating overhead (indirect costs) to specific products and workstations. This is because traditional allocation procedures do not take into account the complexity of these costs when automation projects are involved and therefore use wrong drivers. This allocation problem has been found especially crucial for new manufacturing systems (which involve high automation), information technologies, and ergonomics, where health and safety costs are not easily traced to workstations.

The main difficulties for the analyst are to determine the proper amount of cost to allocate, where to allocate it, and to make sure the allocation error (if any) is kept to a minimum. The allocation error depends on the quality of the cost model used. It is well known that improper allocation of indirect production costs (e.g. setup, warehousing, production planning and control, and tooling) impedes implementation of automation and flexibility within the firm.

In the fourth step, cash flow profile estimation, the analyst is faced with another set of problems. The importance of having a valid cost model cannot be overemphasized at this point, as future cash flows are to be estimated. It is also here that all proper alternatives should be determined. This is one of the fundamental principles of engineering economy. Its application is particularly important for cash flow computations, since cash flows are determined from differences between alternatives (another fundamental principle), including the "do nothing" alternative, which can be very costly and risky in certain situations. Applying these engineering economy principles becomes crucial when dealing with strategic technological projects.

Tools of engineering economy

As seen here, the evaluation process can be overwhelming to individuals who attempt to justify their projects. Fortunately, significant research has been made in this area for the kinds of projects mentioned here. Without claiming that engineering economy has solved all problems, it can be said that help is available. Engineering economy can contribute to several steps of this evaluation process.

For instance, cost typologies for quality control, computerized information systems, ergonomics interventions, and new manufacturing systems give a comprehensive view of pertinent costs. In the area of manufacturing, several flexibility typologies are used to define costs that are related to the flexibility of new manufacturing technologies. A summary of cost typologies for these typical investments is given in Figure 3.

Total quality processes and programs	Computer and information systems	Ergonomics interventions programs	Manufacturing systems
- Prevention costs - Appraisal costs - Internal failure costs - External failure costs	- Technological costs - Systems costs - Support costs	- Insurance costs - Work-related costs - Perturbation costs	- Technological costs - Operational costs - Support costs

Figure 3. Simplified cost typologies for different classes of projects

These typologies start by pooling costs in families so that similar costs are grouped together for further analysis. For instance, quality costs are usually classified into four categories. Prevention costs cover those related to activities aimed at preventing quality problems. Appraisal costs are related to detection and measuring activities necessary to assess quality. Failure costs are associated with quality problems that occur inside and outside the organization.

Computer and information system costs can be classified into three categories: technological costs, system costs, and support costs. Technological costs are related to computer hardware, opportunity costs due to equipment obsolescence, technological risk associated with new information technology, and the cost of complexity in terms of reach (the number of people that are connected) and range (interactions provided by the new system). System costs are more software related and include the cost of studies, software development costs, training costs, and business reorganization costs. Finally, support costs are those necessary to operate and maintain the system; they include installation costs, facility layout costs, debugging costs, security costs, and insurance costs.

Likewise, manufacturing system costs are classified into three categories: technological costs, which include the cost of manufacturing and/or material-handling equipment and the cost of studies; operational costs, which include direct labor costs and costs related to flexibility; and support costs, which include engineering, planning and control, setup, tooling, maintenance, and material handling. Support costs are also related to flexibility. For instance, engineering, tooling, and material handling costs due to parts revision are measured by the time and cost for these changes; the lower the costs, the more flexible the system.

Once the main cost categories are defined, then more comprehensive cost descriptions are developed; the overall picture of costs is then available for analysis. These full-blown typologies give extensive cost classifications in terms of discrete vs. periodical costs and in terms of tangible, irreducible, and intangible costs. They also include real costs vs. opportunity costs. This last type of cost is usually part of projects such as those mentioned here.

As IEs are exposed during their training to new manufacturing technologies such as information technology (IT), total quality management (TQM), and ergonomics, they can certainly contribute to cost and benefit identification of related projects. Furthermore, their background in systems optimization provides them with an overall perspective on such technologies whose effects are organization-wide and cross-functional. This overall picture is important when prospective technological projects must be aligned with business strategy.

Tools also have been developed for cost modeling (Step 2 of the evaluation process). Major approaches include activity-based costing (ABC) and technology-specific cost modeling. Activity-based accounting came into being as a result of poor allocation methods. Traditional accounting methods could not determine the proper amount of indirect costs to cost objects such as products and workstations. ABC was then devised as a new allocation method. But ABC is also used as a tool for modeling costs in general. ABC explains what drives support costs such as scheduling, maintenance, and material handling. As indirect costs are most important in new technologies, ABC has proved to be a useful cost modeling approach for decision making, including project justification.

Again, IEs can make unique contributions here. ABC modeling is as much an industrial engineering tool as an accounting one. Formal ABC cost models are written from an engineering point of view and can be readily understood and used by IEs. In fact, ABC can be viewed as an extension of operation, workflow, and process analyses.

ABC is also used in Step 4, where cash flows are estimated. Cost improvement or reduction and cost avoidance are part of that step. The quality of the cost model will determine the effectiveness of the estimation of future cash flows. Cost reduction analysis determines real (out-of-pocket) cash flows of alternatives with respect to the *status quo* (the "do nothing" alternative). Cost avoidance analysis determines cost avoided, including lost revenues (opportunity costs) resulting from the investment.

Step 5 is the evaluation itself, where criteria such as the NPV, the IRR, and payback are used. Cost models tailored to specific technologies are usually integrated in the NPV calculations. For instance, the NPV of new manufacturing systems (such as FMS) includes the value of flexibility. This value translates, in dollar amount, all the kinds of flexibility of the new technology. The overall flexibility value depends on the cost of this flexibility and the revenues they generate.

Finally, it is in this step that economic risk analysis is performed. The economic risk can be substantial and depends, among other things, on the technological risk of investments such as those discussed here. Engineering economy provides tools (e.g. sensitivity analysis, risk analysis, simulation) to assess such risk. These tools, of course, are part of the IE domain.

The potential of IE for the firm

Attempting to evaluate and justify complex and strategic capital investments is far from simple. Not only does it require the expertise of several members of the firm, but all this knowledge must be funneled through a systematic process. Industrial engineers are uniquely positioned to contribute to such a process. Their technical background makes it possible for them to bridge the gap between purely technical and financial aspects of an industrial project. Because they are well versed in topics such as total quality, ergonomics, information systems, and manufacturing systems (all essential in today's competitive environment), their ability to play key roles in complex capital investment justification is likely to make them attractive assets to management.

Professional Words and Expressions

Engineering Economics	工程经济学
Information System	信息系统
Ergonomics	功效学
Manufacturing System	制造系统
Project Justification	项目论证
Computer Integrated Manufacturing System	计算机集成制造系统
Investment Analysis	投资分析
Rate of Return	收益率
Internal Rates of Return (IRR)	内部收益率
Concurrent Engineering	并行工程
Flexible Manufacturing Systems (FMS)	柔性制造系统
Net Present Value (NPV)	净现值
Risk Analysis	风险分析
Project Audit	项目审计
Overhead	企业一般管理费
Indirect Cost	间接成本
Cash Flow	现金流
Profile Estimation	轮廓评估
Quality Cost	质量成本
Prevention Cost	预防成本
Appraisal Cost	估价成本
Failure Cost	失败成本

Technological Cost	技术成本
System Cost	系统成本
Support Cost	辅助成本
Equipment Obsolescence	设备老化
Direct Labor Cost	直接劳动力成本
Tangible Cost	有形成本
Irreducible Cost	既约成本
Intangible Cost	无形成本
Real Cost	实际成本
Opportunity Cost	机会成本
Total Quality Management (TQM)	全面质量管理
Activity-Based Costing (ABC)	基于活动的成本分析
Sensitivity Analysis	灵敏度分析

Notes

1. It may seem *trivial* to state that an industrial project must be evaluated in order to justify it.
   为了论证某一项目必须对其进行评价，这样一个论断可能显得无足轻重。
2. As a result, management must resort to the "leap of faith" approach to justify new systems that are intuitively sound from a strategic point of view but that are not convincing economically.
   结果，管理层不得不求助于"信任的跳跃"以便从战略的高度论证那些直观上感觉可行但经济上不能令人信服的新系统。
3. Armed with economic models tailored to specific technologies, industrial engineers are able to measure, for instance, the cost of flexibility and, in turn, help integrate this figure in accounting cost systems and financial justification models.
   掌握了适应各种特定技术的经济模型后，工业工程师就能够对诸如柔性成本等指标进行度量并且能够反过来协助将这些数值与会计成本系统和金融论证模型集成起来。
4. Without going into detail, let's say that IT has far-reaching implications for firms in general, as its enabling capabilities can significantly modify business processes.
   简言之，信息技术对一般的企业都具有深远的影响，因为它有能力对企业的业务流程进行重要修正。
5. Without claiming that engineering economy has solved all problems, it can be said that help is available.
   尽管不能说工程经济学已经解决了所有问题，但可以对问题的解决起到帮助作用。
6. These full-blown typologies give extensive cost classifications in terms of discrete vs. periodical costs and in terms of tangible, irreducible, and intangible costs.
   这些成熟的成本类型学根据离散成本和周期性成本以及有形成本，既约成本和无形成本对

项目中所涉及的成本进行了广泛的分类。

7. Activity-based accounting came into being as a result of poor allocation methods.
质量低劣的成本分配方法导致了基于活动的会计统计方法的产生。
8. Attempting to evaluate and justify complex and strategic capital investments is far from simple.
评价和论证复杂的战略资本投资方案绝对不是一个人可以单打独斗的事。

9 Systems Engineering and Engineering Management
系统工程和工程管理

With the globalization of our manufacturing base, the efficiencies derived from advances in information technology (and the subsequent decrease in mid-management positions), and the shifting of our economy to be service-based, the roles of the technical organization and engineering manager have changed. The 21st century technical organization must be concerned with (1) maintaining a strong business base of products or services in a fluctuating economy, (2) keeping a highly qualified and trained staff of engineers, scientists, and technicians in a rapidly changing technological environment, and (3) demonstrating a high level of capability maturity. Meanwhile, the 21st century engineering manager must now be able to understand and operate in this new paradigm. Systems engineering (SE) is a key aspect of this paradigm. Outsourcing, reduced time to market, customer-driven requirements, and just-in-time inventory are just some of the business practices required to achieve the concerns just outlined. Engineers who practice in the services and manufacturing domains must be able to understand the tools and processes available in defining the fuzzy front end associated with generating conceptual ideas and developing the architectures of innovative and efficient product solutions.

In the academic world, SE and engineering management (EM) are typically taught in the same academic department. The principles of SE are invaluable for enabling practicing engineering managers to deliver effective products on time and within budget that meet customer expectations.

Nature of systems development

A system is an integrated composition of elements that provides a capability to satisfy a stated need or objective. These integrated elements can be products of hardware and software, people, facilities, and procedures. To develop a system successfully, engineers must first define the problem that exists, identify the mission requirements (or business drivers) of the organization(s) needing the problem to be solved, evaluate high-level concepts for solving the problem, select the concept that makes the most sense in light of the mission requirements, develop an operational concept around the selected concept, create system-level requirements, create architectures and derived requirements for the subsystems, components, and configuration items consistent with the decomposition of the system, design the integration and test process for the parts of the system, conduct the integration and test process for the parts of the system, manufacture/assemble the parts of the system, deploy the system, train operators and maintainers, operate/maintain the system, refine the system, and finally, retire the system. All of this life-cycle activity is focused on the product or system to be delivered and used by the organization(s) with the driving need. The system development activities must be brought to bear on the development system, manufacturing system, deployment system, training system, maintenance system, refinement system, and retirement system throughout the life cycle.

The front end of this system development process (definition of the problem through delivery of an operating system) has typically taken years (often five to ten) in many market segments. There has been substantial pressure from stakeholders, marketers, and managers to decrease this time to months or a couple of years. The increasing rate of technological development has both helped and hindered this effort to reduce time to market. More and more system components exist, waiting to be integrated; yet technological churn and competition increases the selection and integration of the right components.

The last decade has seen trends of products or systems having more versions available (though there is often a reduction of feature explosion available to the customer for each version). Also, products are living longer via more upgrades, often quite frequent upgrades to the product. Finally, the concept of a product platform is gaining acceptance in industries from power tools to automobiles to software products to military systems. A product platform is an integrated and interoperable set of components that can be used to create many different products, e.g. power saws, sanders and drills.

These changes in system development are taking place while many technical organizations are being reorganized. The resulting organizations are flatter and provide reduced flexibility in the career path of the engineers (see Exhibit 1). Industry is making far greater use of multidisciplinary teams and asking academia to provide increased experience in teamwork at the undergraduate level.

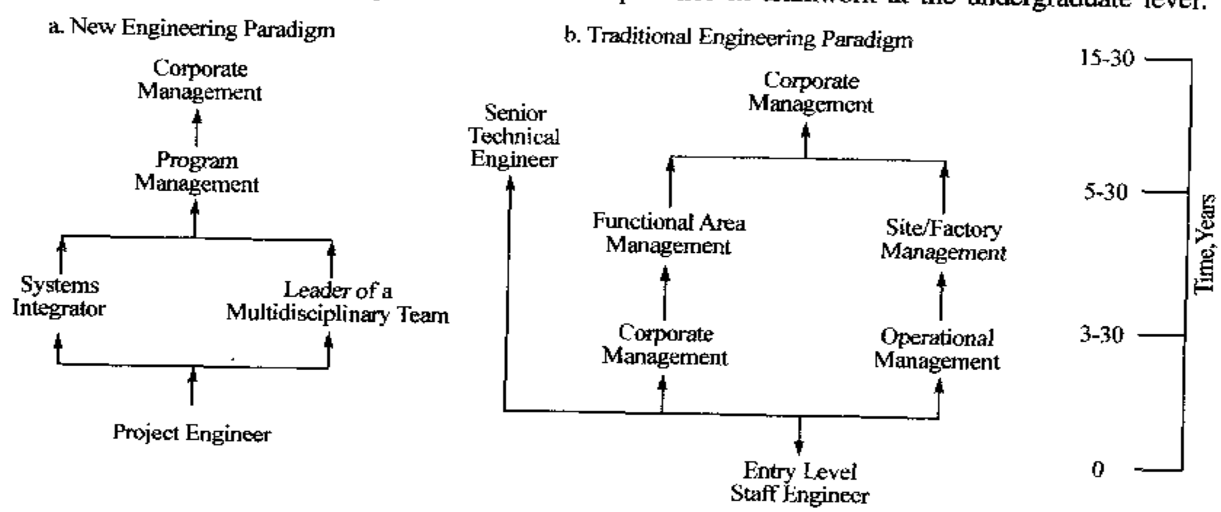


Exhibit 1. Traditional versus new engineering paradigm

Exhibit 2 is a commonly used generalization to explain the importance of good SE. The system life cycle is shown on the horizontal axis. The total life-cycle cost of the system is shown on the vertical axis; any overruns are built into this 100% life-cycle cost as well as reworks due to design mistakes and testing failures. The lower curve in Exhibit 2 shows how the money is spent over the life cycle, rising slowly in the beginning but at an increasing rate. Most of the money is spent in the construction and early operational period. The expenditures slow down again as the system is being retired. The upper curve shows the rate at which cost expenditures are committed by design decisions that get made; these commitments rise rapidly as early decisions with far reaching impacts are made and slow down as more and more detailed decisions get made. Many decisions are made implicitly as design alternatives are ignored or disappear due to the focus of the engineers on other problems. This is clearly a major concern of the engineering managers.

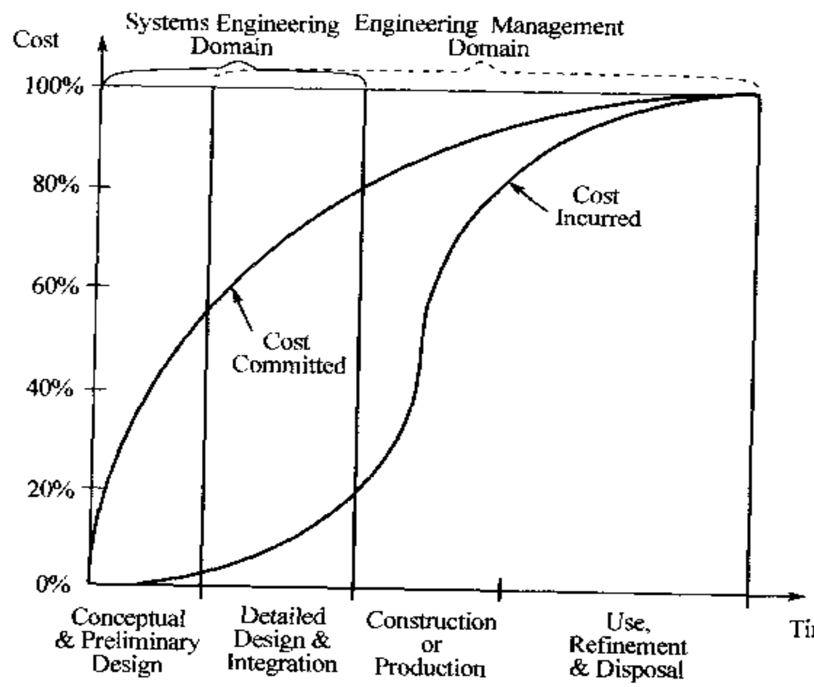


Exhibit 2. Costs as a function of product life cycle

Systems engineering and engineering management

There is substantial overlap between the disciplines of engineering management and systems engineering, and yet, there is substantial confusion in the two professions about what comprises the other.

Systems engineering: Buede (2000) presents seven different definitions of SE. We chose the definition used by the U. S. government because it is still relevant and is the most descriptive for the purposes of this article. Military Standard 499A (1974) defines system engineering as "the application of scientific and engineering efforts to:

- Transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test, and evaluation;
- Integrate related technical parameters and ensure compatibility of all related, functional, and program interfaces in a manner that optimizes the total system definition and design;
- Integrate reliability, maintainability, safety, and survivability, human, and other such factors into the total engineering effort to meet cost, schedule, and technical performance objectives."

World War II was the first time people needed to integrate and coordinate complex organizations focused on material, people, and information in order to accomplish prescribed objectives. After the war, many felt the techniques could be generalized and applied to other fields. Many other types of "quantitative management" techniques also grew out of World War II. By the late 1950s, systems thinking focused on the methodologies and processes needed to define the SE discipline. Numerous formal systems design processes currently exist.

Engineering management: Few formal definitions exist in the literature for EM. Kocaolgu (1984) defined EM as a field of study in five interrelated categories, namely:

- Management of Engineering and Scientists: Motivation and leadership in engineering, technical obsolescence, communications transition from technical specialty to technical management.
- Management of Research, Development, and Engineering (RD&E) Projects: Selection, evaluation, scheduling and control of technical projects.
- Management of Technical Organizations: Design of technical organizations, authority/responsibility patterns in functional, project, matrix, and venture organizations, the role of participative management in technical organizations.
- Management of Technical Resources: Use of statistics, operations research, decision theory and computer simulation in resource optimization, management of raw materials, technical manpower planning, financial management in engineering.
- Management of Technological Systems: Management of innovation, entrepreneurship, technological planning and forecasting, technological risk management, engineering law, research and development management, and productivity.

Babcock (1996) perhaps best describes the role of the traditional engineer versus that of other types of management in that "the engineering manager is distinguished from other managers because he or she possesses both the ability to apply engineering principles and a skill in organizing and directing people and projects. He or she is uniquely qualified for two types of jobs: the management of technical functions (such as design or production) in almost any enterprise, or the management of broader functions (such as marketing or top management) in a high technology enterprise."

Overlap, difference, and synergies

Functional perspective. If you build upon Babcock's definition, an engineering manager must be able to apply engineering principles such as SE. The role of a systems engineer within a product life cycle is graphically demonstrated in Exhibit 3. Whereas the EM can be responsible for any of the steps in the product cycle or even the total product life cycle, the SE is usually more focused on the early stages of the product cycles as shown in Exhibit 3.

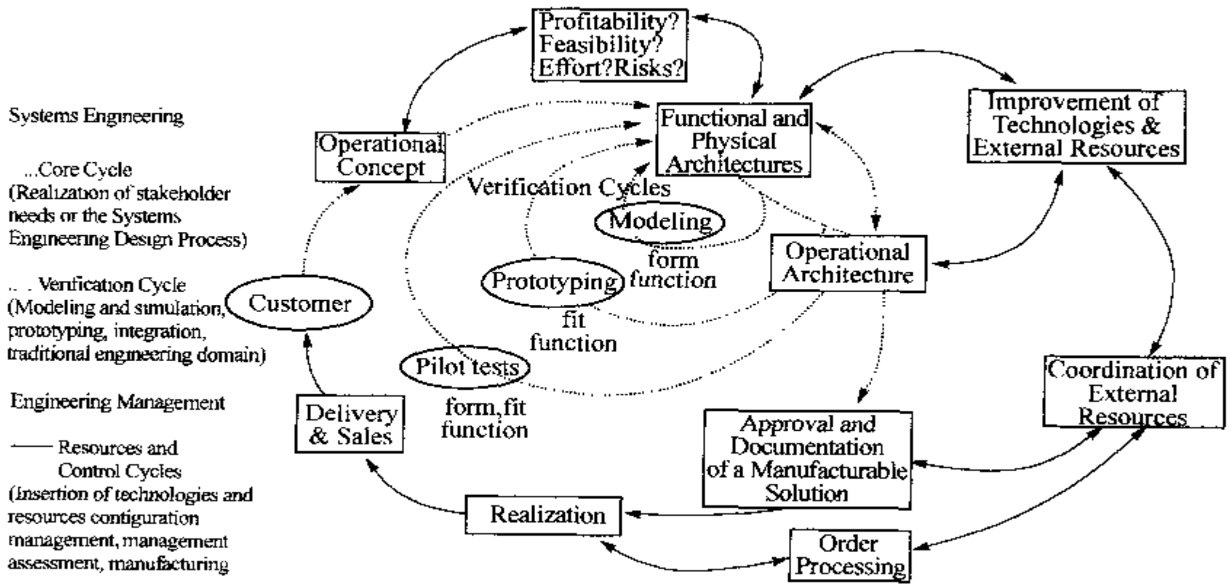


Exhibit 3. Product life cycle

Career development perspective. The career paths of the systems engineer and engineering manager are very different. The EM often comes from the ranks of the traditional engineer. The EM career path is typically characterized by progressive responsibility for larger systems (see Exhibit 1). These are typically larger systems within the same product line (e.g. gears for a transmission, transmission, power train, etc.). Most systems engineers also come from the ranks of traditional engineers. Like EM, there are few undergraduate programs in SE; however, the number of SE programs at the undergraduate level is on the increase. After an initial apprentice position, they typically move into the role of systems integrators. Within most organizations, the SE functions as part of an interdisciplinary effort.

Professional Words and Expressions

Systems Engineering	系统工程
Engineering Management	工程管理
Outsourcing	外包
System/Product Life Cycle	系统/产品生命周期

Iterative Process	反复/迭代过程
Reliability	可靠性
Maintainability	可维护性
Quantitative Management	定量化管理
Innovation Management	创新管理
Entrepreneurship Management	企业家管理
Technological Risk Management	技术风险管理
Research and Development Management	研发管理
Operations Research	运筹学
Decision Theory	决策理论
Computer Simulation	计算机仿真
Apprentice Position	见习职位,实习岗位

Notes

1. To develop a system successfully, engineers must first define ... the system.
   句中 must 后为一系列的并列结构,详细阐述了系统开发生命周期过程中需要完成的各项活动。
2. A product platform is an integrated and interoperable set of components that can be used to create many different products, e. g. power saws, sanders and drills.
   一个产品开发平台是指一组可以集成和互换的零件,基于这些零件,可以产生多种不同的产品,如电锯、打磨机和电钻等。
3. Military Standard 499A (1974) defines system engineering as ... and technical performance objectives.
   这里给出了系统工程的定义。可翻译为:
   1974 年的美国军方标准 499A 把系统工程定义为将科学和工程知识用于实现如下功能的应用:
   - 经过从定义、合成、分析、设计、测试到评价的不断反复过程将运作需求转换为对系统行为参数的描述以及系统配置;
   - 以能够优化整个系统的定义和设计的方式集成相关的技术参数并确保所有相关的功能和程序界面相互兼容;
   - 在满足成本、交期和技术要求的情况下从工程角度综合考虑可靠性、可维护性、安全性、生命力、人因学以及其他因素。
4. Kocaolgu (1984) defined EM as a field of study in ... and productivity.
   这里给出了工程管理的定义。可翻译为:
   1984 年 Kocaolgu 将工程管理定义为一个面向如下五种相互关联的管理类型的研究领域:
   - 工程和科学管理:研究工程领域的动机和领导、技术的废弃、从技术专业化到技术管理的

过渡等。

- 研究、开发与工程项目管理:研究技术项目的选择、评价、规划和控制。
- 技术型组织的管理:研究技术型组织的设计和功能型、项目型、矩阵型和风险型组织的职能模式设计以及全员参与管理在技术型组织中的角色。
- 技术资源管理:将统计学、运筹学、决策理论和计算机仿真应用在工程领域的资源优化、原材料管理、技术人员规划和金融管理。
- 技术系统管理:研究创新管理、企业家管理、技术规划和预测、技术风险管理、工程法律、研发管理和生产率管理。

第三篇

现代工业工程

10 Concurrent Engineering 并行工程

According to Department of Defense (DoD) Regulations 5000. 1 and 5000. 2, concurrent engineering (CE) will be used for development of all future military systems. The primary requirements for successfully implementing a CE philosophy are management support, enhanced communication, team building and appropriate tool use. Where CE has been successful, much credit is attributed to the involvement of senior management in establishing goals of improved quality, cost and schedule; in forming teams of qualified people; and in providing teams with the necessary tools and resources. Management must commit the necessary funding and resources for a successful CE program, and they must allow ample time for the new philosophy to generate benefits.

To ensure that the U. S. Army Missile Command (MICOM) managed weapons systems adhered to the CE design philosophy, a CE steering committee was formed. This steering committee, consisting of command-wide representation, examined current design environments at MICOM, and determined some impediments to CE implementation. The committee determined that most personnel had not received adequate information about CE, and in general there were many misconceptions concerning its requirements. Therefore, it was decided that additional training should be provided to both MICOM and project management personnel. The production engineering division (PED) of the Systems Engineering and Production Directorate was tasked by the steering committee to develop a training program to assist in the advancement of the CE concept and provide guidelines for CE implementation.

The training philosophy

The content of the CE training modules presents a well-rounded knowledge of all important aspects of CE. Training, which addresses a philosophy can often digress into an intense training course on a specific tool or technology that supports that philosophy. That was a pitfall which was avoided with the formation of this training. While tools and methodologies were given adequate coverage, more philosophical aspects of CE (i. e. improving communication, organizational and team structure, etc.) were not slighted. To achieve the right mix of training, seven training modules were created. Each module addresses a different, equally important aspect of CE implementation:

Module 1: Introduction to MICOM CE steering committee; Module 2: CE overview; Module 3: Team building for CE; Module 4: CE tools and methodologies; Module 5: The MICOM CE design process; Module 6: Government/Contractor roles/responsibilities; Module 7: Program specific CE activities.

MICOM CE steering committee

The first module used in the CE training course serves to inform the training participants of the existence and mission of the MICOM CE steering committee. This was considered an important first step in the training process. It is imperative that recipients of this training realize the commitment of top management to the CE design philosophy. By demonstrating this commitment at the outset of the training program, participants should realize the dedication and determination of MICOM management to successfully implement CE.

The CE team that will be trained using these modules will consist of managers and engineers representing many functional areas of MICOM. To reinforce this idea of multi-disciplinary teamwork, the CE steering committee consists of representatives from these same diverse areas. By emphasizing that the steering committee "practices what it preaches," the point will be made from the outset as to what is required for CE success.

CE overview

The CE overview module is used to give all participants a set of common definitions and terminology for the ensuing training. One of the most prevalent problems in implementing CE is the lack of a commonly agreed upon definition for the term. For the purpose of the training modules, the definition as developed by the Institute for Defense Analysis was used. Many other misconceptions are related to CE. In some cases, these misconceptions have become the barriers to successful CE implementation. This module discusses the confusion commonly noted throughout the MICOM and DoD community. Common misunderstandings, such as the difference between CE, systems engineering and total quality management, are explained.

In preparing this training module, lessons learned and critical factors for success were captured from

CE leaders in industry and the government. From this information, as well as MICOM's own lessons learned, CE implementation guidelines were developed and included. This portion of the training discusses the importance of management-driven implementation, adequate funding profiles, multi-functional teaming, training, customer/supplier involvement, integrated require-merits definition, integrated product/process design, and CE tools and computer-based support initiatives.

Upon completion of the CE overview module, participants should have a good understanding of what CE is and is not. With everyone working with a common set of assumptions, the training moves to the importance of team building.

Team building for CE

Multi-disciplinary teams are at the very heart of CE because, when properly constructed, they contain the intelligence base for a successful program. CE involves integrating the contributions of diverse specialists. These teams facilitate the optimization of all important measures of a product's function — performance, producibility, ease of maintenance, reliability, cost and quality. Management forms a team of specialists who have knowledge in different phases of the product's life cycle to concurrently engineer both the product and downstream processes for production and support.

The problem with developing and maintaining a CE team is that most people are not accustomed to working (or trained to work) in teams. The first lesson of the module establishes how CE team members are selected, what part they play as individuals, and how they become a working unit. A team dynamics discussion and group exercises are an important aspect of this lesson. The second lesson focuses on the mechanics of the team in order to facilitate an increase in effectiveness.

This module also stresses that the voice of the customer must be represented to ensure requirements are correctly stated and understood by the CE team. All program requirements should have their foundation in a need or expectation of the customer, internal or external. At the same time, CE teams must maintain a balance between the customer's needs and expectations and a reasonably scoped program.

CE tools and methodologies

Throughout industry and government, there are many proponents for the use of multi-disciplined teams for successful CE implementation, or for the use of CE-related tools and methodologies as the needed ingredient for success. MICOM believes both are required to truly optimize the design process. During discussions on CE tools with various sources in industry and government, it became obvious there were several misconceptions and barriers associated with CE tool/methodology implementation. First, most technical personnel appeared interested only in computer-based tools. This led to management's misinterpretation that all CE tools required new computer systems and software. One of the objectives of this training module was to inform the

MICOM design community of the array of tools and methodologies available to them. This module included an examination of a number of technologies currently being used in government and industry, and how these technologies have or can be more fully integrated into more comprehensive design tools. Technologies researched and analyzed included, but were not limited to Taguchi methods, quality function deployment, rapid prototyping, computer-aided design, computer-aided manufacturing, computer-aided process planning, design for assembly/manufacturability, design for reusability, design for maintain-ability and design for reliability.

Technological innovations have vastly improved the arsenal of tools available to the systems engineer. However, there is still a lack of required integration of the design tools. The first step in integrating the design tools is to understand where they should be utilized in the product life cycle. Training addressed this issue by identifying various technologies and relating those to the system life cycle phases.

MICOM CE design process

The MICOM CE design process module was developed to provide a CE design process specific to MICOM's organizational structure and mission and functions. The module is intended to be used as a handbook to assist new project leaders in understanding each organization's area of expertise and the level of input they have during each life cycle phase. Stressing the importance of communication and knowledge of one's own organization, this module presented the life-cycle model with each MICOM organization's role defined. For example, 23 directorates/offices within MICOM worked with the CE steering committee to define their primary activities, major areas of input, and milestone design review (MDR) required documents into which they provide input.

The module instructs participants on steps required to ensure that all necessary players are used appropriately in each life cycle phase of the project. For example, the project manager first uses the CE design team functional makeup model to determine the functional areas typically represented on the CE team during the particular life cycle phase of the program. The project manager then utilizes the module handbook to obtain detailed information on each of the MICOM organizations that would be involved. This information includes the organization's mission, function, and major activities during the life cycle phase. From these tools and program-specific information, the project manager can determine the team's necessary makeup, and determine how each member will support the team.

Government/contractor roles and responsibilities

Successful implementation of CE will require communication channels be established and used not only between functions, but between contractor and government. In recent years, the DoD and its contractors have been willing to reexamine traditional roles each have historically played in design process. Most notably, they have shown willingness to openly share information, and work as partners to solve problems rather than to establish blame. This has been a keystone to their successes.

Stereotypes attributed to both government and contractor personnel have contributed to the difficulty in defining CE integration into a project encompassing government and contractor CE teams. In order to understand these stereotypes, training module developers asked both types of personnel the following: "If you were drawing a caricature of a typical government/contractor person, what would you include?"

Industry personnel stated that the government person would be wearing a sign stating that "He/She was the government;" would be carrying a multitude of specifications and standards with a label saying "Just do it;" and would have a red ink pen in hand to mark up program deliverables.

The government personnel stated that the contractor person would be holding a bottle of snake oil for sale, would have their hand stretched out wanting more money, and have information hidden in their back pocket. Although this was a humorous way to obtain information, it did provide vast insight into the mistrust and negative views which can be involved.

Contractor personnel also highlighted concerns over a lack of definitive requirements in requests for proposals (RFPs) and funding variations over the course of a program. Conversely, the government personnel stated that, due to the reduction in defense funding, contractors will agree to anything in order to win a contract, while knowing that they may not have the expertise to adequately complete the contract within cost and schedule. The fundamental mistrust that underlies contractor-government relations results in a lack of cooperation and undermines attempts to work as a team. Although these broad-based concerns were highlighted by many different sources, it was evident that many government/contractor programs had managed to eliminate the issue of mistrust. Personnel in these programs worked at developing long-term relationships based on respect. All members of the project team believed that if the program failed, they failed. It was also noted that, in these programs, government personnel always brought something to the table. Typically, government is viewed as an overseer, but in these cases they brought previously performed research, military parts experts, industrial base knowledge, lessons learned, and other information to the team.

This training module strives to take this concept of teamwork one step further through implementation of CE throughout the project. Most DoD contractors, at least at the prime level, are attempting to utilize CE teams. The government is now attempting to do the same. This training module provides the participant with a simplistic model that serves as the framework for this new teamwork. The model describes the lines of communication between the two teams and addresses information flow. For example, currently it is common for most of the information flow between the government and contractor to be between two engineering specialists (low-level communication) or through the project managers (high-level communication). With the advent of CE, many sources believe that all work should be performed in the team environment and that government engineering specialist to contractor engineering specialist communications should be reduced or eliminated. The MICOM CE steering committee does not believe this is appropriate or realistic. Although design decisions and problem resolutions will be handled in the team environment, the one-on-one relationship is absolutely necessary to achieving the trust and resolving day-to-day issues necessary for a successful program. The model also provides for the creation of supporting teams made up of government and contractor personnel to address critical problem areas, on an as needed basis.

Program specific CE activities

The last training module, program specific CE activities, is used to put the participants to work on their program, using the CE design philosophy that was covered in the previous modules. This serves several purposes. First, as training is completed, team members have the opportunity to immediately employ what they have learned. There is no time delay so that confusion can cloud the lesson. Second, instructors are still available to facilitate activities of the group, and to answer any questions that may arise. And finally, the team has just shared the common training experience: People are familiar with their team members, and are more inspired to tackle the task at hand.

Successful implementation of CE within DoD requires its practitioners to have a common understanding of the philosophy. Team building, managerial support, and government/contractor cooperation are additional key ingredients, along with numerous tools and methodologies that can smooth the transition to the CE design environment. CE requires a cultural change, with new tools, roles and responsibilities. Its implementation will not be easy. That is why training is important.

MICOM has seen the need for an innovative approach to training its managers and design teams in CE. The undertaking was not only successful, but used the CE philosophy in its own creation. The CE steering committee, bringing together the collective knowledge of the MICOM design environment, used many of the same tools and techniques to create a set of training modules to address all aspects of CE, and integrate those lessons into models that could be used within MICOM and DoD.

Professional Words and Expressions

Concurrent Engineering	并行工程
Department of Defense (DoD)	美国国防部

The Institute for Defense Analysis (IDA)	防御分析研究所
Management Support	管理层支持
Enhanced Communication	强化沟通
Team Building	团队建设
U.S. Army Missile Command (MICOM)	美国战术导弹指挥部
Steering Committee	控制委员会,指导委员会
Taguchi Methods	田口法
Quality Function Deployment	质量功能展开
Rapid Prototyping	快速原型
Computer-Aided Design	计算机辅助设计
Computer-Aided Manufacturing	计算机辅助制造
Computer-Aided Process Planning	计算机辅助工艺规划
Design for Assembly/Manufacturability	面向装配/制造的设计
Design for Reusability	面向可重复使用的设计
Design for Maintainability	面向维护的设计
Design for Reliability	面向可靠性的设计
Technological Innovation	技术创新,技术革新
Product Life Cycle	产品生命周期

Notes

1. According to Department of Defense (DoD) Regulations 5000.1 and 5000.2, concurrent engineering (CE) will be used for development of all future military systems.
   并行工程的概念是1986年由美国国防部防御分析研究所提出。可以定义为集成地、并行地设计产品及其相关的各种过程(包括制造过程和支持过程)的系统方法,这种方法要求产品开发人员在一开始就考虑产品整个生命周期中的从概念设计到产品报废的所有因素,包括质量、成本、进度规划和用户要求。
2. While tools and methodologies were given adequate coverage, more philosophical aspects of CE (i.e. improving communication, organizational and team structure, etc.), were not slighted.
   在给予各种工具和方法足够重视的同时,对诸如沟通、组织和团队结构的改善等并行工程的哲学层面的内容也给予了相应的尊重。
3. Contractor personnel also highlighted concerns over a lack of definitive requirements in requests for proposals (RFPs) and funding variations over the course of a program.
   契约商对建议书中缺少明确的需求信息以及项目进行过程中资助的变化也很担心并予以强调。

11 New Product Development
新产品开发

The failure to integrate a product strategy, a well-planned portfolio, and a facilitating organization structure with clearly identified customer needs, a well-defined product concept, and a project plan can severely hamper new product development.

Many companies formulate product strategies, routinely choose among new product concepts, and plan new product development projects. Yet, when asked where the greatest weakness in product innovation is, the managers at these companies indicate the fuzzy front end. They recite some familiar symptoms of front-end failure:

- New products are abruptly canceled in midstream because they don't "match the company strategy."
- "Top priority" new product projects suffer because key people are "too busy" to spend the required time on them.
- New products are frequently introduced later than announced because the product concept has become a moving target.

Times have changed since 1983 when Donald Schön described product development as a "game" in which "general managers distance themselves from the uncertainties inherent in product development and... technical personnel protect themselves against the loss of corporate commitment. Since then, new product development has become a core business activity that needs to be closely tied to the business strategy and a process that must be managed through analysis and decision making. Now, general managers cannot distance themselves from the uncertainties of product development, nor can technical personnel protect themselves against corporate commitment.

As enhanced capabilities for concurrent engineering, rapid prototyping, and smoothly functioning supplier partnerships have helped reduce product design and development times, management attention has begun to shift to the cross-functional, front-end strategic, conceptual, and planning activities that typically precede the detailed design and development of a new product. Here, new product ideas gain the shape, justification, plans, and support leading to their approval and subsequent execution. Yet, despite widespread recognition of the front end's importance, there has been limited systematic examination directed at improving its effectiveness.

What is the "front end"?

Prior research has focused on the success factors for new product development (NPD). While many of these factors relate to design execution and project management issues, some pertain to the front end. Consistent with Roberts's model, we classified the front-end-related success factors identified in prior research into foundation and project-specific elements. The distinction is important because the two require different skills and levels of effort. Also, without adequate foundation elements, product and project success becomes a matter of luck. Project-specific activities focus on the individual project and require the project team's effort to ensure a useful product definition and project plan. These include a product concept statement and evaluation, product definition, and project planning. Foundation elements, on the other hand, cut across projects and form the basis for project-specific activities. Thus they typically require enterprise wide support, senior management participation, and a cross-functional effort.

Foundation elements

Without a clear product strategy, a well-planned portfolio of new products, and an organization structure that facilitates product development via ongoing communications and cross-functional sharing of responsibilities, front-end decisions become ineffective. Achieving these preconditions provides a foundation for streams of successful new products.

Key product strategy elements include the formulation and communication of a strategic vision, a product-platform strategy, and a product-line strategy to support the go/no-go decision for a new product. Previous research suggests that familiarity with the product strategy enables appropriate decisions on NPD timing and target markets and also an assessment of the fit between the product and the core competence of the business unit.

In addition to a product vision, business units need to plan their portfolio of new product development activities, which goes beyond the traditional marketing view of having a product for every segment, market, and price point. Portfolio planning should map all new product initiatives across the business to balance risk and potential return, short and long time horizons, or mature and emerging markets. At the same time, the portfolio plan should ensure consistency with the product and business strategy. If well done, it facilitates the allocation of scarce resources to new product development projects.

An essential precondition is establishing the organization structure for new product development. Decisions on structure, communication networks, and roles are made at a business-unit level. Research has highlighted several requirements for the product development organization and its functioning, such as using a matrix or project form, organizing NPD around core business/product teams rather than traditional functions, using design and communication tools including information systems, and establishing controls and incentives as rewards.

Project-specific elements

Product-specific front-end activities help clarify the product concept, define product and market requirements, and develop plans, schedules, and estimates of the project's resource requirements. However, they stop far short of creating detailed designs and specifications for the product and its components.

The product concept is a preliminary identification of customer needs, market segments, competitive situations, business prospects, and alignment with existing business and technology plans. Research suggests that the product concept should be clear so that managers can sense whether the newly defined opportunity seems worth exploring. Managers need to understand customer needs and identify the potential technologies and applications to satisfy them. For tangible products, the product concept is usually illustrated with a sketch or three-dimensional model. Because such concepts are relatively inexpensive to produce, managers often create several before selecting one to fully design and develop. Early targets —measured in product cost, product performance, project cost, and time to market — set the stage for generating various product concepts.

The product definition, an elaboration of the product concept, incorporates judgments about the target market, competitive offerings, and the time and resources for bringing the new product to market. The definition activity includes identification of customer and user needs, technologies, and regulatory requirements. These lead to a choice of product features and functions, target market segments, and design priorities. Research on the implementation of the front end indicates that an explicit, stable product definition and an understanding of the trade-offs among customer requirements, technology, and resource/cost constraints are important factors for success.

Project planning includes project priorities and tasks, a master schedule, projected resource requirements, and other supporting information. Here, it is critical to communicate the project priorities, provide adequate resources, and anticipate contingencies. And, despite progress in new product development practices, typical systems do not adequately address these critical issues.

The front-end process

We take a process view of the front end because earlier studies and our preliminary research suggested that the individual activities, while logically interrelated, often are treated independently. Accordingly, we present a systems view of the front end (see Figure 1). This process description is consistent with growing empirical evidence of the need to simultaneously consider overall product strategy (foundation elements) with project-relevant input such as product ideas, market analysis, and technology options. Thus understanding the interrelationships between the activities is as important as the activities themselves.

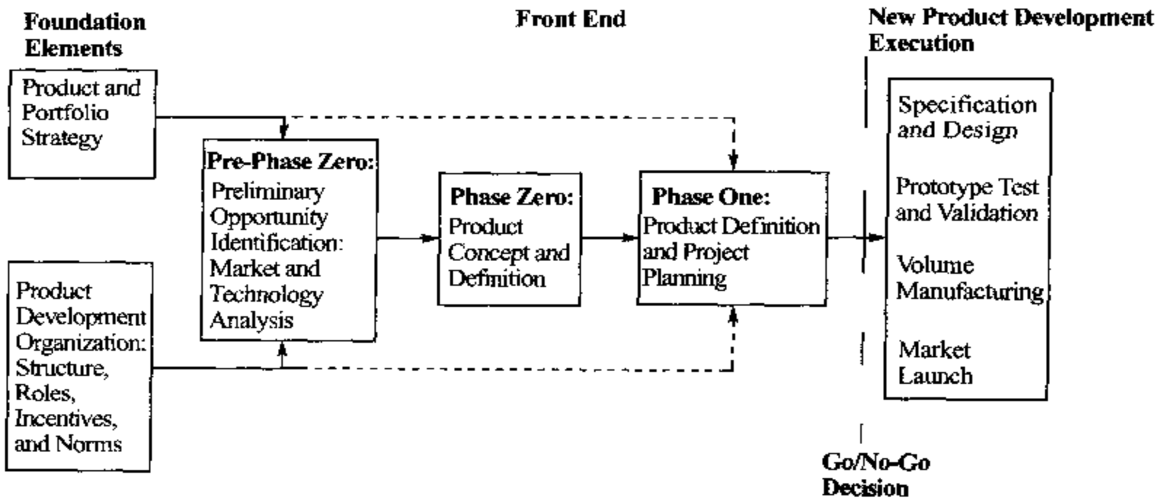


Figure 1. A model of the new product development front end

Product strategy and portfolio plans should drive the complete new product development effort, in conjunction with the capabilities and competencies of the product development organization, with its inherent assumptions about roles, communications, and culture. These elements are thus preconditions or foundations for the explicit activities in new product development. Many companies implement a formal phase-review management system to define and guide the explicit project-specific activities; this review process involves the process itself, roles that make it work, and primary deliverables.

- **Phases of the front-end process.** Companies generally begin work on new product opportunities (often called "pre-phase zero") when they first recognize, in a semiformal way, an opportunity. If the newly defined opportunity is worth exploring, the company assigns a small group, sometimes including suppliers, to work together on the product concept and definition (phase zero).

  In phase one, the company assesses the business and technical feasibility of the new product, confirms the product definition, and plans the NPD project. Thus the development team identifies the new product, its development, and the business rationale for proceeding. The front end is complete at the end of this phase when the team presents the business case and the business unit either commits to funding, staffing, and launch of the project or kills the project.

- **Front-end roles.** A core team (including the project leader) and an executive review committee of senior functional managers responsible for making the go/no-go decision typically conduct the process we've described. During Phase One, if not sooner, companies assign individuals from all functional areas as members of the core team for the product development project. Normally, if a company approves the project at the end of

Phase One, a full complement of people to design, develop, test, manufacture, and launch the new product supplements the core team. Previous studies have indicated that team structure varies in composition, size, and leadership. Often, the core team includes selected suppliers as partners; their knowledge of technology, costs, and design and manufacturing lead times can contribute to product definition and project planning.

- **Primary front-end deliverables.** The front-end activities result in the product concept (clear and aligned with customer needs), the product definition (explicit and stable), and the project plan (priorities, resource plans, and project schedules).

A well-engineered front-end process

How can a company improve its front-end practices to achieve success in new product development? Is it enough to improve the activities we have described? We suggest that best practice in new product development goes beyond simply adopting these activities. Success depends on how companies integrate dimensions and elements of product development.

Our research highlighted certain challenges in integration of the front end beyond the obvious need for cross-functional effort. First, because project-specific activities build on foundation activities, companies should ensure that the foundation elements are aligned with the product development process and project-specific activities. Second, they should ensure consistency between strategic and operational activities. The challenge is to make strategy explicit enough to guide day-to-day choices for new product development. We found the integration of these two factors was rare but extremely potent. At the companies studied, we observed several kinds of integration problems:

- Senior managers sometimes delegated the formulation of a product strategy to product and R&D managers.
- The product development staff often made decisions that affected other products and business unit strategy. (While the core team faces technical uncertainty about the product and manufacturing and distribution processes, resolving cross-project issues or providing guidelines should be senior management responsibilities.)
- Managers in various functions and organizational levels rarely ensured consistency and links among R&D activities, product strategy, and current product development.
- Managers frequently took on product development projects without committing adequate resources. (Often there is a misconception that product development staff working on multiple projects improves efficiency. The result is long delays in product launch and lost revenues. With ongoing downsizing in many companies, this kind of neglect is becoming chronic. Senior managers need to help product and R&D managers understand a project's relative importance.)
- Senior managers did little to measure and reward cross-functional teamwork. (Front-end participants need to know that management values their contributions.)

Balancing front-end explicitness and flexibility

Management of the front end also requires a balance between getting things right and being flexible during NPD execution. Other front-end elements and activities should also be balanced. There is a natural tension between planning to reduce risk and responding to inherent uncertainties. For example, we suggest that product strategy and portfolio planning be explicit, yet we recognize that some subsequent shifts in the product definition are inevitable, forcing contingent actions. Furthermore, postponing the final decisions at the front end by continuing the development of parallel concepts or solutions may reduce uncertainty. While our research did not focus on this issue, we believe that there must be a balance between front-end planned activities and ongoing iteration during the NPD project, between making "final" decisions early and intentionally keeping open parallel alternatives, and between establishing product development targets through analysis and working by instinct alone.

Diagnosing front-end activities

Based on our study findings, we propose that companies evaluate their front end on degree of formality and the integration of activities. The dimensions — formality and process integration — can be measured on a checklist. The diagnostic statements evaluate the explicitness and formality of front-end practices. The statements on integration document how well these and other front-end activities are integrated.

A senior business unit manager such as the vice president of R&D, chief technology officer, or director of new product development should assess business practices and then calculate the score of the business unit, counting a check for any item as one point. The sum of the scores on the formality statements gives the formality score; the sum of the integration statements, the integration score. The manager can then map the score on each dimension on the front-end capability map (see Figure 2).

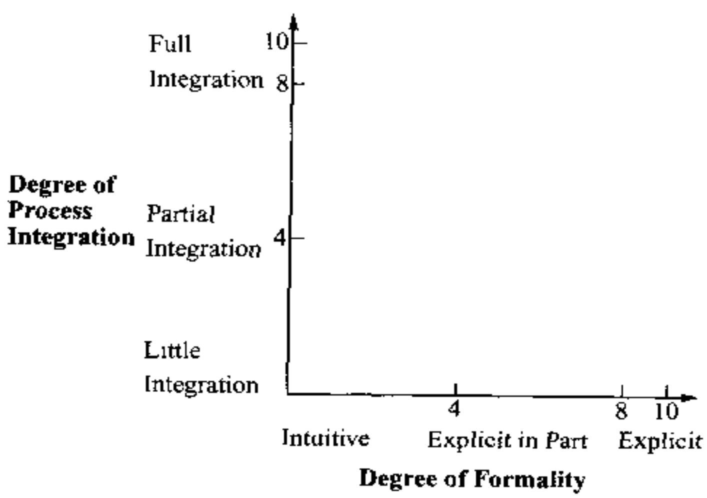


Figure 2. The fornt-end capability map

The mapping indicates how well (or poorly) a business unit is doing along the two dimensions of formality and integration. Research indicates that world-class companies score eight or more on both dimensions. Companies that score three or less on either dimension have a deficient front end and are likely to have major problems with their product development efforts. Senior management needs to find ways to improve these efforts; the checklist is a first step to understanding where and what to improve. What is more difficult is to understand how. In the next section, we discuss how companies and business units can plan a transition to a better-managed front end.

Managing the transition

All the companies studied were moving toward a more explicit, integrated front end. They were trying to build complementary capabilities to support the critical go/no-go decisions and development plans for new product concepts. Yet each was taking a different path at a different rate.

Stages of evolution

We see three stages in the product development front-end, not including the stage in which a company has no formal front end — the pre-emergent stage. The next stages are "awareness," "islands of capability," and "integrated capability" (see Figure 3). The triggers to reach the awareness stage from the pre-emergent stage are typically growth, additional product line complexity; or competitive pressures for either more product innovation or lower product development costs. In any case, at the awareness stage, companies recognize the significance of the front end but have little capability associated with it. They score poorly on both the formality and integration dimensions.

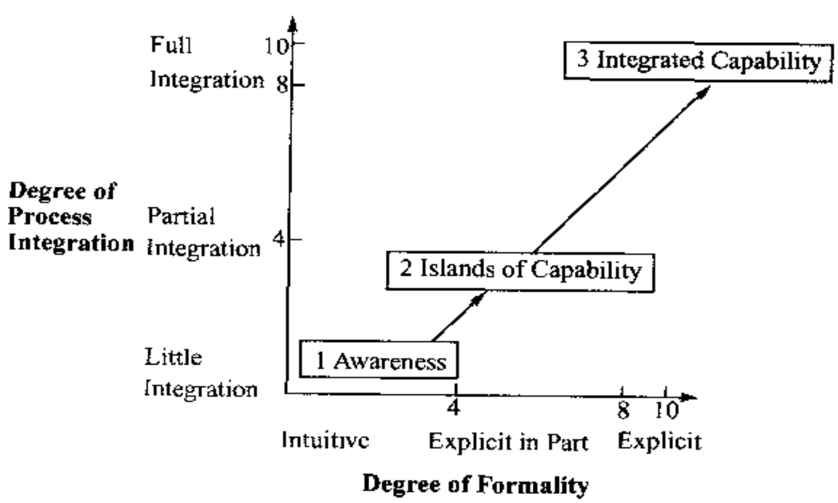


Figure 3. Stages in the transition to a mature front end

- Islands of Capability (Stage Two). Study suggests that most leading product innovators are at the islands of capability stage. These companies realize the potential of having a well-managed front end and have some of the required capabilities, but inconsistently. Missing are many elements of front-end process integration. Companies find it easier to improve the formality of this process than to address the subtle gaps in integration.

How can companies evolve from "awareness" to "islands of capability"? That depends on what the business unit has already achieved and what capabilities it needs, given its industry and company. We identified two broad approaches to achieving Stage Two. First, those companies that have barely begun to understand the importance of the front end should recognize that product development is a senior management responsibility. Managers should carry out several structured activities, such as the diagnostic test. Second, those companies that recognize the importance of the front end should formally and systematically conduct various front-end activities. Those activities include having an explicit product definition, estimating technology requirements early, and planning resources.

- Integrated Capability (Stage Three). Front-end product development integration, the hallmark of Stage Three, is quite rare. We believe that most companies don't understand that this stage is significant in terms of required capabilities, and achieving it takes concerted effort. At the few companies with this degree of process integration, analysis and decisions have been both explicit and rigorous, and all front-end activities are managed as a single process. Stage Three companies execute NPD projects better and faster than their competitors and are more likely to introduce a winning product. One can honestly say of these companies that "well begun is more than half done."

How can companies make a transition from "islands of capability" to "integrated capability?" Some Stage Two companies have much of the required formality but not necessarily the degree of integration to yield substantial benefits. Most Stage Two companies should focus on understanding the various dimensions of integration. Among our sample, we identified three clusters of companies that required somewhat different approaches to get to Stage Three. These three clusters represent generic front-end states and problems that many companies face.

While companies in the first cluster have passed Stage One, they still have a long way to go. They need to focus closely on senior management involvement in creating a product vision. Improvements in front-end formality and integration, while not easy, will be easier if the product development group can understand its purpose better.

Second cluster companies will realize improvements from refinements in the front-end process. They need to make their front-end activities more explicit and, in particular, understand how to better manage their technology and resource requirements. Once they progress on these dimensions, they can focus more on cross functional and integration problems.

The third cluster of companies were the most advanced among the Stage Two companies. Front-end explicitness is not their main problem. Instead, their challenge is to work on cross-project issues and technological uncertainties. By having close ties among strategic planners and project personnel, they will understand the links among projects and anticipate matches or mismatches between future market needs and current technology and product plans. They need to establish closer connections between their R&D and product development groups so that they can anticipate overall technological progress and product-specific technological uncertainty.

- Sustaining Stage Three. Clearly, reaching Stage Three is not easy; even those companies that have achieved it continue to require improvements. Changes in competition, technologies, tools, and organizational structures and relationships may need changes in at least some front-end practices.

Conclusion

Most companies have unnecessarily fuzzy front-end systems. The best way to integrate the front-end process is to use an overall systems perspective and thoroughly assess the current state of the front end. Fixing what appears to be broken requires the ability to see the interrelatedness of issues and the development of a coherent agenda.

We caution against oversimplification: not all companies should adopt the same front-end solution, and most will need to adopt more than one. For example, we found that companies used executive reviews in different ways with mixed success; some case study companies changed the role of the executive review group for different products. In general, company size, decision-making style, operating culture, and frequency of new product introduction are some factors that are critical to a preferred front-end solution. We discourage companies from importing a particular process or procedure that has worked well for others unless their contexts are clearly similar.

Managing to become less fuzzy means integrating seemingly disparate but related strategic and operational activities, typically crossing functional boundaries. The solution must be balanced with the emerging realities of business and the environment. With proper diagnosis, consensus, and commitment, companies can enhance product development performance over the long term.

Professional Words and Expressions

New Product Development	新产品开发
Research and Development (R&D)	研究与开发,研发
Product Strategy	产品策略
Product Portfolio	产品汇总表
Customer Needs	顾客需求

Product Concept	产品概念
Project Plan	项目计划
Concurrent Engineering	并行工程
Rapid Prototyping	快速原型
Product Concept Statement	产品概念陈述
Product Definition	产品定义
Project Planning	项目规划
Foundation Element	基本要素
Project-Specific Element	项目特有要素
Tangible Product	实物产品
Sketch	草图
Three-Dimensional Model	三维模型
Product Feature and Function	产品特征和功能
Target Market Segment	目标市场部分
Design Priority	设计优先级
Resource Constraint	资源限制
Important Factor	关键因素
Project Priority	项目优先级
Task	任务
Projected Resource Requirement	资源需求预估

Notes

1. As enhanced capabilities for concurrent engineering, rapid prototyping, and smoothly functioning supplier partnerships have helped reduce product design and development times, management attention has begun to shift to the cross-functional, front-end strategic, conceptual, and planning activities that typically precede the detailed design and development of a new product.

   随着能力增强的并行工程、快速原型和与供应商的和谐伙伴关系对产品设计和开发时间的缩短,(产品开发)管理的注意力已经转向交叉职能性的、前期策略性的、概念性和规划性的活动。这些活动通常在新产品的详细设计和开发之前(展开)。

2. Also, without adequate foundation elements, product and project success becomes a matter of luck.

   而且,如果不具备充分的基本要素,产品和项目的成功与否就靠运气了。

3. However, they stop far short of creating detailed designs and specifications for the product and its components.

   然而,产品特有的前期活动早在产生详细的产品设计(方案)和规格以及产品的构成零件之

前就结束了。

4. We found the integration of these two factors was rare but extremely potent.
   我们发现就两者有机集成起来的(公司)很少,但这种集成具有相当大的潜力。
5. Fixing what appears to be broken requires the ability to see the interrelatedness of issues and the development of a coherent agenda.
   弥补缺陷需要具备识别问题间的相互依赖性和制定紧凑的行动计划的能力。

12 Computer Integrated Manufacturing
计算机集成制造

The goal of CIM is to integrate and coordinate, via computer hardware and software, all aspects of design, manufacturing and related functions. CIM may be viewed as the management technology that makes feasible the fully-automated factory-of-the-future.

Certain computer-based technologies falling within the broad realm of CIM have been sufficiently well developed to merit specific attention. These include computer-aided design (CAD), computer-aided process planning (CAPP), material requirement planning (MRP), manufacturing resources planning (MRP II), capacity requirements planning (CPR) and shop-floor control (SFC). Also of importance is group technology (GT), which significantly facilitates computer-aided process planning (CAPP), and computer-aided manufacturing (CAM). The topic of networks (telecommunications between computerized elements) pervades many of the specific technologies listed above, and hence deserves special consideration.

Computer-aided design

Computer-aided design (CAD) allows the designer to draw a design on a visual display unit (VDU), or computer monitor screen. Computer graphics is the term applied to the combination of hardware and software that makes this possible. Completed designs are stored in a design database.

Most CAD systems allow the designer to draw a model of the design by making available a set of primitives. These are simple geometric figures such as lines and circles in two-dimensional modeling. Primitives may be brought onto the screen and re-sized, re-oriented, partially trimmed or otherwise adjusted to create the desired drawing. In other words, each more complex part in the design is broken down into a set of simpler figures that, when appropriately positioned, create a graphic image of the whole part. The use of different colors in different portions of the design display helps make drawings even clearer and easier to understand. Another aspect of CAD graphics that substantially enhances clarity is that a drawing may be rotated so the designer can view it from many different angles. This is accomplished by having the computer calculate a large number of coordinate transformations — a repetitive mathematical process that a computer is well-suited to do quickly. Some CAD systems can also simulate movement of the part if, for example, a piece of it is hinged. The ability to rotate or cause movement in the design allows testing for clearance and frequently leads to a major reduction in the cost of prototyping.

Having access to a computerized design database makes it easy for a designer to quickly modify an old design to meet new design requirements — an event that occurs quite frequently. This enhances designer productivity; speeds up the design process; reduces design errors resulting from hurried, inaccurate copying; and reduces the number of designers needed to perform the same amount of work. It also means the designers can focus on doing work that is mostly non-routine, while the CAD system does most of the routine work. Another advantage associated with a CAD database is that all of the designs are based on the same standards: standard primitives, standard colors and other standard design rules. This reduces unpleasant surprises for a designer attempting to modify a previous design that might, under a manual system, be based on a different set of rules or assumptions that the ones (s)he is following.

Computer-aided engineering

Computer-aided engineering (CAE) enables engineers to do complex engineering analysis on the computer. Once CAD work had been completed, a designer can use CAE to analyze the design and determine if it will work like the designer thought it would. For example, if a simulation of a circuit design shows that the circuit produces a few unanticipated and undesired outputs, some re-design is clearly necessary. Likewise, if a stress analysis shows that a particular design would break down if subjected to more than 15 pounds of pressure, and the specifications call for withstanding 30 pounds, it is back to the drawing board.

Electronic computer-aided engineering (ECAE) is primarily used to design integrated circuits and printed-circuit boards. The term computer-aided software engineering (CASE) is sometimes used to distinguish software development tools from hardware development tools. Circuit-design, circuit-checking and project management software are the major elements of CASE. Mechanical computer-aided engineering (MCAE) deals with the mechanical aspects of design, making sure that all of the pieces fit together and that all of them actually fit into the box as planned. When these designs are subjected to spreadsheet-like "what if" analysis based on engineering equations contained in the software, the essentials of the design can be optimized before the design engineer spends a lot of time getting down into the fine details. Part of the optimization can include manufacturability.

With any kind of CAE, detailed engineering analysis provides data, which will probably be useful when actually manufacturing the product. Such data not only include product specifications, but also process information on the design of tools or molds, programs used for controlling the motions of numerical control (NC) machines or robots. Thus a database created as a result of CAD/CAE may then be used to support computer-aided manufacturing (CAM).

Computer-aided manufacturing

Computer-aided manufacturing (CAM) encompasses the computer-aided techniques that facilitate the planning, operation and control of a production facility. Such techniques include computer-aided process planning (CAPP), numerical control part programming, robotics programming, computer-generated work standards, material requirements planning (MRP), manufacturing resources planning (MRP II), capacity requirements planning (CRP) and shop-floor control (SFC).

Computer-aided process planning (CAPP) creates the sequence of steps that must be followed to produce a given part or product. It instances where a variety of similar products are to be produced. Process planning is typically a sophisticated, but largely repetitive task. Hence, it is a task for which a computer is well suited, provided a well-organized system is devised for the computer to follow.

Group technology (GT) is the methodology that usually provides the basis for the well-organized system required by CAPP. GT classifies parts quite efficiently by dividing the parts into families that exhibit similar characteristics. One common basis for similarity is the characteristics of the part itself, such as its shape, its size, or the material from which the part is made. Another common basis for similarity is the characteristics of the manufacturing process for the part, such as the process sequences or routings the part must follow, or the types of equipment used to make the part.

Any of a variety of coding schemes may be applied to uniquely identify each part by a number of an alphanumeric (letters plus numbers). These may range from less than 10 to more than 30 characters in length. Each character adds a little more information about the part.

Once all parts have been coded, standard process plans may be developed for each family of parts. After this phase has been completed, process planning for a new but similar part may be accomplished by slight modifications to the standard plan for the part's family. If the part has been built before, the plan is simply called up from the CAPP database.

The system just described is called variant CAPP because human users get involved to deal with variants of the standard plans retrieved from the CAPP database. A more sophisticated approach is generative CAPP, wherein CAPP more accurately stands for computer-automated process planning. Generative CAPP allows the computer to automatically generate optimal process plans based on a series of algorithms imbedded in the system software. The algorithms can take into account a variety of relevant concerns, including differences in speed, quality and cost for various alternative methods, prior results, the age of the equipment involved (if tool wear or potential for breakdown are factors), etc. In current practice, the capabilities of generative CAPP systems are rather limited.

Material requirements planning (MRP) is a computerized system for the timely planning and control of inventory. MRP requires the estimates of the demand for a particular finished product in a particular week be developed based on forecasts, available capacity and other factors. MRP then analyzes the bill of materials (BOM) — the list of all of the parts needed to build the product — and calculates when each of these parts should be ordered so that enough of them will be on hand when they are required by manufacturing. This sounds logical and straightforward, but can actually get quite complicated in practice.

For example, a particular finished product may contain a number of complex subassemblies, which are in turn made of less complex sub-assemblies, which are made of simple subassemblies, which are made of a variety of parts! Then, in addition to these levels of complexity, imagine that the lead-times required to order and receive certain parts in simple sub-assembly #127 are 12 weeks instead of the more typical five, six or seven weeks. Compound this problem with the possibility that the 12-week lead-time for those parts might suddenly rocket up to 20 weeks due to an unexpected increase in supplier demand or problems in the supplier manufacturing process. Then suppose that in-house manufacturing difficulties could cause a temporary slowdown in the anticipated production rate for simple sub-assemblies in general. Given this degree of variety and complexity, the tremendous appeal of a computerized technique for keeping track of all these interdependent factors is obvious.

Also obvious from the hypothetical scenario outlined above is that the MRP program must be supplied with the best possible estimates for both the lead-times required to manufacture any of these parts, sub-assemblies or final assemblies in-house and the leadtimes required to purchase any of these items from outside suppliers. Changes in the original schedule are then noted by the computer, which issues change notice to relevant factory personnel. MRP systems that take into account feedback from manufacturing and other functions are often referred to as closed-loop MRP systems, since the feedback serves to close information loops between concerned parties.

Manufacturing resources planning (MRP II) is basically an extended version of material requirements planning (MRP). Parts are required at various times and MRP II determines the costs of the parts and the cash flows required to pay for them. It also estimates cash flows for related expenditures such as wages, tools, equipment repairs and even the power bills. Sophisticated MRP II programs can predict cash requirements, by departmental unit, for a year or more in advance, thus accomplishing computerized budgeting. Also, because MRP II converts all of its inputs into equivalent cash flows, it can be used as a simulator to answer a variety of "what if" questions about actions that may be taken by any given department. The results of such simulations can then be used as a basis for more complex analyses to determine how proposed changes would impact other parts of the organizational system.

Capacity requirements planning (CPR) is a different variation on the MRP theme. Instead of focusing on timely acquisition of inventory or controlling cash flows, CRP analyzes available capacity to perform the manufacturing function. Important concerns are people and equipment. How much output can each person or machine provide per hour or day? Factors such as break-times, fatigue, absenteeism and so forth affect a plant's people-related capacity, which can be further modified by special arrangements such as overtime work. Equipment-related capacity is an interactive function of the speed of the machine; the rate at which inputs can be supplied to the machine, and outputs removes; planned or unplanned maintenance; how many machines of a particular type are on hand, etc. Since these capacities are likely to vary in complexity over time in a manner similar to the lead-times and levels issues of MRP, computerized tracking of capacity is another logical addition to CAM.

Shop floor control (SFC) is another aspect of CAM to be considered. SFC systems make use of the computer to monitor and control what occurs on the factory (shop) floor. Key functions of SFC include prioritizing shop orders; monitoring the status of current shop orders; and comparing data on actual work-in-process (WIP) with MRP and CRP plans. If WIP does not match the MRP/CRP plans, SFC facilities adjustments as necessary.

Networks

Thus far a substantial number of computer-aided techniques that contribute toward computer integrated manufacturing (CIM) have been reviewed, but nothing has been said about how they might be computer integrated. Integration may be achieved through one or more networks, which electronically link together all of the various computerized entities or systems in the factory.

Getting different types and makes of computers to talk to one another is not a problem readily resolved. Attempts are being made at the international level as well as at the national level within the United States to develop standards that will make this possible. The open systems interconnection (OSI) model is currently the most well-developed standard. It features a seven-layer system, each layer dealing with a different aspect of data communications compatibility. Layer 1 is concerned with standards for the actual physical linkage of one machine to another, such as the kinds of hardware connectors that should be used. As another example, Layer 6 is concerned with the form of data representation; i.e. whether the data is coded in the American standard code for information interchange (ASCII), extended binary-coded-decimal interchange code (ECDIC) or some other code. It also is responsible for converting any incoming stream of data into a common code format.

A pair of industry-driven network systems based on the OSI model are manufacturing automation protocol (MAP) and technical and office protocol (TOP). MAP was initially developed by General Motors, but is now gaining the support of a large number of CIM suppliers and users.

TOP is a similar networking standard developed by Boeing computer services for business office and engineering applications. MAP and TOP are now being integrated into a single MAP/TOP network system.

Networking is further complicated by the need to have networks that operate at different hierarchical levels within a CIM environment, such as a substantially or fully automated factory. For example, the highest-level networking might integrate an entire factory, much like a plant manager does. At the next level down several networks might act like middle managers to plan and coordinate activities within and between various functions within the factory. The level below that might consist of networks that monitor and control the activities of various groups of automated machines (departments), such as a flexible manufacturing system. Additional levels might contain networks responsible for activities like material handling between workstations, and finally networks that cause the action of individual workstations.

The actual physical network that link together various computers and computer controlled equipment (e. g. robots, automated test equipment) within a single plant site are called local-area networks (LANs). These typically consist of coaxial and fiber-optic cables, which interconnect the machines and network computers that manage the flow of data through the network. Larger-scale networks linking a variety of locations are termed wide-area networks (WANs).

Other key elements of factory automation

The factory automation technologies discussed thus far have, for the most part, consisted of computer hardware and software. Other key technologies, while also computerized to at least some extent, are more recognizable as physically active machines. Hard automation will be contrasted with forms of flexible automation such as numerical control, programmable logic controllers (PLCs), automatic test equipment (ATE) and robot. Various systems, including flexible manufacturing systems (FMSs), automated storage and retrieval systems (AS/RS) and pathways for automated guided vehicles (AGVs) are also important aspects of factory automation.

Hard automation

Automation may be defined as the replacement of manual labor with machine labor. In simpler forms of automation, the machine does the work while a human guides the machine. Examples include drilling a hole with an electric drill, cleaning up a dusty workbench with a miniature vacuum cleaner, or assembling a metal or plastic box with a power screwdriver. In more sophisticated forms of automation, a human need not guide the activities of the machine continuously. Instead, the machine is programmed to perform tasks in appropriate ways.

A machine designed to cycle through only one specific set of motion is an example of fixed or hard automation. A toaster is such a machine. It automatically exposes bread to heat, converting it into toast. A dishwasher, a coffee-making machine and a traffic light are also forms of hard automation.

Numerical control

Numerical control (NC) machines consist of combinations of cutting and shaping tools, such as lathes and drill presses, which are controlled by instruction coded onto a paper tape. As the tape passes through a paper-tape reader, the various tools reshape the work piece according to the pattern prescribed by the instructions on the tape. Any described change in the pattern is accomplished by simply changing a new version of the paper tape.

Modern approaches to numerical control are CNC and DNC. In computer numerical control (CNC), a small computer replaces the conventional controller unit of the NC machine.

Direct numerical control (DNC) differs from CNC in that a larger computer controls a number of NC machines simultaneously. A combination of CNC and DNC is also possible. In this hybrid approach, the larger computer stores the NC part programs. These are downloaded as needed to the smaller CNC computers, which then control the NC machines.

Programmable logic controllers

Programmable logic controllers (PLCs) are, in essence, small and simple computers that can be programmed to control industrial equipment in relatively simple ways. They differ from other types of computers in that they are specifically designed to cope with an industrial environment, which may exhibit relatively extreme temperatures (for computers), high humidity, significant vibration and substantial amounts of electro-magnetic interference (EMI).

Applications of PLCs include monitoring output of production equipment; monitoring tool wear; monitoring reporting and controlling plant power and energy usage; controlling temperature and pressure for plastic injection-molding machines; and controlling materials handling equipment (transfer-line machines). As personal computers (PCs) become smaller and more ruggedly built, they will probably replace PLCs in many applications.

Automatic test equipment

Automatic test equipment (ATE) currently plays a very significant role in testing integrated circuits (ICs) and printed-circuit boards (PCBs), both of which are key elements in computer and telecommunications equipment. Once properly programmed, ATE can rapidly and accurately perform a large number of tests on the circuit in question. This is really a form of computer-automated inspection (CAI). So ATE plays an important role in assuring high levels of quality. Most ATE systems consist of:

- a general-purpose microcomputer or workstation;
- a hardware interface that connects the circuits being tested to the circuits under the control

of the computer;

- a variety of testing software, which must be frequently updated. Some customization is typically required to meet the needs of each specific application.

Robotics

Robots, according to the Robot Institute of America, are "reprogrammable, multi-functional manipulators designed to move material, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks." While the traits of reprogrammability and multi-functionality apply to numerical control (NC) machines as well, the latter consist of combinations of specific tools rather than of one of two very general-purpose manipulators to which a wide variety of tools might be attached. Robotic manipulators are typically more mobile than the tools in NC machines. Industrial robots consist of four basic components:

- manipulators;
- end-effectors;
- sensors;
- controllers.

Manipulators are the counterparts to human arms and wrists. They require joints or articulations in order to move. Robotic manipulators are hydraulically- (liquid-), pneumatically- (gas-) or electrically-powered. The lengths of most industrial robots' manipulators range from a few inches to about 10 feet.

End-effectors are attached to the ends of manipulators. An effector is a device that effects in action, like picking up a part of manipulating a tool. Thus an effector attached to the end of a manipulator is called an end-effector.

Sensors convert information concerning what is happening in the robot's world (e.g. workpiece-reflected light rays for vision) into electronic signals that can be analyzed by the computer(s) controlling the robot. The robotic sensors of greatest interest include vision, tactile (touch) and force sensors.

Controllers are robotic brains, the computers that tell the robot what to do next. Robotic controllers vary from simple to complex. The level of controller intelligence required by a robot is dependent upon the sophistication of the manipulator(s), end effector(s) and sensor(s) to be incorporated in that robot.

The simplest robots do not actually require a computer at all. They just move their arms or grippers in a direction until pressure or the arm or gripper triggers a halt in motion. These pick-and-place robots, and those on the next highest level of sophistication, may be classified as point-to-point (PTP) robots.

The most sophisticated modern robots are controlled by one or more computers. Such robots may be programmed to follow a continuous path or contour rather than simply moving directly from one point to another, and hence are known as continuous-path robots. They exhibit considerably greater accuracy and dexterity than PTP robots. Continuous path robots may be taught their tasks via the lead-through method — using a remote controlled box called a teaching pendant — or via off-line programming.

Some major applications of robots in high-technology operations include material handling, parts positioning and assembly. Robots are also commonly used in welding, drilling and spray-painting applications.

Flexible manufacturing systems

In general, a flexible manufacturing system (FMS) is a major grouping of computer controlled manufacturing devices linked to a computer that acts as their manager. An FMS is intended to operate with little or no human intervention. Key attributes of an FMS are:

- flexible work stations that can make a wide variety of parts with very short set-up times;
- a flexible materials handling system that moves the parts between work stations;
- computer control in real time.

A typical FMS might consist of a half dozen numerical control (NC) machines that are loaded and unloaded by robots, all of whom report to a minicomputer. The NC machines would most likely operate under distributed numerical control (DNC II), a hybrid combination of CNC and DNC. The robots would probably be continuous path robots, for greater flexibility. The lowest three levels of the network systems hierarchy discussed earlier would be applied within such an FMS. Broadly speaking, an FMS is a work group or department within an automated factory. An FMS may be considered an evolutionary step towards a truly fully-automated factory.

Related to flexible manufacturing systems is the concept of flexible manufacturing cells (FMCs). FMCs are usually smaller and less automated than FMSs, typically involving two to four machines plus at least one human operator. The operator(s) monitor the equipment, inspect the output of the cell for quality, perform maintenance, cope with any unusual situation, and may also get involved in changing programs for some of the equipment, such as NC machines.

Automated storage and retrieval systems

An automated storage and retrieval system (AS/RS) essentially functions as an automated warehouse, though it should be noted that some AS/RSs are considerably closer to warehouse-size than others. Parts are stored in bins that can be delivered to one or more collection and distributions-points, where more parts may be added or needed parts may be removed and sent on to manufacturing. A computer keeps track of how many of which kinds of parts are stored in which bins, and controls the mechanical system that selects the desired bin and moves it to a collection or distribution point.

Besides enhancing the accuracy of material pulls (i. e. the removal of material to fill an internal or customer order), AS/RS is space efficient, providing better use of the available volume of storage space.

Automated guided vehicles

Automated guided vehicles (AGVs) are a form of truck that does not require a human driver. Guidance is provided by a system of pathways in or on the factory floor. In some AGV systems, the pathways consist of a grid of wires embedded in the concrete floor, through which radio siguals may be sent to be picked up by sensing units in the undersides of the AGVs. In another approach, the pathways consist of painted strips, and the units in the undersides of the AGVs are designed to detect or activate the special paints (e. g. photoreflective paint). Whatever method is used, the basic idea is that a computer can send its fleet of AGVs to the right places at the right times in order to transfer materials to other locations on the factory floor.

An AGV can be designed to contain additional microprocessor-based intelligence, useful for coping with unanticipated events — such as some unintelligent person crossing the AGV's path while it goes about its assigned tasks. AGVs can be designed to transport a wide variety of containers, or even standard wooden pallets on which containers are stacked.

Professional Words and Expressions

Computer Integrated Manufacturing (CIM)	计算机集成制造
Computer-Aided Design (CAD)	计算机辅助设计
Computer-Aided Process Planning (CAPP)	计算机辅助工艺规划
Material Requirement Planning (MRP)	物料需求规划
Manufacturing Resources Planning (MRP Ⅱ)	制造资源规划
Capacity Requirements Planning (CPR)	能力需求规划
Shop-Floor Control (SFC)	车间控制
Group Technology (GT)	成组技术
Computer-Aided Manufacturing (CAM)	计算机辅助制造

Computer Graphics	计算机图形学
Primitives	基本构图要素
Coordinate Transformation	坐标变换
Prototyping	原型
Computer-Aided Engineering (CAE)	计算机辅助工程
Stress Analysis	应力分析
Integrated Circuit Board	集成电路板
Printed-Circuit Board	印刷电路板
Computer-Aided Software Engineering (CASE)	计算机辅助软件工程
Numerical Control (NC) Machine	数控机床
Numerical Control Part Programming	数控零件编程
Robotics Programming	机器人编程
Computer-Generated Work Standard	计算机生成的工作标准
Variant CAPP	变异式计算机辅助工艺规划
Generative CAPP	牛成式计算机辅助工艺规划
Bill Of Materials (BOM)	物料清单
Change Notice	变更通知单
Closed-Loop MRP System	闭环 MRP 系统
Open Systems Interconnection (OSI)	开放系统互联
American Standard Code for Information Interchange (ASCII)	用于信息交换的美国标准编码
Extended Binary-Coded-Decimal Interchange Code (ECDIC)	扩展的十进制二元编码交换码
Manufacturing Automation Protocol (MAP)	制造自动化协议
Technical and Office Protocol (TOP)	技术和办公协议
Flexible Manufacturing System	柔性制造系统
Automated Test Equipment (ATE)	自动检测设备
Local-Area Network (LAN)	局域网
Coaxial Cable	同轴电缆
Fiber-Optic Cable	光纤电缆
Wide-Area Network (WAN)	广域网
Factory Automation	工厂自动化
Hard Automation	刚性自动化
Flexible Automation	柔性自动化
Programmable Logic Controller (PLC)	可编程逻辑控制器

Automated Storage and Retrieval System (AS/RS)	自动存取系统
Automated Guided Vehicle (AGV)	自动导航设备
Computer Numerical Control (CNC)	计算机数控
Direct Numerical Control (DNC)	直接数控
Distributed Numerical Control (DNC II)	分布式数控
Electro-Magnetic Interference (EMI)	电磁干涉
Plastic Injection-Molding Machine	塑料注塑机
Computer-Automated Inspection (CAI)	计算机自动检测
Manipulators	操作件
End-Effector	执行件
Sensor	传感器
Controller	控制器
Hydraulically- powered *a.*	液动的
Pneumatically- powered *a.*	气动的
Electrically-powered *a.*	电动的
Vision Sensor	视觉传感器
Tactile Sensor	触觉传感器
Force Sensor	压力传感器
Point-To-Point (PTP) robot	点到点机器人
Flexible Manufacturing Cell (FMC)	柔性制造单元

Notes

1. Certain computer-based technologies falling within the broad realm of CIM have been sufficiently well developed to merit specific attention.
   计算机集成制造这一广博领域中包括一些已经得到充分发展并且值得注意的基于计算机的技术。
2. Most CAD systems allow the designer to draw a model of the design by making available a set of primitives.
   大部分的计算机辅助设计系统都向设计者提供一组基本构图元素(如二维绘图中的线、圆等),基于这些基本构图元素,设计者可以绘出(零部件)设计的(计算机)模型。
3. When these designs are subjected to spreadsheet-like "what if" analysis based on engineering equations contained in the software, the essentials of the design can be optimized before the design engineer spends a lot of time getting down into the fine details.
   当需要用包含在软件中的工程方程对这些设计进行类似于电子数据表格的"如果……会怎么样……"的分析时,设计的本质内容在没有必要等到设计工程师花费许多时间以得到详

细设计的情况下就能够得到优化。

4. It instances where a variety of similar products are to be produced.
计算机辅助工艺规划系统基于已有零部件产品的工艺方案，通过实例化来生成新的相似零部件的工艺方案。
5. Any of a variety of coding schemes may be applied to uniquely identify each part by a number of an alphanumeric (letters plus numbers).
各种编码方法中的任何一个都可以利用一个字母数字串来惟一地标识每一个零件。
6. Given this degree of variety and complexity, the tremendous appeal of a computerized technique for keeping track of all these interdependent factors is obvious.
考虑到这样的变化程度和复杂程度，能够用来跟踪这些相互关联的变量的计算机技术就显得非常有吸引力。
7. Sophisticated MRP II programs can predict cash requirements, by departmental unit, for a year or more in advance, thus accomplishing computerized budgeting.
复杂的制造资源规划系统能够提前一年甚至更长时间预测每一个功能单元的现金需求，因此可以用来实现预算的计算机化。
8. Getting different types and makes of computers to talk to one another is not a problem readily resolved.
使得不同类型和构造的计算机之间能够通讯畅通不是一件容易的事情。

13 Simulation Modeling and Analysis
仿真建模与分析

The nature of simulation

This is a paper about techniques for using computers to imitate, or simulate, the operations of various kinds of real-world facilities or processes. The facility or process of interest is usually called a system, and in order to study it scientifically we often have to make a set of assumptions about how it works. These assumptions, which usually take the form of mathematical or logical relationships, constitute a model that is used to try to gain some understanding of how the corresponding system behaves.

If the relationships that compose the model are simple enough, it may be possible to use mathematical methods (such as algebra, calculus, or probability theory) to obtain exact information on questions of interest; this is called an analytic solution. However, most real-world systems are too complex to allow realistic models to be evaluated analytically, and these models must be studied by means of simulation. In a simulation we use a computer to evaluate a model numerically, and data are gathered in order to estimate the desired true characteristics of the model.

As an example of the use of simulation, consider a manufacturing company that is contemplating building a large extension onto one of its plants but is not sure if the potential gain in productivity would justify the construction cost. It certainly would not be cost-effective to build the extension and then remove it later if it does not work out. However, a careful simulation study could shed some light on the question by simulating the operation of the plant as it currently exists and as it would be if the plant were expanded.

Application areas for simulation are numerous and diverse. Below is a list of some particular kinds of problems for which simulation has been found to be a useful and powerful tool:

- Designing and analyzing manufacturing systems
- Evaluating military weapons systems or their logistics requirements
- Determining hardware requirements or protocols for communications networks
- Determining hardware and software requirements for a computer system
- Designing and operating transportation systems such as airports, freeways, ports, and subways
- Evaluating designs for service organizations such as call centers, fast-food restaurants,

hospitals, and post offices

- Reengineering of business processes
- Determining ordering policies for an inventory system
- Analyzing financial or economic systems

Simulation is one of the most widely used operations research and management-science techniques, if not the most widely used. One indication of this is the Winter Simulation Conference, which attracts 600 to 700 people every year. In addition, there are several simulation vendor users' conferences with more than 100 participants per year.

There are also several surveys related to the use of operations research techniques. For example, Lane, Mansour, and Harpell (1993) reported from a longitudinal study, spanning 1973 through 1988, that simulation was consistently ranked as one of the three most important "operations-research techniques." The other two were "math programming" (a catch-all term that includes many individual techniques such as linear programming, nonlinear programming, etc.) and "statistics" (which is not an operations-research technique per se). Gupta (1997) analyzed 1294 papers from the journal Interfaces (one of the leading journals dealing with applications of operations research) from 1970 through 1992, and found that simulation was second only to "math programming" among 13 techniques considered.

There have been, however, several impediments to even wider acceptance and usefulness of simulation. First, models used to study large-scale systems tend to be very complex, and writing computer programs to execute them can be an arduous task indeed. This task has been made much easier in recent years by the development of excellent software products that automatically provide many of the features needed to "program" a simulation model. A second problem with simulation of complex systems is that a large amount of computer time is sometimes required. However, this difficulty is becoming much less severe as computers become faster and cheaper. Finally, there appears to be an unfortunate impression that simulation is just an exercise in computer programming, albeit a complicated one. Consequently, many simulation "studies" have been composed of heuristic model building, coding, and a single run of the program to obtain "the answer." We fear that this attitude, which neglects the important issue of how a properly coded model should be used to make inferences about the system of interest, has doubtless led to erroneous conclusions being drawn from many simulation studies.

Systems, models, and simulation

A system is defined to be a collection of entities, e.g. people or machines, that act and interact together toward the accomplishment of some logical end. In practice, what is meant by "the system" depends on the objectives of a particular study. The collection of entities that comprise a system for one study might be ouly a subset of the overall system for another. For example, if one wants to study a bank to determine the number of tellers needed to provide adequate service for customers who want just to cash a check or make a savings deposit, the system can be defined to be that portion of the bank consisting of the tellers and the customers waiting in line or being served. If, on the other hand, the loan officer and the safety deposit boxes are to be included, the definition of the system must be expanded in an obvious way. We define the state of a system to be that collection of variables necessary to describe a system at a particular time, relative to the objectives of a study. In a study of a bank, examples of possible state variables are the number of busy tellers, the number of customers in the bank, and the time of arrival of each customer in the bank.

We categorize systems to be of two types, discrete and continuous. A discrete system is one for which the state variables change instantaneously at separated points in time. A bank is an example of a discrete system, since state variables — e. g. the number of customers in the bank — change only when a customer arrives or when a customer finishes being served and departs. A continuous system is one for which the state variables change continuously with respect to time. An airplane moving through the air is an example of a continuous system, since state variables such as position and velocity can change continuously with respect to time. Few systems in practice are wholly discrete or wholly continuous; but since one type of change predominates for most systems, it will usually be possible to classify a system as being either discrete or continuous.

At some points in the lives of most systems, there is a need to study them to try to gain some insight into the relationships among various components, or to predict performance under some new conditions being considered. Figure 1 maps out different ways in which a system might be studied.

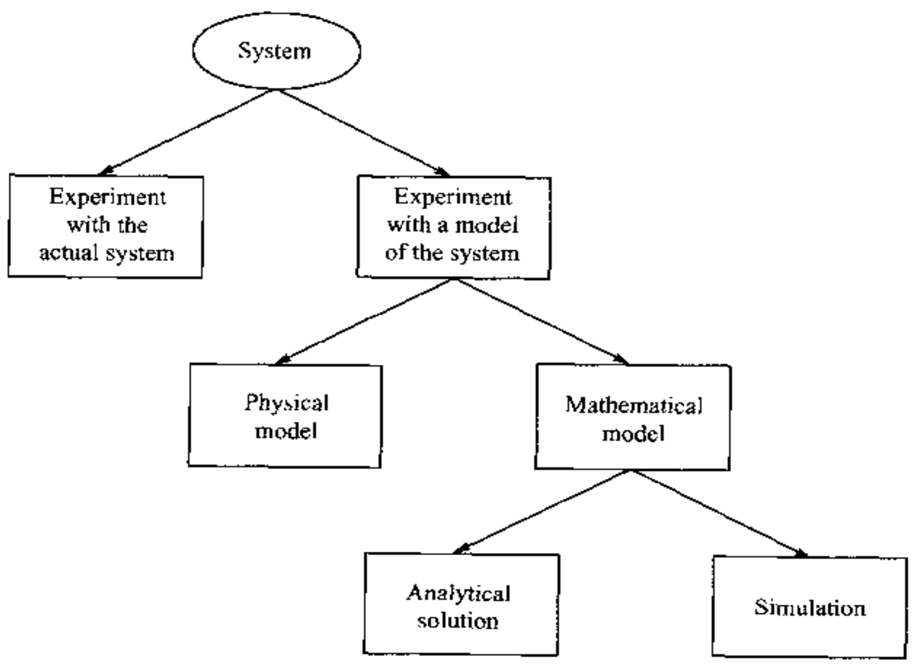


Figure 1. Ways to study a system

- *Experiment with the Actual System vs. Experiment with a Model of the System.* If it is possible (and cost-effective) to alter the system physically and then let it operate under the new conditions, it is probably desirable to do so, for in this case there is no question about whether what we study is valid. However, it is rarely feasible to do this, because such an experiment would often be too costly or too disruptive to the system. For example, a bank may be contemplating reducing the number of tellers to decrease costs, but actually trying this could lead to long customer delays and alienation. More graphically, the "system" might not even exist, but we nevertheless want to study it in its various proposed alternative configurations to see how it should be built in the first place; examples of this situation might be a proposed communications network, or a strategic nuclear weapons system. For these reasons, it is usually necessary to build a model as a representation of the system and study it as a surrogate for the actual system. When using a model, there is always the question of whether it accurately reflects the system for the purposes of the decisions to be made.
- *Physical Model vs. Mathematical Model.* To most people, the word "model" evokes images of clay cars in wind tunnels, cockpits disconnected from their air planes to be used in pilot training, or miniature supertankers scurrying about in a swimming pool. These are examples of physical models (also called iconic models), and are not typical of the kinds of models that are usually of interest in operations research and systems analysis. Occasionally, however, it has been found useful to build physical models to study engineering or management systems; examples include tabletop scale models of material-handling systems, and in at least one case a full-scale physical model of a fast-food restaurant inside a warehouse, complete with full-scale, real (and presumably hungry) humans. But the vast majority of models built for such purposes are mathematical, representing a system in terms of logical and quantitative relationships that are then manipulated and changed to see how the model reacts, and thus how the system would react—if the mathematical model is a valid one. Perhaps the simplest example of a mathematical model is the familiar relation $d = rt$, where r is the rate of travel, t is the time spent traveling, and d is the distance traveled. This might provide a valid model in one instance (e. g. a space probe to another planet after it has attained its flight velocity) but a very poor model for other purposes (e. g. rush-hour commuting on congested urban freeways).
- *Analytical Solution vs. Simulation.* Once we have built a mathematical model, it must then be examined to see how it can be used to answer the questions of interest about the system it is supposed to represent. If the model is simple enough, it may be possible to work with its relationships and quantities to get an exact, analytical solution. In the $d = rt$ example, if we know the distance to be traveled and the velocity, then we can work with the model to get $t = d/r$ as the time that will be required. This is a very simple, closed-form solution obtainable with just paper and pencil, but some analytical solutions can

become extraordinarily complex, requiring vast computing resources; inverting a large nonsparse matrix is a well-known example of a situation in which there is an analytical formula known in principle, but obtaining it numerically in a given instance is far from trivial. If an analytical solution to a mathematical model is available and is computationally efficient, it is usually desirable to study the model in this way rather than via a simulation. However, many systems are highly complex, so that valid mathematical models of them are themselves complex, precluding any possibility of an analytical solution. In this case, the model must be studied by means of simulation, i. e. numerically exercising the model for the inputs in question to see how they affect the output measures of performance.

While there may be a small element of truth to pejorative old saws such as "method of last resort" sometimes used to describe simulation, the fact is that we are very quickly led to simulation in most situations, due to the sheer complexity of the systems of interest and of the models necessary to represent them in a valid way.

Given, then, that we have a mathematical model to be studied by means of simulation (henceforth referred to as a simulation model), we must then look for particular tools to do this. It is useful for this purpose to classify simulation models along three different dimensions:

- *Static vs. Dynamic Simulation Models.* A static simulation model is a representation of a system at a particular time, or one that may be used to represent a system in which time simply plays no role; examples of static simulations are Monte Carlo models. On the other hand, a dynamic simulation model represents a system as it evolves over time, such as a conveyor system in a factory.
- *Deterministic vs. Stochastic Simulation Models.* If a simulation model does not contain any probabilistic (i.e. random) components, it is called deterministic; a complicated (and analytically intractable) system of differential equations describing a chemical reaction might be such a model. In deterministic models, the output is "determined" once the set of input quantities and relationships in the model have been specified, even though it might take a lot of computer time to evaluate what it is. Many systems, however, must be modeled as having at least some random input components, and these give rise to stochastic simulation models. Most queueing and inventory systems are modeled stochastically. Stochastic simulation models produce output that is itself random, and must therefore be treated as only an estimate of the true characteristics of the model; this is one of the main disadvantages of simulation.
- *Continuous vs. Discrete Simulation Models.* Loosely speaking, we define discrete and continuous simulation models analogously to the way discrete and continuous systems were defined above. It should be mentioned that a discrete model is not always used to model a discrete system, and vice versa. The decision whether to use a discrete or a continuous model for a particular system depends on the specific objectives of the study.

For example, a model of traffic flow on a freeway would be discrete if the characteristics and movement of individual cars are important. Alternatively, if the cars can be treated "in the aggregate," the flow of traffic can be described by differential equations in a continuous model.

Advantages, disadvantages, and pitfalls of simulation

We conclude by listing some good and bad characteristics of simulation (as opposed to other methods of studying systems), and by noting some common mistakes made in simulation studies that can impair or even ruin a simulation project. Simulation is a widely used and increasingly popular method for studying complex systems. Some possible advantages of simulation that may account for its widespread appeal are the following:

- Most complex, real-world systems with stochastic elements cannot be accurately described by a mathematical model that can be evaluated analytically. Thus, a simulation is often the only type of investigation possible.
- Simulation allows one to estimate the performance of an existing system under some projected set of operating conditions.
- Alternative proposed system designs (or alternative operating policies for a single system) can be compared via simulation to see which best meets a specified requirement.
- In a simulation we can maintain much better control over experimental conditions than would generally be possible when experimenting with the system itself.
- Simulation allows us to study a system with a long time frame — e.g. an economic system—in compressed time, or alternatively to study the detailed workings of a system in expanded time.

Simulation is not without its drawbacks. Some disadvantages are as follows:

- Each run of a stochastic simulation model produces only estimates of a model's true characteristics for a particular set of input parameters. Thus, several independent runs of the model will probably be required for each set of input parameters to be studied. For this reason, simulation models are generally not as good at optimization as they are at comparing a fixed number of specified alternative system designs. On the other hand, an analytic model, if appropriate, can often easily produce the exact true characteristics of that model for a variety of sets of input parameters. Thus, if a "valid" analytic model is available or can easily be developed, it will generally be preferable to a simulation model.
- Simulation models are often expensive and time-consuming to develop.
- The large volume of numbers produced by a simulation study or the persuasive impact of a realistic animation often creates a tendency to place greater confidence in a study's results than is justified. If a model is not a "valid" representation of a system under study, the simulation results, no matter how impressive they appear, will provide little useful information about the actual system.

When deciding whether or not a simulation study is appropriate in a given situation, we can only advise that these advantages and drawbacks be kept in mind and that all other relevant facets of one's particular situation be brought to bear as well. Finally, note that in some studies both simulation and analytic models might be useful. In particular, simulation can be used to check the validity of assumptions needed in an analytic model. On the other hand, an analytic model can suggest reasonable alternatives to investigate in a simulation study.

Assuming that a decision has been made to use simulation, we have found the following pitfalls to the successful completion of a simulation study:

- Failure to have a well-defined set of objectives at the beginning of the simulation study;
- Inappropriate level of model detail;
- Failure to communicate with management throughout the course of the simulation study;
- Misunderstanding of simulation by management;
- Treating a simulation study as if it were primarily an exercise in computer programming;
- Failure to have people with a knowledge of simulation methodology and statistics on the modeling team;
- Failure to collect good system data;
- Inappropriate simulation software;
- Obliviously using simulation software products whose complex macro statements may not be well documented and may not implement the desired modeling logic;
- Belief that easy-to-use simulation packages, which require little or no programming, require a significantly lower level of technical competence;
- Misuse of animation;
- Failure to account correctly for sources of randomness in the actual system;
- Using arbitrary distributions (e. g. normal, uniform, or triangular) as input to the simulation;
- Analyzing the output data from one simulation run (replication) using formulas that assume independence;
- Making a single replication of a particular system design and treating the output statistics as the "true answers";
- Comparing alternative system designs on the basis of one replication for each design;
- Using the wrong performance measures.

Professional Words and Expressions

Simulation	仿真
Mathematical Relationship	数学关系
Logical Relationship	逻辑关系
Model	模型
Algebra	代数学
Calculus	微积分
Probability Theory	概率论
Analytic Solution	解析解,分析解
Operations Research	运筹学
Management Science	管理科学
Discrete System	离散系统
Continuous System	连续系统
State Variable	状态变量
Physical/Iconic Model	物理模型
Mathematical Model	数学模型
Nonsparse Matrix	非稀疏矩阵
Static Simulation Model	静态仿真模型
Dynamic Simulation Model	动态仿真模型
Monte Carlo Model	蒙特卡罗模型
Deterministic Simulation Model	确定型仿真模型
Stochastic Simulation Model	随机仿真模型
Continuous Simulation Model	连续仿真模型
Discrete Simulation Model	离散仿真模型

Notes

1. There have been, however, several impediments to even wider acceptance and usefulness of simulation.

   然而,几个障碍限制了仿真被更广泛地接受及其实用性的发挥。

2. We fear that this attitude, which neglects the important issue of how a properly coded model should be used to make inferences about the system of interest, has doubtless led to erroneous conclusions being drawn from many simulation studies.

   对关于如何正确应用计算机模型去推断所研究系统的结果这样重要问题的忽视态度恐怕是导致许多仿真研究得出错误结论的原因。

3. However, many systems are highly complex, so that valid mathematical models of them are themselves complex, precluding any possibility of an analytical solution.
然而，许多系统非常复杂以至于与之对应的数学模型也很复杂，不能通过解析方法进行求解。
4. While there may be a small element of truth to pejorative old saws such as "method of last resort" sometimes used to describe simulation, the fact is that we are very quickly led to simulation in most situations, due to the sheer complexity of the systems of interest and of the models necessary to represent them in a valid way.
尽管有时用来描述仿真的带有贬义的格言（如"最后一招"）可能有一点真实性，但实际情况是：在大多数情况下，由于所要研究的系统的复杂性以及系统有效模型的复杂性，仿真通常是用来研究这些系统的首选方法。
5. When deciding whether or not a simulation study is appropriate in a given situation, we can only advise that these advantages and drawbacks be kept in mind and that all other relevant facets of one's particular situation be brought to bear as well.
在决定仿真在某一特定场合是否适用时，只能建议要牢记仿真的优缺点，同时也要考虑该场合下所有其他相关方面（因素）的影响。

14 Classification of JIT Techniques
准时化技术的分类

This is an endeavor to understand JIT from the inside by analyzing its techniques, classifying them and examining their possible relations. More than 6 years of research devoted to the JIT system have led to tentatively distinguish among its elements two main categories: JIT's industrial engineering techniques and Japanese management-related features of JIT. The interconnections among the elements are shown in Figure 1.

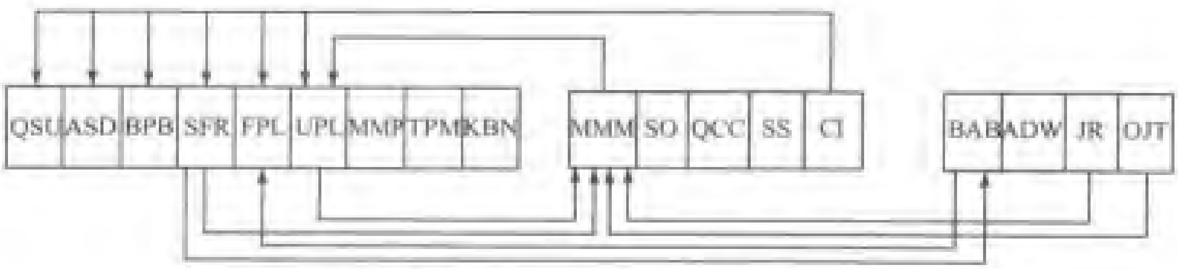


Figure 1. Interconnection among the groups

It is a question of JIT techniques that can be seen as belonging or related to the field of industrial engineering. They can be divided into two groups. There are pure industrial engineering methods and there are industrial engineering elements that are closely associated with the worker's actions.

JIT's pure engineering elements

In this category, one has to find techniques that are universally valid like laws of physics or mathematics. They have no close relationship with the social, cultural, economic or managerial environment in which they appear or are discovered for the first time. Those elements can therefore be applied anywhere and yield the same results. The following are elements of the JIT production system identified as belonging to that group:

- Quick set-up (QSU);
- Automation (ASD) (poka yoke or automatic stopping device, full-work system);
- Breaking of physical barriers (BPB) between processes, sections or departments; Shop floor reduction (SFR);
- Flow-of-products-oriented layout of processes and machines (FPL);
- U-formed processing line (UPL);

- Mass production of mixed models (MMP)—on the same line;
- Total preventive maintenance (TPM);
- Kanban (KBN).

Those engineering elements constitute the "technical side" of JIT or "technical JIT". Applying them anywhere would unavoidably contribute to the reduction of cost, production lead time, defective parts (work), overproduction of work-in-process inventories and workforce.

Worker's operations/activities as JIT elements

The worker's operations can and do constitute some JIT elements. In other words, you have JIT techniques that are part of the worker's activities and that interact with the human being. Their application and realization or success depend also on the human factor. If they are accepted by the work force, then they can work, otherwise they cannot. In that group may be included the following JIT techniques or methods:

- Multi-machine manning working system (MMM);
- Standard operations (SO);
- Quality control circles (QCC);
- Suggestions system (SS);
- Continuous improvement (CI).

Japanese management-related elements of JIT

Japanese-management-related elements of JIT are JIT methods that are either imported directly from or highly conditioned by Japanese management. Included in that category are the following techniques:

- Breaking of administrative barriers (BAB) between processes from the point of view of the paper work and work function definition;
- Autonomation (ADW) (decision by worker to stop the line);
- Job rotation (JR);
- On-the-job training (OJT).

BAB means eliminating the paper work that has to be completed before the move of products from one station or process to another or from one section to another takes place. ADW refers to an "autonomous" worker capable of stopping, based on his own judgment, the production line in case of trouble occurrence.

It is worth pointing out that autonomation and the breaking of barriers each have two assets: a technical and a managerial aspect. Therefore, they have been mentioned as JIT elements pertaining to industrial engineering as well as to Japanese management.

Is the classification justifiable?

One may wonder why the human-related elements have not been dealt with as a sub-group in the group of management features of JIT. The multi-machine handling seems to be too technical to be classified in the category of management-related features of JIT. It has been thought of as a set of technical actions, motions and operations requiring technical skills that do not have much in common with the pure management features. There is a strong influence from the Japanese management system on the multi-machine working system. This occurs because of similarities of situations one finds in both the Japanese management and JIT systems. But MMM remains a technique of industrial engineering.

The same question may be also raised about QCC, SS and CI. Are they not Japanese management-related elements of JIT? QCC, SS and CI are now so wide-spread in almost all kinds of Japanese companies, regardless of their respective industry, that they may be thought of as management features that JIT has adopted. That would be an error of perception. One should remember that QCC, for example, did not proceed or develop from the well-known small groups that are recognized as being specific to Japanese management. They have their origins in the quality control ideas introduced in Japan by Dr. Deming, and in the famous zero defects of NASA. The notions of zero defects and quality control evoke the shop floor environment and at the same time suggest the idea of CI. Suggestions for CI are closely related to QCC, and can even be seen as an emanation of QCC. The main difference between the two elements is that SS may involve either an individual or a group while QCC is always a matter of a group or a team.

This article attempts to put into the category of management-related techniques of JIT only the "raw" features of Japanese management. Raw referring to the management characteristics that are found unchanged in JIT (e. g. JR). Those elements are found not only in the factory management but in any kind of Japanese company regardless of the type of industry.

There are reasons the other side of autonomation among management features of JIT are included. At first, it is sure that autonomation, as a whole, may sound too technical. This is true when it refers only to machines and processes. But when applied to the person of the worker, it loses its technical resonance. An autonomous worker refers only to an officially recognized responsible and trusted worker. Such a worker is not the only one confined in the production shop floor and who deals primarily with machines. The Japanese office worker is also very autonomous because he is given the powers to perform many duties that in other countries are in the sphere of the management authorities. Take, for example, the simple case of student's academic record transcripts. Both in Zaire and in Japan, they bear the stamp and / or signature of the dean. The main difference is that in Zaire the dean signs it himself while in Japan the dean's name is stamped by a clerk.

Significance of the classification

Grasping the nature of JIT components is like understanding the individuals who belong to a community, an approach that helps in dealing with the community one wants to know about. In a similar manner, the comprehension of the nature of the JIT elements (and if possible their internal relationship) should prove an efficient way of:

- grasping JIT as a system itself;
- examining the possibility of its transfer in another environment.

For a number of observers, JIT may look only like a pure production method having little or nothing to do with the surrounding environment. One should, however, keep in mind the fact that it was born and developed neither at a technical research center nor in an engineering department of some university. It took form on a shop floor. And in the shop, the work force and management are the most important role players. In fact, the work force performs its job within and through the company-defined management framework. That is why the work hypothesis has been that JIT as a production system draws many of its elements from three primary sources: industrial engineering, work force (worker's operations) and (Japanese) company management. The different classes of JIT elements are not independent. They are part of the same reality (i. e. JIT), and they are closely related to each other.

In fact, one should have realized that JR and OJT, which have been classified as management-related features, are crucial factors in transforming the line workers into MMM operators.

Closely related to the MMM system is UPL. UPL becomes useful and effective if the work force accepts performing many operations simultaneously. Therefore its success depends also on that of the MMM acceptability by the work force.

On the other hand, the UPL should be viewed as a technical tool of making the MMM system more efficient thanks to the flexibility it offers. It helps increase or decrease the number of processes or machines an operator can simultaneously handle. It can facilitate the checking or recording of the processing lead time of each item because of the fact that the starting and final points may be at the same position. If the work force resists becoming multimachine handlers, UPL would play only the role of a technical ornamentation.

Lessons

There are lessons to draw from the suggested classification of JIT elements. First, JIT pure-engineering elements can be applied efficiently anywhere. Second, both Japanese-management-related and worker's-operations-related features of JIT will not necessarily work in different context, due to their entrenchment in the Japanese socio-cultural environment. Third, due to the complexity of links between all elements of JIT, it seems that even the pure engineering JIT could not be as productive as it is in Japan unless it is accompanied by other JIT elements or equivalently compensated for by local features.

Besides those overall lessons, it is necessary to point to the fact that within each class, JIT elements are linked to each other.

Five observations can be made concerning JIT's pure industrial engineering elements. First, QSU should be considered as having an order of precedence over the other elements especially while dealing with the introduction of JIT. In order not to be trapped by the famous economic lot size, the shortening of the changeover time should be the first thing to realize before starting. Furthermore, it is meaningless for machines to stop themselves in cases of slight malfunctioning or errors if changeovers take many hours. The wise option would be to correct errors by rework. ASD would not pay off, but would backfire if machines are not maintained. Frequent breakdowns and defective occurrences would trigger the autonomation mechanism, which would frequently shut down the entire production line.

Second, though SFR slashed the production lead time by curtailing the transportation time, that would not be so significant if there were no flow of products, and if the products had to go through twistedly complicated ways (absence of FPL). SFR gets more effective as it is sustained by FPL.

Third, BPB makes sense only if the production of defectives is neither allowed nor tolerated. And this is achieved through ASDs such as poka yoke. Otherwise, barriers would be required to check the acceptability of each lot before it moves to or enters another process. Barriers would be necessary as they would fulfill the role of inspection stations.

Fourth, UPL is impossible to realize if barriers between processes are not torn down. Such a layout would be neither useful nor effective if machines and processes are not arranged in the sense of the flow of products. Besides it would be impossible to join different processes to form a U-line if those processes are too far from each other.

Fifth, kanban is effective only if the kanban-controlled production and the kanban itself can flow smoothly between processes. TPM prevents machines from breaking down and/or malfunctioning during the production time and also contributes to the efficiency of kanban.

Though pure IE elements of JIT have been thought of as able to work in any environment, all isolated elements may not. The order of their implementation is crucial. Otherwise, the implementation cannot be brought into fruition. In order to be effective, the kanban needs the QSU. Figure 2 shows clearly that the mass production of mixed models depends on both the implementation of the kanban and QSU. On the other hand, QSU that is aiming neither at the MMM system nor at MMP does not seem necessary. And the kanban without the QSU will result in a failure with devastating effects.

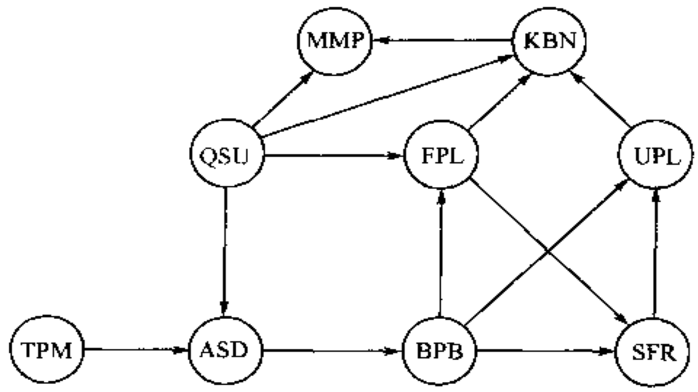


Figure 2. Interconnection between pure IE features

As for workers' operations that are considered JIT elements, it should be noted first that the MMM system and SO are closely associated and their core is the multi-machine handling system. SO can be understood within the MMM system. In fact, SO can be seen as a method, a means for:

- coordinating and harmonizing different actions or operations of a MMM worker;
- synchronizing them with those of other multimachine handling operators working on the same production line.

QCC and SS are the best instances of CI activities. And CI sustains the system dynamics that prevents it from ever being 100 percent satisfied with its own achievements by setting up reasonably unreachable goals such as zero set-up times, zero inventories, zero defects, one-at-a-time processing line, JIT delivery, etc. In such a context, SO are under CI, and the number of machines an operator can handle varies continuously due to CI activities.

Figure 3 shows that QCC and SS contribute to the success of CI. The latter contributes to the multi-machine manning system and SO being effective. At the same time, SO sustains MMM.

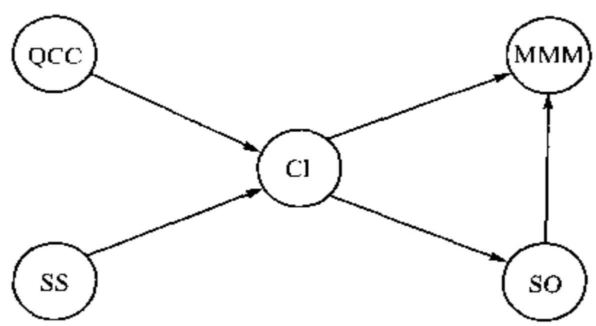


Figure 3. Interconnection between worker operations

For Japanese management elements that have become part of JIT, JR and OJT are directly related. JR could not work if there are no on-the-site-training programs. Besides, removing barriers facilitates JR. And both BAB and JR clarify to workers the fact that an operator can

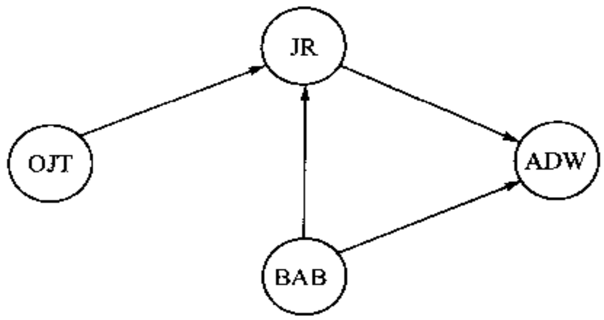


Figure 4. Interconnection between management features

stop the entire processing line while some problem occurs in the process. Other line workers know that if they are in a similar situation they would use the same powers they are given to stop the entire processing line. The interconnections among management features are shown in Figure 4.

Summary

JIT's pure industrial elements seem to make up the core of that production system. However workers' operations and management features that have become JIT elements also play an important role. JIT is a complex reality whose effectiveness depends upon a wide range of parameters.

Should one want to have the full JIT successfully carried out, he has a much harder task, since there are more steps to go through methodically and maybe simultaneously or sequentially. A partial implementation of JIT, say the "technical" JIT, is less demanding and it has more chance of being fruitful because there are fewer steps to undertake. It would, however, have ouly limited results.

In either case, it should be emphasized that skipping a conditioning step may have destructive effects. Switching to the mass production of mixed models would never work and would be costly if there is no quick setup and no defect-free production.

From the practical point of view, the figures can fulfill the role of either instruments for evaluating JIT or instructions for JIT implementation. Why did you succeed or fall, partially or completely, in implementing JIT at your company? The Figures can provide some answers to this question. By showing causal links between JIT elements, the Figures suggest some necessary steps to follow while switching to the JIT production and can prevent or minimize the risk of inadvertently skipping important steps.

Professional Words and Expressions

Just In Time (JIT)	准时制造
Japanese Management	日式管理
Quick Set-Up (QSU)	快速启动
Automation (ASD)	自动化
Poka Yoke or Automatic Stopping Device	自动停线设施

Breaking of Physical Barriers (BPB)	打破物理分隔
Shop Floor Reduction (SFR)	车间缩减
Flow-of-Products-oriented Layout (FPL)	面向产品流动的布局
U-formed Processing Line (UPL)	U 形生产线
Mass Production of Mixed Models (MMP)	混合型号产品的大规模生产
Total Preventive Maintenance (TPM)	全面预防性维护
Kanban (KBN)	看板
Production Lead Time	生产提前期
Defective Part	次品
Work-In-Process	在制品
Multi-Machine Manning Working System (MMM)	多设备配员工作系统
Standard Operations (SO)	操作标准化
Quality Control Circles (QCC)	质量控制圈
Suggestions System (SS)	建议系统
Continuous Improvement (CI)	持续改进
Breaking of Administrative Barriers (BAB)	打破管理界线
Autonomation (ADW)	员工自治(有决定停线的权利)
Job Rotation (JR)	工作轮换,轮岗
On-the-Job Training (OJT)	在线培训,在岗培训
Zero Inventories	零库存
Zero Defects	零缺陷

Notes

They have their origins in the quality control ideas introduced in Japan by Dr. Deming, and in the famous zero defects of NASA.

戴明博士(Dr. W. Edwards Deming, 1900. 10. 14—1993. 12. 20):是近代著名的质量管理大师,1928 年从耶鲁大学获得了数学物理学博士。他是一位教日本人提升品质的美国人。1950 年 7 月,戴明受邀至日本对一群日本企业领导人讲述质量管理的重要性。他的理念鼓舞了日本产业的革新,并进而反过来给了美国经济沉重的打击。他被日本人尊称为"质量之神"。1951 年起,以他的名字命名的戴明奖已被日本企业界视为最高荣誉。

第四篇

工业工程前沿

15 Total Quality Management 全面质量管理

Introduction

Right from the dawn of history, people in all walks of life around the globe have been striving to survive in a highly competitive world. The industrial scenario is no different. Corporate executives have been working overtime to achieve business excellence by striving to find solutions to those problems which have defeated their counterparts in other parts of the globe. The message is amply clear: the gospel of globalization has come to occupy center stage. The focus on price, which hitherto ruled the competition, has shifted to both price and quality. Today, customers are demanding quality in products, services and in life. They have become increasingly discerning and have started looking for options more in tune with their basic needs, requirements and self-esteem. In fact, they are prepared to pay a premium for a quality product or service. One of the approaches that seems to provide the solution to the aforesaid challenges is the management philosophy of total quality management (TQM).

TQM is an approach for continuously improving the quality of every aspect of business life, i. e. it is a never-ending process of improvement for individuals, groups of people and the whole organization. It is an integrated approach and set of practices that emphasizes, *inter alia*, management commitment, continuous improvement, customer focus, long-range thinking, increased employee involvement and teamwork, employee empowerment, process management, competitive benchmarking, etc.

The origin of the TQM movement dates back to the early 20th century when Walter Shewart, in the early 1920s, first introduced the concept of statistical process control (SPC) to monitor quality in mass production manufacturing. This was followed by many quality management gurus and practitioners who all advocated various approaches to TQM. Crosby (1979), the four absolutes, Deming (1986), fourteen points, Feigenbaum (1993), total quality control, Ishikawa (1985), quality control circles, Juran *et al.* (1988), quality triology and Taguchi (1986), loss function, have prescribed different techniques and organizational requirements for effective implementation of TQM.

The evolution of the quality improvement movement is a conglomeration of various Japanese and US philosophies, precepts, strategies and approaches. Even though the Japanese first took the lead in successfully applying the strategy later named TQM in the USA, it is also true that several Americans are recognized internationally as the drivers behind the concept. The genesis of modern management/administrative theory (let alone quality management) had its roots in the manufacturing milieu and blossomed under the auspices of the manufacturing stalwarts right from the early 20th century when Fredrick W. Taylor in 1911, introduced the concept of scientific management. This development can be attributed to the fact that the entire industrial world was predominantly manufacturing oriented and undergoing a revolution with a prime focus on assembly lines, mass production manufacturing, supplier partnerships, just-in-time (JIT) production and cellular manufacturing, etc. Because of these factors, most of the techniques and strategies of administrative theory, and naturally quality management, were quantitative in nature and targeted to address the problems of the production line.

The management of service organizations and marketing of services has been a Cinderella among the organizational behavior and marketing literature in the past, in contrast to the management of manufacturing organizations and marketing of goods. But with the blossoming of the service sector in almost every economy, quality imperatives are no longer the sole concern and province of manufacturing. Of late, service providers are facing the same ground realities that confronted their manufacturing counterparts in the past.

The subject of quality management in manufacturing industry has been a matter of great interest and concern for business and academia alike. Several works have thoroughly investigated the various dimensions, techniques and organizational requirements for effective implementation of TQM. These dimensions include top management commitment and leadership, quality policy, training, product/service design, supplier quality management, process management, quality data and reporting, employee relations, workforce management, customer focus, customer involvement, benchmarking, SPC, employee empowerment, employee involvement, corporate quality culture and strategic quality management. These dimensions are, in essence, tools of the intellect that were forget in the administrative theory, tempered in manufacturing quality management and therefore are naturally expected to be honed to cutting sharpness in service quality management. *Per contra*, though most of these dimensions and other techniques and strategies proposed by various theorists and practitioners, starting from the birth of the quality revolution, seem to provide a near-universal remedy to the problems of the manufacturing business, they are not a complete yardstick for service quality improvement. The reasoning here is that although from a logical point of view most of the dimensions of manufacturing quality management should naturally apply to services, the transferability of manufacturing quality management dimensions to services calls for some serious soul-searching as services differ from the manufacture of goods in a number of different ways: service intangibility, simultaneity of production, delivery and consumption, perishability, variability of expectations of the customers and the participatory role of customers in the service delivery.

Interestingly, the literature on TQM with respect to services, i. e. total quality service (TQS), seems to be bereft of an integrative framework that will include all the critical dimensions of TQS by addressing the issue of possible transferability of manufacturing quality management dimensions to services, and by focusing on those dimensions that are unique to service organizations. The present study attempts to develop a conceptual model of TQS by comparing and contrasting the criticality of the different dimensions of quality management in both manufacturing and service organizations.

The research problem

It is evident that the research literature on manufacturing TQM is quite extensive and exhaustive, covering all the aspects of TQM, viz.

- the critical dimensions of TQM;
- the relationships between quality management practices and organizational /business performance;
- the soft issues (i. e. people oriented issues) of TQM;
- the influence of contextual factors on TQM;
- the relationships between product quality and customers' perceptions of product quality;
- the demarcation between TQM and non-TQM firms;
- the effect of TQM age on operational results, etc.

Concerning the literature on TQS, the various aspects of TQM in service organizations have also been independently subjected to extensive research, e. g.

- customers' perceptions of service quality;
- the concept of 'service culture';
- the critical role of the personnel and HRM function;
- the influence of operational, organizational and human resources factors on service quality;
- the effect of the 'built environment';
- customer satisfaction, loyalty and purchase intentions;

- service switching, service encounters, critical incidents and recovery;
- financial outcomes of service quality initiatives.

The critical dimensions of TQS

The present work, based on the thorough review of the prescriptive, conceptual, practitioner and empirical literature on TQM and TQS spanning over 100 articles, identifies 12 dimensions of quality management as critical for the institution of a TQM environment in service organizations. The dimensions that have been identified are as follows:

- Top management commitment and visionary leadership;
- Human resource management;
- Technical system;
- Information and analysis system;
- Benchmarking;
- Continuous improvement;
- Customer focus;
- Employee satisfaction;
- Union intervention;
- Social responsibility;
- Servicescapes;
- Service culture.

These dimensions can be broadly grouped under three categories as follows:

- Those dimensions of quality management that are generic to both manufacturing and service organizations, but which were initially practiced in the manufacturing set-up and later transferred to service milieu (these include dimensions such as Top management commitment and visionary leadership, Human resource management, Design and management of processes, Information and analysis, Benchmarking, Continuous improvement, Employee satisfaction and Customer focus and satisfaction).
- Those dimensions that are seldom addressed in the literature but are, nevertheless, key elements of TQM in both manufacturing and service organizations (e.g. Union intervention and Social responsibility).
- Finally, those factors that are unique to service organizations (namely, Servicescapes—the man-made physical environment—and Service culture).

Table 1 briefly explains the 12 critical factors of TQS. Several works have underlined the importance of these dimensions. Given the fact that services have certain unique characteristics, the different roles that each of these dimensions play and the various aspects that they bring into the picture (like skills, values, tools, techniques and other requirements) vary from manufacturing to service organizations. Table 2 compares and contrasts the significance and relevance of the various quality management dimensions in manufacturing and service organizations.

Table 1. The critical dimensions of TQS

No. Critical Dimensions	Explanation of the critical dimensions
1. Top management commitment and visionary leadership	Top management commitment is a prerequisite for effective and successful TQS implementation. Although different researchers proclaim various theories on the organizational requirements for effective implementation of TQS, all would agree that the impetus for any quality improvement effort should come from the top. Visionary leadership is the art of leading and espousing a mental, strategic and spiritual change in the organization by the formulation of a long-range vision for the development of the organization, propagating the vision throughout the organization, devising and developing a plan of action and finally stimulating the entire organization towards the accomplishment of the vision
2. Human resource management	This refers to the number of organizational behavior issues (ranging from selection and recruitment, training and education, employee empowerment to employee involvement) that form the cornerstone upon which the corporate strategy is built. The moot point here is that only if the employers treat their employees as precious resources would the employees, in turn, treat their customers as valuable. Therefore, it is indispensable for service organizations to look upon HRM as a source of competitive advantage
3. Technical system	The technical system includes design quality management and process management Sound and reliable service design echoes an organization's strategic quality planning abilities and enables the organization to surmount customers' needs, expectations and desires, consequently resulting in improved business performance Service process management essentially involves the procedures, systems and technology that are required to streamline the service delivery so that customers can receive the service without any hassles, i. e. it delineates the non-human element of service delivery, as opposed to human element which is captured in the dimension 'service culture'
4. Information and analysis system	Services, unlike manufactured goods, cannot be inventoried and used in times of emergency or demand. Therefore, during rush or peak periods, unless organizations keep themselves prepared for any such eventualities, they may not be able to provide quality service to customers. This can only be achieved by equipping the employees with information regarding the process and the customers. Prompt, sufficient and pertinent data that are critical to the implementation and practice of TQM constitute information and analysis. In a TQS ambience people need to communicate across organizational levels, functions and locations to work out current problems, eschew new ones and implement change. Measures for proactive prevention rather than reactive correction are employed to monitor quality in order to sustain a true customer focus

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No. Critical Dimensions	Explanation of the critical dimensions
5. Benchmarking	Benchmarking is actually a comparison standard that consists of analyzing the best products/services and processes of the best organizations in the world and then analyzing and using that information to improve one's own products or services and processes. While in manufacturing, standards such as product characteristics, process, cost, strategy, etc. are used as benchmarks, it is all the more difficult to benchmark services. Because of the very puzzling nature of services and the consequent organizational contingencies that it warrants for its design, production, delivery and consumption, organizations need to focus on benchmarking not only hard data, but also certain behavioral features such as customer satisfaction and employee satisfaction, apart from comparing the services and processes through which they are delivered. An organization can achieve a world-class tag if benchmarking is targeted at the key or critical business processes
6. Continuous improvement	The quest for quality improvement is not a specific destination but a continuous journey that throws up more and more opportunities for improvement. Improvement should be viewed as an ongoing process in the sense once targets are met, new ones must be set, aiming for even higher levels of service efficiency. It is a race which has no finish line but has the sole objective of striving for continuous improvement, and looking for breakthroughs with revolutionary order of magnitude changes that will result in the transmogrification of the organization into a world-class one
7. Customer focus	Customer focus is the ultimate goal of any TQS program because organizations can outscore their competitors by effectively addressing customers' needs and demands and anticipating and responding to their evolving interests and wants. Focusing on customer needs and wants enables organizations to have a better market orientation than ever before by providing a competitive edge over their rivals, thereby resulting in enhanced business performance. In service organizations, as customer expectations are highly dynamic and complex in nature, focusing only on customer-defined areas (specific customer needs) so as to satisfy the customers will not yield fruit. In today's world of intense competition, satisfying customers may not be enough. The competitive advantage in a quality revolution comes only from customer delight. Customer satisfaction is a short-term concept which may or may not lead to commitment. The management's responsibility is to ensure that satisfaction manifests itself as commitment in the long run
8. Employee satisfaction	Employee satisfaction is a multi-dimensional concept, which is defined as the degree to which employees of an organization believe that their needs and wants are continuously satisfied by the organization. An organization must not only have a focus on service quality/customers, but also concentrate on employee satisfaction, as research has shown much evidence of strong relationships between employee perceptions of employee well-being and customer perceptions of service quality and satisfaction

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No. Critical Dimensions	Explanation of the critical dimensions
9. Union intervention	With a major chunk of the workforce in both developed and developing nations working in service organizations, industrial relations issues are as crucial (if not more) as they are in manufacturing industries. As TQM is an organization-wide approach, its success is greatly influenced by its employee union. These employee relations issues affect the organizational system and consequently determine the nature and extent of TQM implementation. And, with the technological growth (in terms of computerization, networking, etc.) gripping the service sector, and the known aversions and apprehensions of the unions towards such advancements, it could be concluded that union attitudes play a critical role in any quality improvement effort
10. Social responsibility	The concept of corporate citizenship should come to the fore if an organization has to be successful and progress towards achieving business excellence. No doubt, a business or industrial enterprise exists to make profits. This can be achieved by fulfilling its mission. At the same time, an organization must also grow and have a good image, i. e. it should meet its social and community obligations. At the end of the day, it is not just the profit or revenue that counts for an organization, but an indomitable belief in corporate responsibility to its society becomes indispensable. With the entire world undergoing an upheaval—a quality revolution—it is this attitude that will certainly give an organization a competitive edge in the long run over many others who vie for greater honors in terms of profits, return on investments (ROI), market share, etc. completely ignoring the fact that they are accountable to the society in which they thrive upon. This subtle, but none the less powerful dimension sends strong signals towards improving the organization's image and goodwill, and consequently effecting the customers' overall satisfaction with the services and their loyalty to the organization
11. Servicescapes	The tangible facets of the service facility, i. e. the man-made physical environment (such as equipment, machinery, signage and employee appearance — the servicescape), strongly influence both employees and customers in physiological, psychological, emotional, sociological and cognitive ways, particularly as the core service becomes more intangible
12. Service culture	In service organizations the boundary separating the customers and employees is very frail and pervious, with the result that the physical and psychological propinquity between them is so intense that only a firm's culture that stresses service quality throughout the organization could establish the seamlessness in the service delivery. Service culture is actually the extent to which the employees at all levels realize that the real purpose of their existence is 'service to customers'. While customer focus is seen as a goal of the TQS movement, service culture is an organizational strategy that motivates the employees to have a service orientation in whatever they do. An organization characterized by such a service orientation is more likely to offer a reliable, responsive, empathetic service to customers and provide them with assurance in conveying trust and confidence that will result in improved quality in service delivery, which, in turn, will lead to higher perceived service quality from the customers' point of view. A strong internal culture helps an organization to effect and sustain an organizational change that will make the TQS approach more effective

Table 2. Significance of the quality management dimensions in manufacturing and service settings

Function/dimension	Manufacturing	Service
Impetus	Top management commitment and visionary leadership	Top management commitment and visionary leadership
Organizational system HRM		
Recruitment and selection	Task-oriented skills, teamwork, technical skills and quality values	Interpersonal relations, teamwork and quality values
Training and education	Hard topics: Accounting, engineering, statistics, etc.	Soft topics: communication skills, interpersonal relations, teamwork, employee behavior and customer service
Employee empowerment	Supporting infrastructure such as required resource and technical assistance, increasing autonomy and responsibility; emphasis on shop-floor workers	Providing power, information, rewards and knowledge; protection of employees in times of their inadvertent and unforeseen behavior during customer service; emphasis on customer contact personnel
Employment involvement	Quality control circles, problem hit squads, quality improvement teams, suggestion schemes, brainstorming, Gordon technique, etc.	Quality control circles, problem hit squads, quality improvement teams, suggestion schemes, brainstorming, Gordon technique, etc.; greater emphasis on employee involvement in service organizations as they run the service operation, market the services and are equated with the service by the customers
Technical system		
Design quality management	Quality function deployment, house of quality, Taguchi's design of experiments, error prevention and zero fault strategy, failure mode effect analysis, poke-yoke, etc.	Error prevention and zero fault strategy; gap analysis; critical incident technique
Process management	Statistical process control, statistical quality control, just-in-time production, cellular manufacturing, six sigma quality, 5S approach, seven old and new tools of quality, etc.	Systematization, standardization, simplification and streamlining of the service delivery processes; Computerization; networking of operations, etc.
Information system	Data related to cost and financial accounting, sales, marketing, purchasing, etc.	Data related to customer satisfaction, service quality and employee satisfaction

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Culture	Though the importance of culture is acknowledged even in the manufacturing literature, the emphasis has been more on technology	Seamlessness in service delivery, moments of truth, critical incident and recovery
Tangibles	Not applicable	Ambient conditions such as temperature, ventilation, noise, odor, etc. signs, symbols, advertisement boards, pamphlets, employee appearance and other artifacts in the organization; physical layout of premises and other furnishings
Social responsibility	Environmental management, ISO 14,000, etc.	Corporate citizenship — to lead as a corporate citizen by promoting ethical conduct in everything the organization does
Industrial relations	Role played by the Union in establishing the policies strategies and procedures of the organization; Union's influence in recruitment, selection and career development programs, and the extent of automation	Role played by the Union in establishing the policies, strategies and procedures of the organization; Union's influence in recruitment, selection and career development programs, and the extent of automation; Union's support and co-operation in the drive for customer focus, quality conscious culture and continuous improvement
Benchmarking	Product characteristics, processes, cost, strategy, etc.	Behavioral features such as customer satisfaction, employee satisfaction and service quality apart from the service product and processes through which they are delivered
Goals		
Customer focus	Though customer satisfaction and employee satisfaction are acknowledged as vital elements of TQM, they are not seen as goals of a TQM process. The focus is on product quality, elimination of defects, conformance to specifications, requirements, reliability, durability, fitness for use, etc.	Customer delight and loyalty, favorable purchase intentions, repeat business, etc. customers are treated as productive human resources, substitutes for leadership and as organizational consultants
Employee satisfaction		Employee satisfaction and commitment—recognition for small as well as big quality contributions and achievements, better behavior, work values, ethics, etc.
Ambience	Continuous improvement	Continuous improvement

Summary

As firms aspire to spread their wings in the global market, TQM promises to provide a potential solution to many of their business-related problems. Though many corporations throughout the globe have already set out on this never-ending odyssey and many others have started exploring what is required in order to embark on a TQM journey, the question of how to start a TQM program is still shrouded in uncertainty. As decision-makers become more involved in implementing TQM, questions are raised about which management practices should be accentuated. This scenario gains even more significance, especially in a service business where the very concept of quality itself is difficult to define.

Professional Words and Expressions

Total Quality Management (TQM)	全面质量管理
Management Commitment	管理承诺
Continuous Improvement	持续改进
Customer Focus	以客户为中心
Employee Involvement	员工参与
Teamwork	团队合作
Employee Empowerment	员工授权
Process Management	流程管理
Benchmarking	标杆超越
Statistical Process Control (SPC)	随机过程控制
Quality Control Circle	质量控制圈
Assembly Line	装配线
Mass Production	大规模生产
Supplier Partnership	与供应商的伙伴关系
Just-In-Time (JIT)	准时生产
Cellular Manufacturing	单元制造
Quality Policy	质量政策
Training	培训
Product/Service Design	产品/服务设计
Supplier Quality Management	供应商质量管理
Employee Relations	员工关系
Customer Involvement	顾客参与
Corporate Quality Culture	企业质量文化
Strategic Quality Management	战略质量管理
Service Intangibility	服务的无形性
Simultaneity of Production	生产的同时性
Perishability	易逝性
Total Quality Service (TQS)	全面质量服务

Notes

1. Right from the dawn of history, people in all walks of life around the globe have been striving to survive in a highly competitive world. The industrial scenario is no different.
有史以来,全世界所有的人就在这个高度竞争的世界中奋斗。工业界也同样如此。
2. The genesis of modern management/administrative theory (let alone quality management) had its roots in the manufacturing milieu and blossomed under the auspices of the manufacturing stalwarts right from the early 20th century when Fredrick W. Taylor in 1911, introduced the concept of scientific management.
现代管理理论(更不用说质量管理理论)起源于制造环境,并以从 20 世纪早期(1911 年)弗雷德里克·泰勒引入科学管理理念以来的制造业健康发展为前兆走向繁荣与发展。
3. *Per contra*, though most of these dimensions and other techniques and strategies proposed by various theorists and practitioners, starting from the birth of the quality revolution, seem to provide a near-universal remedy to the problems of the manufacturing business, they are not a complete yardstick for service quality improvement.
相反,尽管上述的由各种理论家和实践者从质量革命以来所倡导的大部分理论和相关技术和策略似乎可以提供解决制造领域(质量)问题的灵丹妙药,但它们并不能作为服务业质量改善的完全标准。

16 Agile Manufacturing
敏捷制造

Introduction

Businesses are restructuring and re-engineering themselves in response to the challenges and demands of the 21st century. The 21st century business will have to overcome the challenges of customers seeking high-quality, low-cost products, and be responsive to customers' specific unique and rapidly changing needs. Agile enterprises represent a global industrial competition mode for 21st century manufacturing. "Agility" addresses new ways of running companies to meet these challenges. In a changing competitive environment, there is a need to develop organizations and facilities that are significantly more flexible and responsive than existing ones.

Agility requires the capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services. The key enablers of agile manufacturing include: (i) virtual enterprise formation tools/metrics; (ii) physically distributed manufacturing architecture and teams; (iii) rapid partnership formation tools/metrics; (iv) concurrent engineering; (v) integrated product/production/business information system; (vi) rapid prototyping; (vii) electronic commerce.

Agile manufacturing is a vision of manufacturing that is a natural development from the original concept of 'lean manufacturing'. In lean manufacturing, the emphasis is on the elimination of waste. The requirement for organizations and facilities to become more flexible and responsive to customers led to the concept of 'agile' manufacturing as a differentiation from the 'lean' organization. This requirement for manufacturing to be able to respond to unique demands moves the balance back to the situation prior to the introduction of lean production, where manufacturing had to respond to whatever pressures were imposed upon it, with the risks to cost, speed and quality. Agility should be based on not only responsiveness and flexibility, but also the cost and quality of goods and services that the customers are prepared to accept. It is, however, essential to link agile capabilities in manufacturing with product needs in the marketplace. Agility as a concept increases the emphasis on speed of response to new market opportunities. Thus, it is more relevant to a One-of-a-Kind Product (OKP) than it is to commodity products that compete primarily on price.

Agile manufacturing — definitions

In this section, we explore a variety of definitions and a range of concepts with the objective of developing a new and feasible concept of AM. The reason for analyzing the present conceptions and definitions of AM is to identify the gap between practice and theory in order to enhance the confidence of practitioners. Manufacturing processes based on agile manufacturing are characterized by customer integrated processes for designing, manufacturing, marketing, and support for all products and services; decision-making at functional knowledge points; stable unit costs; flexible manufacturing; easy access to integrated data; and modular production facilities. The focus is on the integration of critical functional areas with the help of advanced design and manufacturing technologies, and alignment between strategies.

Table 1. A summary of agile definitions and key concepts

Authors	Definition	Keywords
DeVor and Mills (1995)	Ability to thrive in a competitive environment of continuous and unanticipated change and to respond quickly to rapidly changing markets driven by customer-based valuing of products and services	A new, post-mass production systems for the creation and distribution of goods and services
Booth (1996), McGrath (1996)	More flexible and responsive	Moving from lean to agile
Adamides (1996)	Responsibility-based manufacturing (RBM)	Most adjustments for process and product variety to take place dynamically during production without *a priori* system reconfiguration
Gupta and Mittal (1996)	Agile stresses the importance of being highly responsive to meet the 'total needs' of the customer, while simultaneously striving to be lean. Agile places a higher priority on responsiveness than cost-efficiency while a manufacturer whose primary goal is to be lean compromises responsiveness over cost-efficiencies	Integrates organizations, people, and technology into a meaningful unit by deploying advanced information technologies and flexible and nimble organization structures to support highly skilled, knowledgeable and motivated people
James-Moore (1996), Kidd (1996), Gould (1997)	More flexible and responsive than current	New ways of running business, casting off old ways of doing things
Hong *et al.* (1996)	Flexibility and rapid response to market demands	Flexible technologies such as Rapid Prototyping, Robots, Internet, AGVs, CAD/CAE, CAPP and CIM, FMS
Abair (1997)	Provides competitiveness	Customer-integrated process for designing, manufacturing, marketing and support, flexible manufacturing, cooperation to enhance competitiveness, organizing to manage change and uncertainty and leveraging people and information

续表

Authors	Definition	Keywords
Kusiak and He (1997)	Driven by the need to quickly respond to changing customer requirements	Demands a manufacturing system to be able to produce efficiently a large variety of products and be reconfigurable to accommodate changes in the product mix and product designs, Design for assembly
Gunasekaran	Capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets	Virtual Enterprise, E-Commerce, Strategic Partnership formation, and Rapid prototyping
Cho *et al.*, (1996), Gunasekaran (1999a), Yusuf *et al.* (1999)	Capability for surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets	Standard Exchange for Product (STEP) models, Concurrent Engineering, Virtual Manufacturing

According to Gupta and Mittal (1996), AM is a business concept that integrates organizations, people and technology into a meaningful unit by deploying advanced information technologies and flexible and nimble organization structures to support highly skilled, knowledgeable and motivated people. 'Lean' implies high productivity and quality, but it does not necessarily imply being responsive. 'Agile', on the other hand, stresses the importance of being highly responsive to meet the 'total needs' of the customer, while simultaneously striving to be lean — a manufacturer whose primary goal is to be lean compromises responsiveness over cost-efficiencies. Agile manufacturers place equal importance on both cost and responsiveness. This is the main reason for incorporating cost and quality into agile competitive bases.

Agile manufacturing can be said to be a relatively new, post-mass-production concept for the creation and distribution of goods and services. It is the ability to thrive in a competitive environment of continuous and unanticipated change and to respond quickly to rapidly changing markets driven by customer-based valuing of products and services. It includes rapid product realization, highly flexible manufacturing, and distributed enterprise integration. DeVor and Mills (1995) argue that technology alone does not make an agile enterprise. Companies should find the right combination of strategies, culture, business practices, and technology that are necessary to make it agile, taking into account the market characteristics.

As stated before, agile manufacturing is driven by the need to respond quickly to changing customer requirements. It demands a manufacturing system that is able to produce effectively a large variety of products and to be reconfigurable to accommodate changes in the product mix and product designs. Manufacturing system reconfigurability and product variety are critical aspects of agile manufacturing. The concept of agility has an impact on the design of assemblies. To implement agile manufacturing, methodologies for the design of agile manufacturing are needed. Design for agile assembly is accomplished by considering the operational issues of assembly systems at the early product design stage.

According to Tu (1997), the manufacturing industry, particularly the OKP (One-of-a-Kind Production) industry, tends to be lean, agile and global. This tendency leads to a new concept of a virtual company that consists of several subproduction units geographically dispersed in the world as branches, joint ventures and subcontractors. Many OKP companies, such as those in shipbuilding have become virtual companies. For these virtual companies, traditional production control and management systems, methods and theories do not satisfy their needs for production planning and control. For some companies, therefore, there is a need to be transformed into a virtual enterprise in order to become agile. However, selecting partners based on flexibility and responsiveness alone will not lead to a reduction in cost and an improvement in the quality of products and services. A much wider spectrum of factors needs to be taken into account.

Agile manufacturing is an expression that is used to represent the ability of a producer of goods and services. The changes needed for agile manufacturers to thrive in the face of continuous change can occur in markets, in technologies, in business relationships and in all facets of the business enterprise. Such changes, according to Kidd (1996), are not about small-scale continuous improvements, but an entirely different way of doing business. Agile manufacturing requires one to meet the changing market requirements by suitable alliances based on core-complementary competencies, organizing to manage change and uncertainty, and leveraging people and information.

The analyses of various definitions and concepts of AM (see Table 1) shows that all these definitions are polarized in a similar direction. Most definitions and concepts seem to highlight flexibility and responsiveness as well as virtual enterprises and information technologies. However, the question is whether one can achieve agility with minimum investment in technologies and processes. Hence, there is a need to redefine the definition of agility within this context. Figure 1 presents the new model for explaining the agile manufacturing paradigm. The model takes into account the characteristics of the market, infrastructure, technologies and strategies. Its purpose is to highlight the new dimension of the definition of the agile manufacturing paradigm. The justifications for the need to redefine the agility are listed below.

- In some cases, flexibility and cost are not complementary. Yet, there is a need to consider the *cost* aspects of agility. Agility without cost effectiveness is not a real competitive strategy. Therefore, there is a need to consider cost in defining agility.
- The implications of technologies in achieving agility are paramount compared with

partnership formation that is based on core competencies in a virtual enterprise. For certain businesses one needs to identify a set of technologies that are more important to the selected market segments, and to product and service requirements. Yet, the implications of integrating complementary core competencies are highly significant. A lack of focus on utilizing core competencies would not improve productivity and quality.

- The nature of a given market certainly defines the characteristics of agile organizations. No organizations can satisfy unlimited product/service requirements of different markets. The characteristics of markets may vary from industry to industry and from country to country.
- The implications of e-commerce have not been properly addressed in the development of agile manufacturing systems. Direct input from customers, the reduction in response time and the cost of identifying market requirements using Concurrent Engineering principles would certainly reduce the gap between marketing and production.
- Human resources play a significant role in the development of agile manufacturing systems. However, the issue of an agile workforce has not been well addressed. It is still not clear how the agility of the workforce and its characteristics can be defined with reference to changing market requirements and value-adding systems.
- Logistics play an important role, especially in physically distributed virtual enterprises. Therefore, due attention should be paid to the effective management of logistics and, in turn, to supporting agility in manufacturing.

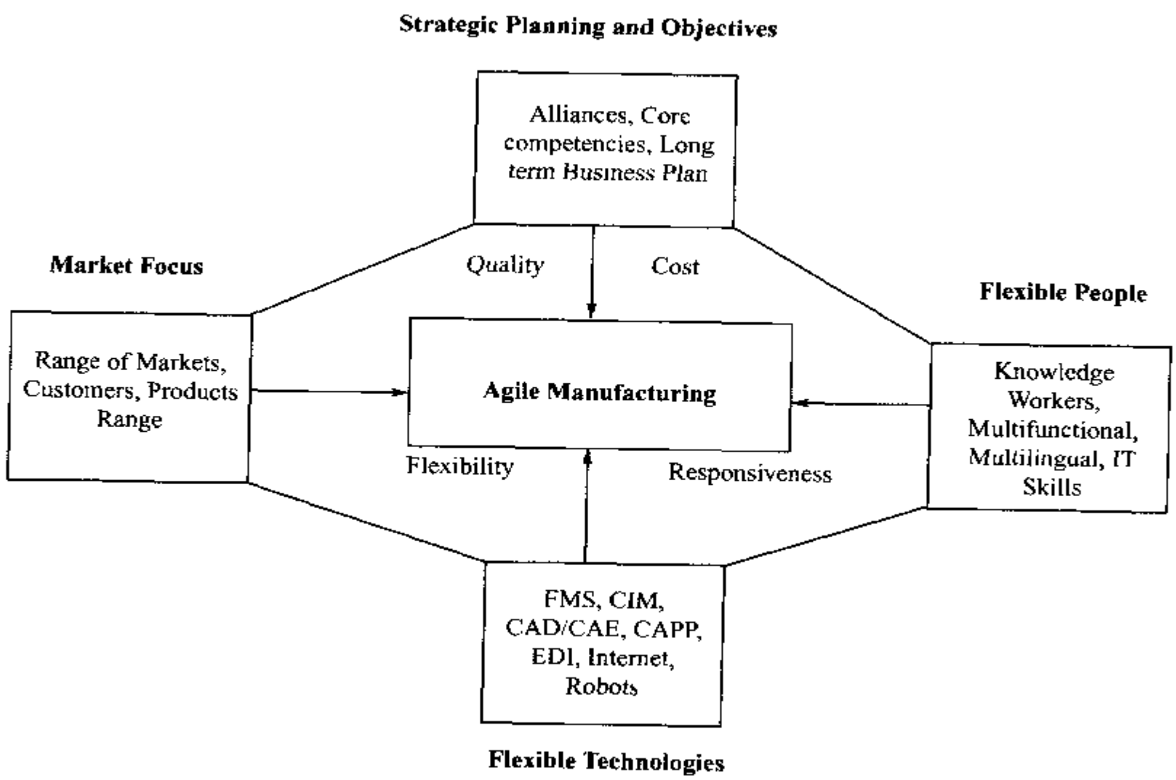

Figure 1. Agile manufacturing paradigm

Based on some of these observations, agility in manufacturing may be defined as: The capability of an organization, by proactively establishing virtual manufacturing with an efficient product development system, to (i) meet the changing market requirements, (ii) maximize customer service level and (iii) minimize the cost of goods, with an objective of being competitive in a global market and for an increased chance of long-term survival and profit potential. This must be supported by flexible people, processes and technologies.

Agile manufacturing strategies and technologies

Analyzing the overall characteristics of strategies and technologies, the literature available on AM can be grouped under the following themes: (i) strategic planning, (ii) product design, (iii) virtual enterprise, and (iv) automation and Information Technology (IT). The details of the classification are illustrated in Figure 2. Achieving agility may require focusing on strategic planning, product design, virtual enterprise and automation and IT.

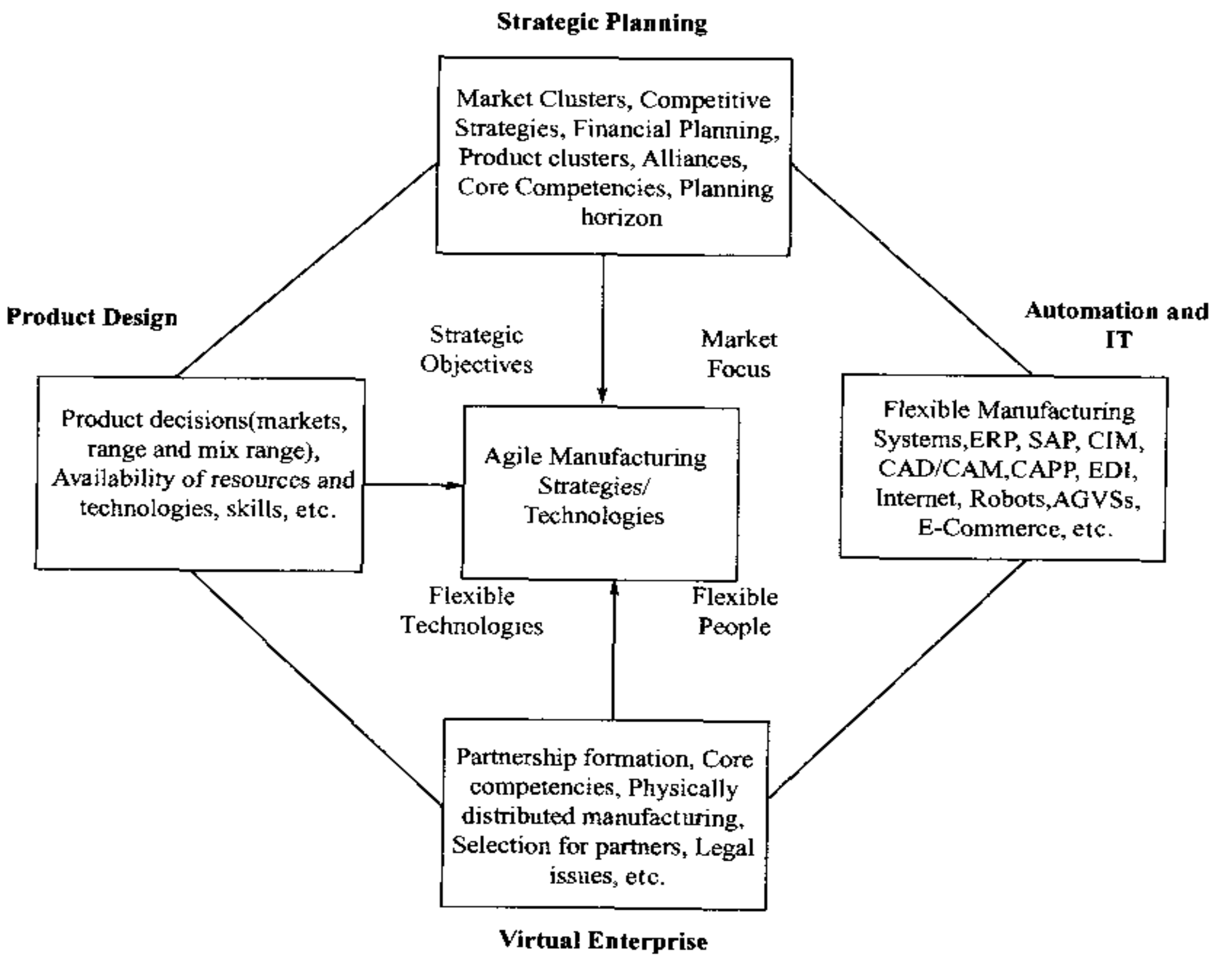

Figure 2. Agile manufacturing strategies/techniques

A framework for the development of agile manufacturing

The framework proposed here constitutes the following major strategies and technologies for achieving agile manufacturing:

- Partnership formation and supplier development;
- IT in manufacturing;
- Enterprise Integration and Management with the help of advanced IT/IS;
- Virtual reality tools and techniques in manufacturing;
- The application of most of the advanced manufacturing concepts and technologies, such as Computer-Integrated Manufacturing/Services, Manufacturing/Service Strategy, Enterprise Integration, Rapid Prototyping, CE, New Product Development, BPR, Systems Design and Operations and SCM;
- Global manufacturing/service perspectives (physically distributed manufacturing environments) with the help of IT, such as E-Commerce, ERP, SAP, Internet, WWW, CAD/CAM, Simulation, Multimedia and MRPII.

Summary and conclusions

In this paper, an attempt has been made to review the literature on AM with the aim of revising the outlook for agility in manufacturing and identifying corresponding major strategies and technologies of AM. In addition, a framework has been offered in the paper to develop an AMS.

Two key characteristics of manufacturing companies discussed in this paper are 'Agility'— the ability of a company to effect changes in its systems, structure and organization — and 'Responsiveness'— the ability of a company to gather iuformation from its commercial environment and to detect and anticipate changes, to recover from changes and to improve as a result of change. Manufacturing companies, even those operating in relatively stable conditions with good market positions, are facing fast and often unanticipated changes in their commercial environment. Being agile in such environments means being flexible, cost effective, productive and producing with consistent high quality. Each company will respond in a specific and different way deploying its own agile characteristics. The problem of identifying, analyzing and evaluating agility is that no commonly accepted practical frame of referencc or analytical structure exists.

The literature available on an AM workforce is rather limited. The reason for this is that there is no clear-cut framework for identifying the implications of AM on workforce characteristics, and most of the literature deals with enabling technologies and some strategies of AM. However, human factors play a significant role in the successful development and implementation of AM. The key issues of human factors that need to be considered in agile environment are knowledge workers, multilingual workforce, multinational workforce, incentive schemes, type and level of education and training, relation with unions, and pay award. Most of the available systems (control and information) are developed for traditional manufacturing environments where a static market behavior and resources have been employed for producing goods and services. The support systems for AMS rely heavily on computer-based information systems such as EDI, Internet and Electronic Commerce. Therefore, a flexible architecture for systems to accommodate temporary alliances will help improve enterprise integration and hence agility in organizations.

The following is the summary of issues that should be addressed in an attempt to fully embrace agile manufacturing: (i) the implications of temporary alliances on the enterprise communication and coordination, (ii) the influence of a virtual enterprise and physically distributed manufacturing on human relations management, and (iii) the technologies and human skills required for the information intensive manufacturing environment. Agile Manufacturing/Service requires multidisciplinary skills, which include manufacturing management, computer science, operational research, software engineering, systems design, sensors, mechatronics, robotics, systems integration, virtual manufacturing /services, enterprise integration and management and Advanced Information Technologies. The major problems that need most attention in the development of AM are: (i) modeling of evolutionary and concurrent product development and production under a continuous customer's influence; (ii) real-time monitoring and control of the production progress in virtual OKP; (iii) a flexible or dynamic company control structure to cope with uncertainties in the market; (iv) an adaptive production scheduling structure and the algorithms to cope with the uncertainties of a production state in virtual OKP; (v) modeling of production states and a control system in virtual OKP; and (vi) the reference architecture for a virtual OKP company.

Professional Words and Expressions

Agile Manufacturing	敏捷制造
Agile Enterprise	敏捷企业
Virtual Enterprise	虚拟企业
Concurrent Engineering	并行工程
Rapid Prototyping	快速原型
Electronic Commerce	电子商务
Reconfigurability	可重组性,可重塑性
Supplier Development	供应商开发
Virtual Reality	虚拟现实
Computer-Integrated Manufacturing/Services	计算机集成制造/服务
Manufacturing/Service Strategy	制造/服务战略
Enterprise Integration	企业集成
New Product Development	新产品开发

Business Process Reengineering (BPR)	企业流程再造
Systems Design and Operations	系统设计和运作
Supply Chain Management (SCM)	供应链管理
Enterprise Resource Planning (ERP)	企业资源规划
Simulation	仿真
Manufacturing Management	制造管理
Computer Science	计算机科学
Operational Research	运筹学
Software Engineering	软件工程
Systems Design	系统设计
Mechatronics	机械电子学
Robotics	机器人
Systems Integration	系统集成
Virtual Manufacturing/Services	虚拟制造/服务
Advanced Information Technologies	先进信息技术

Notes

1. Agile manufacturing is a vision of manufacturing that is a natural development from the original concept of 'lean manufacturing'.
   敏捷制造是在精益制造原始概念基础上自然发展起来的一个对未来制造业的展望。
2. This requirement for manufacturing to be able to respond to unique demands moves the balance back to the situation prior to the introduction of lean production, where manufacturing had to respond to whatever pressures were imposed upon it, with the risks to cost, speed and quality.
   对顾客独特需求迅速响应能力的要求使得制造企业运作重点的权衡又回到了精益制造出现前的情形,即企业不得不在冒着成本、速度和质量等风险的情况下对其所面临的各种压力做出响应。
3. 'Lean' implies high productivity and quality, but it does not necessarily imply being responsive.
   "精益"意指高生产率和质量,但并不一定指迅速应变的能力。

17 Theory of Constraints
约束理论

Introduction

Since The Goal first appeared in print (Goldratt and Cox 1984), the concepts introduced and collectively termed as "constraint management" or the "Theory of Constraints (TOC)" have drawn a wide range of responses from practitioners as well as from academicians. This has been particularly true in the academic world. There is a plethora of research published in the scientific literature that compares and contrasts constraints management ideas with existing production management tools and concepts such as linear programming, material requirements planning, just-in-time (JIT) and, lately, with lean manufacturing, supply chain management and six sigma.

Dr. Goldratt has long argued that production management has now become a science and that TOC research provides a scientific knowledge base. TOC has evolved from a manufacturing scheduling method to a management philosophy that can be used to understand and improve the performance of complex systems. Thus, he claimed that TOC is a theory of managing manufacturing organizations.

Judging by the large amount and wide range of the academic literature in the past few years, the TOC manufacturing management philosophy appears to be attracting an increasing amount of attention from both the academic and business communities. The number of researchers working in the area of TOC has increased quite dramatically as can be seen from the variety of scientific journals (e.g. International Journal of Production Research, Production and Operations Management Journal, International Journal of Operations and Production Management, Production and Inventory Management Journal) and conferences (e.g. The TOC World Conference organized by the Avraham Y. Goldratt Institute (AGI) and academic conferences organized by the Production and Operations Management Society, and Decision Sciences) where TOC research has been published and presented on a regular basis.

Historical background and basic concepts of TOC

The papers represent an addition to the large and growing body of TOC literature. The roots of TOC can be traced to the development of a commercial software product known as Optimized Production Technology (OPT) in the late 1970s. Since then, Goldratt and many other independent scholars have published a number of business novels and other books, operations management (OM) textbooks have begun to incorporate a complete chapter on TOC, suggesting that TOC is gaining acceptance and popularity among both academics and practitioners. A number of success stories have been reported and analyzed in the literature to suggest significant improvements. For example, Mabin and Balderstone (2000) concluded from their survey of over 100 published case studies in various industries such as automotive, semiconductor, furniture and apparel that, on average, inventories were reduced by 49%, production times measured in terms of lead times, cycle times or due date performance improved by over 60%, and financial performance improved by 60%. A significant number of journal articles have been written (i) to trace the history of OPT as well as TOC, (ii) to review the basic concepts of TOC, (iii) to categorize TOC concepts and terms, (iv) to review TOC literature and (v) to demonstrate its applications in various areas such as supply chain management, enterprise resource planning, sales and marketing, and human resource management.

In summary, the TOC has two broad viewpoints: that of the business system and of an ongoing improvement process itself. Both perspectives of TOC use unique terminology to describe its basic concepts.

Business system perspective

As it applies to the business system, the TOC emphasizes change process implemented at three levels: the mindset of the organization, the measures that drive the organization and the methods employed within the organization.

One of the main assumptions of TOC theory is that every business has the primary goal of "making more money now as well as in the future" without violating certain necessary conditions. Two examples of such conditions are (i) providing a satisfying work environment to employees and (ii) providing satisfaction to the market. This mindset stipulates that the organization should devote its energy to promote initiatives, e.g. exploring new markets and introducing new products (popularly termed as "throughput world thinking") by using the available resources instead of expending energy to reduce costs or save money, which invariably violates necessary condition(s). Further, this mindset emphasizes the management focus on high leverage points to ensure the financial success of the organization as a whole (i.e. synchronization of the flow among individual processes or functional areas).

The TOC measurement system was developed with an eye towards evaluating the effectiveness of decisions in helping to achieve the primary goal. The system consists of a set of global operational measures (i.e. throughput, inventory and operating expenses) to determine the extent to which the organization is accomplishing the goal. Table 1 has a brief description of these measures. These operational measures are (i) financial in nature, i.e. they can be translated to conventional measures such as net profit, return-on-investment, (ii) are easy to apply at any level of an organization and (iii) ensure that local decisions are aligned with the profit goal of an organization. Of the three measures, TOC views throughput as having the greatest effect on profitability. The emphasis on increasing throughput is referred to as "throughput world thinking", which usually stands in marked contrast to the "cost world thinking" which emphasizes reducing cost (via operating expenses or even inventory).

Table 1. Measure of the theory of constraints

① Throughput (T) is defined as "the rate at which the system generates money through sales". More specifically, it is the selling price minus totally variable costs (i.e. the money not generated by the system, e.g. purchased parts and raw materials).
② Inventory (I) is defined as "all the money invested in purchasing things the system intends to sell". More specifically, it is synonymous with investments such as machines, equipment, etc., and finished goods and work-in-process inventory is reported at the raw material costs, i.e. the value-added component is not recognized.
③ Operating expenses (OE) is defined as "all the money the system spends in turning inventory into throughput". More specifically, it includes wages, salaries, utility expenses, depreciation, etc.
Relationship to standard financial measures • Net profit (NP) = T - OE. • Return on investment (ROI) = (T - OE)/I.
Relationship to standard financial measures • Inventory turns (IT) = T/I. • Productivity ratio (PR) = T/OE.

With a mindset established and a measurement system in place to evaluate the impact of decisions on the goal, the third aspect is a decision-making methodology for continuously improving an organization. TOC states that every business system has at least one constraint (or at most very few). According to Umble and Srikanth (1997), "any specific area, aspect, or process that limits the business performance from a customer, competitive, or profit point of view is a constraint". Constraints can be physical, such as a machine center or lack of material, but they can also be managerial, such as a policy or procedure. Goldratt proposed a five focusing steps (FFS) process for managing constraints and continuously improving an organization. Table 2 briefly summarizes them. Inherent in this FFS process are the concepts of V-A-T process structure analysis, drum-buffer-rope and buffer management (described in Table 3), which are used to describe/analyze the process, develop the constraint's schedule and manage buffer inventories respectively within an organization.

Table 2. Five focusing steps of process improvement

① IDENTIFY the system's constraint(s), whether physical or policy constraint.
② Decide how to EXPLOIT the system's constraint(s), i. e. get the most possible from the limit of the current constraint(s); reduce the effects of the current constraint(s); and make everyone aware of the constraint(s) and its effects on the performance of the system.
③ SUBORDINATE everything else to the above decision, i. e. avoid keeping non-constraint resources busy doing unneeded work.
④ ELEVATE the system's constraint(s), i. e. off-load some demand or expand capability.
⑤ If in the previous steps a constraint has been broken, go back to Step 1, but do not allow INERTIA to cause a system constraint

Table 3. Glossary of TOC-based operational terms

① V-A-T analysis: a constraint management procedure for determining the general flow of parts and products from raw materials to finished products (logical product structure). A V logical structure starts with one or a few raw materials, and the product expands into a number of different products as it flows through its routings. The shape of an A logical structure is dominated by converging points. Many raw materials are fabricated and assembled into a few finished products. A T logical structure consists of numerous similar finished products assembled from common assemblies and subassemblies. Once the general parts flow is determined, the system control points (gating operations, convergent points, divergent points, constraints, and shipping points) can be identified and managed.
② Drum-buffer-rope: the generalized technique used to manage resources to maximize throughput. The drum is the rate or pace of production set by the system's constraint. The buffers establish the protection against uncertainty so the system can maximize throughput. The rope is a communication process from the constraint to the gating operation that checks or limits material released into the system to support the constraint. Buffers can be time or material and support throughput and/or due date performance. Buffers can be maintained at the constraint, convergent points (with a constraint part), divergent points and shipping points.
③ Buffer management: a process in which all expediting in a shop is driven by what is scheduled to be in the buffers (constraint, shipping and assembly buffers). By expediting this material into the buffers, the system helps avoid idleness at the constraint and missed customer due dates. In addition, the causes of items missing from the buffer are identified, and the frequency of occurrences is used to prioritize improvement activities.

Ongoing improvement process perspective

From the perspective of an ongoing improvement process, TOC suggests that an organization must ask three fundamental questions concerning change to accelerate its improvement process: (i) What to change, i. e. how do organizations identify the weakest link, i. e. the constraint(s)? (ii) To what to change, i. e. once the weakest link is identified, how should organizations strengthen it by developing practical and good solutions? and (iii) How to cause the change, i. e. how should organizations implement the solutions?

Though these three questions are not new, Goldratt and his associates have developed a set of techniques (Table 4) known as the thinking processes to address them. The process begins with an identification of a set of undesirable effects (UDEs), i. e. symptoms of a system to be improved. A current reality tree (CRT) connects various UDEs systematically by following the effect-cause-effect diagramming principles and diagnoses what in the system needs to be changed, i. e. what is the core problem. The evaporating cloud (EC) verbalizes the inherent conflict, surfaces the assumptions and provides a mechanism to come up the ideas, which can be used to resolve the core problem. The future reality tree (FRT) takes the ideas from EC and ensures the new reality created would resolve the UDEs without creating any new UDEs. The prerequisite tree (PrT) identifies obstacles to implementation of new ideas and determines intermediate objectives to overcome the obstacles. Finally, the transition tree (TrT) is used to create a step-by-step implementation plan. These tools of the thinking processes can be used as a set of integrated tools to address the specific phase of change management process or as stand-alone tools to address specific aspects of the problem.

Table 4. Tools of thinking processes

Thinking processes	Tools and diagnosis
What to change?	Current reality tree: Why is the system sick?
What to change to?	Evaporating cloud: What conflict is preventing the cure? Future reality tree: Will the injection lead to all desired effects without creating new undesirable effects?
How to cause change?	Prerequisite tree: What currently prevents the implementation of the injections? Transition tree: What actions does the initiator have to take to implement the cure effectively?

Recently, new and successful applications in the areas of distribution, sales/marketing, project management and strategic planning have been demonstrated. Furthermore, the tools of thinking processes have been used to enhance the successful implementation of specific TOC applications.

Issues and research opportunities

Pedagogical perspective

Most of the standard OM textbooks discuss some concepts of TOC, specifically the scheduling of constraint resources. Recently, the OM textbooks have begun to incorporate a complete chapter on TOC summarizing the main concepts. However, if TOC has indeed evolved from a production scheduling technique into an OM philosophy, then its implications for the gamut of OM topics must be discussed and elaborated. Indeed, although the business novels The Goal (Goldratt and Cox 1984), It's Not Luck (Goldratt 1994), Critical Chain (Goldratt 1997) and Necessary But Not Sufficient (Goldratt 2000) provide excellent means to introduce TOC concepts and principles, it is still not clear how best to integrate TOC with conventional OM topics. Various questions still need to be addressed. Should TOC be taught as an important topic of OM (i. e. about 5% ~20% of the time spent to cover TOC contents)? Should TOC be integrated throughout a typical OM course (i. e. about 20% ~50% of the time spent to cover TOC contents)? Should TOC be taught as a stand-alone course in OM (i. e. about 50% ~ 100% of the time spent to cover TOC contents)?

Based on our experience and interaction with OM instructors at the Production and Operations Management Society and Decision Sciences Institute conferences, it appears that only a handful of universities are teaching a complete course with the title "Theory of Constraints" or "Constraints Management", although many are teaching TOC concepts in courses under the labels: "Operations Management" (to a great extent), "Total Quality Management" (to some extent) and "Supply Chain Management" (an evolving possibility). It appears that a more formal survey needs to be performed to identify the alternative ways to integrate TOC topics into core curricula. Regardless of the percentage of time spent to cover TOC concepts in business (and engineering) schools, it appears that a framework to introduce TOC concepts/principles with relevance to OM needs to be developed, evaluated and published to create awareness among academicians.

Research perspective

A quick review of the literature reveals that two main sources of references exist: Rahman (1998) and Mabin and Balderstone (2000). Rahman (1998) is the only comprehensive TOC literature review article in a peer-reviewed journal that has attempted to classify the TOC literature and propose guidance for future research. The paper reviewed TOC publications in refereed and non-refereed journals, conference proceedings, and books between 1980 and 1995, and used a classification framework consisting of three categories: TOC philosophy, TOC application and TOC books. Rahman found that a large number of TOC articles were published in practitioner-oriented production journals (e.g. Production and Inventory Management Journal) and management accounting journals (e.g. Management Accounting, UK and USA), which primarily focused on the concepts and principles of TOC. He also found that several articles (i) compared TOC with other production methods (e.g. MRP, JIT) and management accounting methods (e.g. ABC/M) and (ii) referred to the applications of TOC in actual business settings. The paper found very little TOC research done in the service sector. However, this study did not investigate the TOC literature to discuss implications for various production management decisions (e.g. product-process design, production planning and scheduling, inventory management, quality management and control, and continuous process improvement). Moreover, since 1995, a significant amount of research has appeared in refereed production management journals. This new research needs to be reviewed, classified and synthesized to provide researchers with guidance on directions.

The book by Mabin and Balderstone (2000) is probably the most comprehensive catalogue of TOC literature. The authors have provided keywords and a brief summary of each reference as well as various indices to facilitate searches for TOC literature by author, subject, source (e.g. journal, magazine), industry and publisher. This study did not investigate the TOC literature to discuss implications from an OM point of view or suggest future directions for research.

Although a comprehensive literature review must be done to highlight significant contributions made by specific articles, we would like to make few observations. First, TOC research stresses improvement in organizational performance instead of functional improvement and thus has implications across major functional areas such as accounting, marketing and strategy. Second, early TOC research focused on understanding and illustrating the production planning and scheduling principles of TOC that formed the basis for the TOC-based software referred to as OPT and subsequently explained as basic concepts of TOC in the popular novel, The Goal. Third, a vast amount of research effort has been expended to compare TOC with (i) traditional management and total quality management, (ii) traditional management accounting and activity-based costing, (iii) material requirement planning and JIT systems and (iv) linear programming. Fourth, TOC has the potential to be established as a useful production management theory by developing and testing important research questions. Unlike other theories reported in the production management literature such as trade-off theory, the cumulative theory and the theory of production competence, the TOC is much more comprehensive and widely applicable across the production function. However, the theory of CM has not been empirically developed and tested, which is required if it is to be accepted as a general theory in production management.

Professional Words and Expressions

Constraint Management	约束管理
Theory of Constraints (TOC)	约束理论
Optimized Production Technology (OPT)	最优生产技术
Throughput	产销率
Inventory	库存
Operating Expenses	运作费用
Net Profit	净利润
Return-On-Investment (ROI)	投资收益率
Cash Flow	现金流量
V-A-T process structure analysis	(企业的)VAT 流程结构分析
Drum-Buffer-Rope (DBR)	鼓－缓冲器－绳子
Buffer Management	缓冲器管理
Thinking Process (TP)	思维流程
Negative Branches	负效应枝条
Undesirable Effects (UDEs)	不良效果
Current Reality Tree (CRT)	当前现实树
Evaporating Cloud (EC)	消雾法
Future Reality Tree (FRT)	未来现实树
Prerequisite Tree (PrT)	必备树
Transition Tree (TrT)	转变树

Notes

1. Since The Goal first appeared in print (Goldratt and Cox 1984), ... from practitioners as well as from academicians.

《目标》是一本奇特而有趣的书。其作者高德拉特博士原本是物理学家，但却以这本用小说体裁撰写的关于企业经营与管理密切关系的专著而闻名。该书已经销售 300 多万册并且被翻译为 23 种语言，同时使得瓶颈管理理念风行全球。

2. TOC has evolved from a manufacturing scheduling method to a management philosophy that can be used to understand and improve the performance of complex systems.
约束理论已经从一种制造调度方法发展成为可以用来理解和改善复杂系统绩效的管理哲学。

3. One of the main assumptions of TOC theory is that every business has the primary goal of "making more money now as well as in the future" without violating certain necessary conditions.
约束理论的重要假设之一是商业组织最主要的目标为在不违反特定的必要约束情况下在现在和将来赚更多的钱。

4. Throughput (T) is defined as "the rate at which the system generates money through sales".
产销率被定义为"系统通过销售来赢利的速度"。

5. Inventory (I) is defined as "all the money invested in purchasing things the system intends to sell".
库存被定义为"系统用于购买生产最终产品所需资源上的投资"。

6. Operating expenses (OE) is defined as "all the money the system spends in turning inventory into throughput".
运作费用被定义为"将库存转化为产销率过程中的所有花费"。

7. Indeed, although the business novels The Goal (Goldratt and Cox 1984), It's Not Luck (Goldratt 1994), Critical Chain (Goldratt 1997) and Necessary But Not Sufficient (Goldratt 2000) provide excellent means to introduce TOC concepts and principles, it is still not clear how best to integrate TOC with conventional OM topics.
句中提到高德拉特博士继《目标》之后的一系列作品，如《绝不是靠运气》、《关键链》和《必

要但不充分》等。可以翻译为:“确实,尽管高德拉特博士的诸如《目标》、《绝不是靠运气》、《关键链》和《必要但不充分》等小说体裁的著作对约束理论的概念和原理进行了很好的介绍,但如何很好地将约束理论有机地融入传统的运作管理主题仍然不是很清楚。”

8. A quick review of the literature reveals that two main sources of ... and propose guidance for future research.

句中提到的两个参考文献的详细信息如下:

Rahman, S. U., 1998, Theory of constraints: a review of the philosophy and its applications. International Journal of Operations and Production Management, 18, 336 – 355.

Mabin, V. J. and Balderstone, S. J., 2000, The World of the Theory of Constraints: A Review of the International Literature (Boca Raton, FL: St Lucie).

18 Experimental Economics and Supply Chain Management
实验经济学与供应链管理

Supply chain management is enjoying increased attention from operations practitioners looking for ways to compete in the global economy. Much of this attention focuses on leveraging recent advances in information technology to coordinate decision making across firms. Anticipated benefits include decreased inventory costs, reduced flow times, and better matching of supply and demand. Companies as diverse as Boeing, Target, and Eastman Chemical are investing new initiatives to share information and better coordinate production and order decisions between supply-chain partners.

Academics from many fields, including marketing, operations management, and information management and technology, are developing methods to direct such initiatives and quantify their benefits. For example, over 50 percent of the presentations sponsored by the Manufacturing and Service Operations Management Society (MSOM) at the INFORMS 1998 and 1999 meetings were dedicated to supply-chain-related topics. Academics commonly use operations research tools, such as stochastic modeling, simulation, and math programming to study the dynamics of supply chain decisions. These models normally operate under the assumption that decision makers are rational and have commonly known objectives. In practice, these models break down when (i) the objective function of a firm or of an individual inventory manager is not simple or clearly defined or (ii) the assumption of perfect rationality is violated. Individual preferences, attitudes towards risk, and cognitive abilities vary widely in practice. These realities are difficult to capture in analytic models.

Recently, there has been growing interest in using controlled human experiments to identify and better understand the behavioral factors that affect efforts to coordinate supply chains. Our goal in this paper is to illustrate the potential of experimental economics for better understanding decision making in this setting. We do this by reviewing recent experimental studies of the popular beer distribution game.

The beer distribution game mimics the ordering and production decisions of a four-level serial supply chain. Participants play the game over several hypothetical weeks. In each week, players decide how much product (cases of beer) to order from their immediate suppliers to maintain enough inventory to fill orders from their immediate customers. This task is complicated by delays in order processing, production, and shipping.

Instructors use the beer distribution game in many introductory operations management courses to illustrate an important supply-chain phenomenon known as the bullwhip effect. Proctor and Gamble first coined the term bullwhip effect to describe the systematic ordering behavior witnessed between customers and suppliers of Pampers diapers. While diapers enjoy a fairly constant consumption rate, Proctor and Gamble found that wholesale orders fluctuated considerably over time. The firm also found that the orders it placed for raw materials with its suppliers fluctuated even more than these wholesale orders. Other companies have observed a similar tendency in their internal supply chains. Baganha and Cohen (1998) provide empirical evidence of these problems in industries with high order variation, while Kahn (1987) offers a macroeconomic view of the relationship between order volatility, inventory, and cost.

The effect itself is described by two regularities; oscillations of orders at each level of the supply chain and amplification of these oscillations as one moves farther up the chain. Both oscillation and amplification are costly to supply chains. Although the cause of the bullwhip effect is not completely understood, current research suggests a combination of rational (for example, operational) and behavioral factors.

On the operational side, Lee *et al.* describe four of the most common causes. The first is demand-signal processing, the process a rational decision maker goes through to translate current demand information into a forecast of future demand. For example, Chen *et al.* (1998) show that following a simple forecast formula, such as exponential smoothing or simple moving average, can lead to bullwhip behavior in certain supply-chain settings. A second operational cause is rationing, where suppliers allocate limited resources, such as inventory, across several customers. This practice encourages customers to game the system by inflating their orders to gain a bigger slice of the pie. Other causes include batching orders (ordering once a week or once a month rather than every day) and varying prices (which can encourage forward buying). Ways to alleviate these last three operational problems include schemes to improve capacity allocation, staggered batching of orders, and everyday low pricing.

While operational causes are important, they are not the whole story. Our review of current research demonstrates that the bullwhip phenomenon remains even in idealized supply chains, such as that used in the experiments discussed here, in which normal operational causes are removed. This result leads researchers to investigate other behavioral factors. Because this field of research is still growing, this review is not meant as the last word, but rather an indication of the field's potential. These experiments represent a growing interest in literature concerning the cognitive limitations of managers in business settings. Before providing more details on the beer distribution game and its associated stream of research, we offer our thoughts on why experiments are a particularly relevant tool for studying supply-chain behavior.

Why an experiment?

Experiments are useful for investigating behavior in supply chains for a number of reasons. First, experiments allow us to gauge the extent to which behavioral factors cause empirical regularities, such as the bullwhip effect. In an experiment, we can control the environment each firm faces. In particular, we can design environments devoid of possible operational causes of the bullwhip effect. The beer distribution game provides such an environment.

The game assumes infinite capacity and no competing customers (avoiding inventory-allocation issues), zero setup times (avoiding order-batching problems), and constant retail prices (avoiding price fluctuations). We can also avoid the effects of processing demand signals (forecasting) by making all participants aware of the underlying demand distribution. Chen (1999) shows theoretically that a base-stock ordering policy minimizes total supply-chain cost in such a system when the retail-demand distribution is stationary and commonly known. A base-stock policy implies that participants place orders equal to the orders they receive from their immediate customers. In other words, they pass through the orders they receive, implying no bullwhip effect. This policy was also shown to be optimal for serial systems without delays by Clark and Scarf (1960) and Federgruen and Zipkin (1984).

However, participants in experiments do not simply pass through orders but instead order in ways consistent with the bullwhip effect. Observing the effect in such a controlled environment confirms that behavioral causes do exist and are an important cause of the effect in the lab.

Second, experiments can help us to understand the relative strength of multiple causes of the bullwhip in empirical data. For example, if we observe a threefold amplification of order oscillation in the field (where both behavioral and operational factors exist) and only a two-fold amplification in the lab (where we have eliminated the operational factors), we can estimate the fraction of the effect caused by behavioral factors and the fraction caused by operational factors.

Third, we can use experiments to test operations theory, much as we use them to test economic theory. For example, we can use experiments to compare the extent of the bullwhip effect when the supply-chain relationship is one to one (one supplier, one customer) or one to many (one supplier, many customers). We can compare the performance of supply chains with and without limited manufacturing capability, with and without setup costs, with and without inventory — allocation problems, and so forth. In this way, we can use experiments to put supply-chain-management theory to the test by investigating whether the outcome of a particular operational configuration is consistent with theoretical predictions. While this approach has not yet been taken in the literature, we think it is an important area for future supply-chain research.

Finally, we can use experiments to measure the impact of varying operational factors in the presence of behavioral factors. For example, we can examine the behavioral impact of reducing ordering and shipping delays, adding inventory-information-sharing systems, and adding point-of-sale (POS) data-sharing systems. Within the tightly controlled environment of the experiment, we can demonstrate and quantify the gains from these institutional innovations, holding all else constant, in the presence of behavioral and cognitive limitations. Experimental work is thus an important complement to theoretical work.

The beer distribution game

The beer distribution game mimics the mechanics of a decentralized, serial supply chain operating under a periodic-review order system. The underlying supply chain normally consists of four echelons. The game normally begins as participants enter a laboratory, are assigned randomly to roles, and face a game either on a computer screen or a physical board. Each participant controls one of the four echelons playing the role of a retailer, wholesaler, distributor, or manufacturer of beer. Each participant/firm places orders with its upstream supplier and fills orders placed by its downstream customer over a series of weeks (Figure 1).

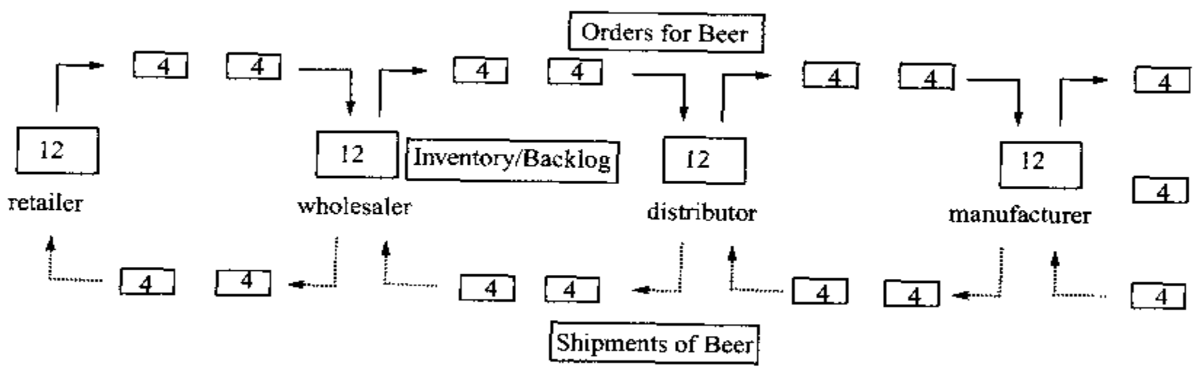

Figure 1. The game board in the noncomputerized experiments has four levels (retailer, wholesaler, distributor, and manufacturer). At each level is the number of units of inventory (or backlog if negative) currently in stock. Along the top of the figure are boxes representing the ordering lags with numbers indicating the units ordered in the previous two weeks. Along the bottom of the figure are boxes representing the shipping lags with numbers indicating the units shipped in the previous two weeks. The manufacturer faces a three-week production delay, the number in these boxes represents the units he has produced in the past three weeks. Each week the units in each position move one box and are incorporated into the inventory or backlog as appropriate. The numbers in the boxes represent the starting position in the game; each echelon member has 12 units in inventory and four units in each position ordering and shipping

The game is complicated by order-processing and shipment delays between each supplier-customer pair. Once a firm specifies an order, some delay occurs (most commonly, two weeks) before the order actually arrives at the supply site. Similarly, once a firm fills an order, another delay occurs (again, two weeks is common) before the shipment arrives at the downstream customer's site. At the highest level (the manufacturer), orders represent production starts and therefore mean a slightly different type of delay (for example, three weeks for production, then two weeks for shipment to the distributor).

At the beginning of each week, shipments arrive from each firm's upstream supplier. After the firm adds these shipments to its inventory, it processes new orders from its downstream customer (for the retailer, these orders are simply final consumer demand). Firms fill and ship orders from current inventory if possible and place excess demand in backlog. Firms earn revenue when they ship product and incur weekly inventory-holding costs and backlog costs. At the end of the week, each firm places an order with its upstream supplier. These orders are the decision variables of interest in the game.

As in most economics experiments, participants are typically paid according to their performance in order to induce preferences similar to those observed in the field. In some experiments, researchers run tournaments with the highest-earning supply chain winning a fixed prize. Others use a continuous incentive scheme in which more profitable chains earn more, either in an absolute sense or a relative sense.

This supply-chain setting eliminates three of the four operational causes of the bullwhip effect cited by Lee *et al.*: inventory allocation (since there are no competing customers and manufacturing capacity is infinite), order batching (since setup times are zero), and price fluctuations (since retail prices are constant). Some experimenters control for the fourth operational cause (demand — signal processing) while others do not.

Table 1 provides an overview of the papers in our survey. These papers can be grouped into two categories: those that establish the existence of behavioral causes, and those that test methods for reducing the bullwhip effect.

Table 1. Summary of the parameters and results of the experiments reviewed

	Number of echelons	Demand function	Incentives	Number of observations	Other roles	Key results
Sterman (1989)	4	Nonstationary and unknown (4 – 8 step)	Tournament	11	Participants	Demonstrated bullwhip and underweighting
Kaminsky and Simchi-Levi (1998)	4	Stationary and unknown (N[6,2])	None	6: 2 week lag 6: 1 week lag	Computer simulated (s, S)	Shorter lead times yielded same amplification but lower costs
Gupta, Steckel, and Banerji (2001)	3	Nonstationary and unknown (4 – 8; S-shaped with and without noise)	Absolute performance	100 divided into 12 treatments	Participants	Shorter lead times yielded lower costs, Sharing POS data yielded equal or lower costs
Croson and Donohue (1999a)	4	Stationary and known (U[0,8])	Relative performance	5 without POS 5 with POS	Participants	Sharing POS data reduced bullwhip

续表

	Number of echelons	Demand function	Incentives	Number of observations	Other roles	Key results
Croson and Donohue (1999b)	4	Stationary and known (U[0,8])	Relative performance	5 without inventory information 7 with inventory information	Participants	Sharing inventory information reduced bullwhip

Note: Demand functions can be stationary (with realizations drawn from the same distribution in each period) or nonstationary (with realizations drawn from different distributions in each period). They can also be known or unknown to the participants in the experiment.

Behavioral causes of the bullwhip effect

Sterman (1989) was the first to use the beer distribution game to rigorously test for the existence of behavioral causes of the bullwhip effect. He ran the experiment using a game board similar to that shown in Figure 1. The players were organized into supply chains (teams) made up of one retailer, one wholesaler, one distributor, and one manufacturer. Each player started with four cases of beer on order and in shipment and 12 cases in inventory.

The incentive scheme used a tournament design. Each participant placed one dollar in a prize fund; the fund went to the team with the lowest supply-chain cost, with the winning team taking all. Sterman defined supply-chain cost as the sum of inventory holding cost and demand-backlog cost at each supply chain level over all weeks. Inventory-holding costs at each level were 50 cents per case of beer per week, while backlog costs were one dollar per case of beer per week.

Sterman used a simple, nonstationary retail-demand function (beginning at four units and jumping to eight units) that was unknown to chain members. In this sense, his experiments control for only three out of the four operational causes cited by Lee *et al*. Demand-signal processing remained as a possible operational cause because the demand distribution was both nonstationary and unknown.

Sterman reports results from 11 groups of four players each. His results duplicate the empirical observations of Procter and Gamble. Inventory levels varied widely over the course of the game, from an average maximum backlog of 46 cases to an average peak inventory of 50 cases of beer.

Sterman demonstrated both aspects of the bullwhip effect: oscillation and amplification of orders. First, he found significant oscillation of orders at all levels. For the 11 retailers, for example, average weekly orders were 15 cases of beer per week, but the average variance of those orders was 13 (for comparison the variance of customer orders was 1.6). Second, he found significant amplification of order variance. The variance of orders averaged 13 for retailers, 23 for wholesalers, 25 for distributors, and 72 for manufacturers.

Sterman went on to analyze individual ordering decisions in an attempt to identify the behavioral cause of the bullwhip effect. His data suggest that most players failed to account adequately for the supply line (that is, for outstanding orders and shipments in transit). Thus in responding to high demand, players increased their orders too much, leading to excess inventory and reduced orders in future weeks.

Sterman was the first to demonstrate that the bullwhip effect had behavioral as well as operational causes. Both aspects of the effect (oscillation and amplification) occurred in controlled conditions with most operational causes removed. Interestingly, when Sterman asked participants how they could have improved their performance, they called for better forecasts of consumer demand. One could control for this operational concern by using a stationary demand distribution and announcing this distribution to all participants before the game begins. Chen and Samroengraja (1999) advocate this approach in a teaching note. They described running the beer distribution game in class with stationary and known demand (demand was distributed normally, with a mean of 50 and a standard deviation of 20, discretized and truncated at zero), and they found that the amplification of orders remained when this last operational cause was removed. However, they presented no statistical tests of their results.

Methods for reducing the bullwhip effect

Once biases in individual decision making have been identified, one can use experiments to test candidate institutions to counteract or ameliorate these biases. The remaining papers in our survey take this approach, demonstrating in controlled settings the behavioral benefits of (i) reducing lags, (ii) sharing inventory information, or (iii) sharing point-of-sale (POS) data across the supply chain. Research suggests that only a subset of these institutions show promise for reducing the bullwhip effect.

Focusing first on the impact of order and delivery lags, Kaminsky and Simchi-Levi (1998) and Gupta *et al.* (2001) examine the impact of decreasing these lags under different supply-chain settings. Both use a computerized version of the beer distribution game. The version employed by Kaminsky and Simchi-Levi (1998) is unique in that the computer automates the decisions of all but one role within the supply chain. These automated decision makers order according to a simple (s, S) policy, in which orders are placed to replenish echelon stock to the level S whenever inventory falls below the threshold level s. They compute s by continuously updating estimates of the demand mean and variance and fix S at 30.

Kaminsky and Simchi-Levi (1998) used a stationary demand function that was normally distributed ($\mu = 6$, $\sigma = 2$) and unknown to their subjects. No incentives were used. Each subject played the role of distributor in the game. In their baseline treatment, they used two week lags. In the reduced-lag treatment, they reduced order and delivery lags to one week. They report results from six subjects in each treatment (12 subjects overall).

In the baseline treatment, Kaminsky and Simchi-Levi again observed the bullwhip effect. Distributor-order oscillations were significant (the average standard deviation of distributor orders was 8.56) and were amplified over those of wholesaler-order oscillations. When they reduced lead times, distributor-order oscillations remained high (average standard deviation of 12.68), but overall costs incurred by the supply chain dropped. The authors argue that this drop was caused by operational factors, particularly the reduced time items spent in the system, which reduced inventory costs. Evidence for behavioral improvement based on lag reduction is primarily anecdotal.

Gupta *et al.* (2001) also show that reduced delays lead to lower supply-chain costs. However, their setup is quite different. They use a three-echelon supply chain with live participants at each level of the supply chain interacting via a networked computer system. Once again, the participants were not informed about retail demand. Unlike other researchers in this area, the authors do not analyze the ordering patterns of participants (choosing instead to focus on supply chain cost) and thus do not report on the existence or reduction of the bullwhip effect. They use nonstationary demand distributions (unlike Kaminsky and Simchi-Levi, who focus on the normal distribution).

Gupta *et al.* examine 12 treatments, including ordering and shipping lags of one or two weeks, total or no access to POS data and varying consumer demand, including a step function (as in Sterman), an S-shaped function, and an S-shaped function with noise. The authors report data from 100 supply channels (300 subjects) divided across these 12 treatments, with five to 13 groups per treatment. Participants were paid in proportion to the total costs incurred by their channels.

Decreasing the lags in the system generally led to reduced costs. With stepped demand and S-shaped demand with no noise, reducing the lags significantly reduced the costs at all three levels and thus over the entire supply chain (since supply-chain costs are simply the sum of the costs at each level). With S-shaped demand with error, reducing the lags significantly reduced costs for the retailer and the wholesaler but not for the manufacturer, resulting in no significant difference in channel costs overall. However, the authors do not provide an analysis of the variance of orders placed. Thus it is unclear whether costs fell because of the reduced inventory costs inherent in shorter lags (as suggested by Kaminsky and Simchi-Levi) or because players can make better decisions in the reduced-lag environment. These results suggest that shorter lags translate into lower supply-chain costs under some conditions. However, the authors also identify conditions under which the efficiency gains may not be as great as anticipated.

Unfortunately, because the participants in both Kaminsky and Simchi-Levi (1998) and Gupta *et al.* (2001) did not know the demand functions facing the retailer, their results cannot be conclusively attributed to behavioral causes. It is difficult to quantify the inherent operational benefits of reducing delays when the retail-demand distribution is not commonly known. Theoretically, removing shipment lags reduces pipeline stock, while removing ordering lags reduces the need for safety stock at both supplier and customer sites. It would be interesting to quantify this theoretical savings and compare it to the actual savings achieved in these experiments, to separate out the behavioral effect. One could do this by running the beer distribution game (with and without lags) subject to a stationary retail-demand distribution that was announced to all players.

Moving on to the second institution, sharing point-of-sale (POS) data, we find that the impact of this intuitional change is again mixed. Gupta *et al.* (2001) and Croson and Donohue (1999a) provide different results.

Gupta *et al.* again focus on settings with a wide range of nonstationary demand distributions which are unknown to the participants. With step demand, sharing POS information significantly reduced the retailer's costs but had no significant effect on the wholesaler's and the manufacturer's costs. With S-shaped demand with no error, sharing POS data had no effect on retailer's costs or on the wholesaler's costs, and it significantly raised the manufacturer's costs (that is, those costs moved opposite to the predicted direction). Finally, with S-shaped demand with error, sharing POS data significantly reduced the retailer's costs but had no significant effect on that of the wholesaler or the manufacturer. However, because participants in the experiments did not know the demand functions and the authors did not analyze ordering behavior, these results cannot be conclusively attributed to behavioral causes.

In their study of POS-data sharing, Croson and Donohue (1999a) control for the remaining operational cause of the bullwhip effect by using a stationary and known distribution (uniform[0, 8]). Their game is similar in spirit to the game advocated by Chen and Samroengraja (1999). They use the traditional four level game with four human participants interacting via a computerized interface. They paid the participants in a continuous manner based on the cumulative chain profit (costs) of the chain relative to the highest — profit chain. This payment was designed to represent the benchmarked performance of an integrated supply chain.

Five groups of four firms played a baseline condition (without POS data) in which they were told only the distribution of consumer demand. Another five groups played in the POS-data-sharing treatment in which the players knew the demand distribution and the realized demand in each week.

The addition of POS-data transmission significantly reduced order oscillation at all levels of the supply chain, particularly at the distributor and manufacturer levels. This asymmetric benefit is consistent with intuition. The retailer gets no new information from POS data (since he sees customer orders anyway); thus we would not expect his behavior to change significantly. Upstream from the retail site, this information is more likely to affect order decisions. Because of this asymmetric reduction in oscillation, amplification of order variation significantly decreased when POS data was shared.

Croson and Donohue also replicate Sterman's result that players do not give enough weight to the supply line. They present a new analysis of individual behavior on the demand line; examining what information firms use when making their ordering decisions. They find, as predicted, that when POS data is available, participants incorporate it into their ordering decisions, supplementing the information contained in their downstream customers' orders.

This analysis suggests the mechanism by which POS data can affect performance in supply chains and helps to organize Gupta, Steckel, and Banerji's results. When demand is stationary and known, sharing POS data can help reduce the bullwhip effect and reduce supply chain costs (as Croson and Donohue show) by helping upstream suppliers better anticipate their customers' needs without biasing their estimates of future demand. In contrast, when the distribution of consumer demand is nonstationary and unknown, POS data can bias upstream participants' estimates of future demand, which can increase (rather than decrease) costs (as Gupta, Steckel, and Banerji argue). It remains unclear whether the cost increase in this case is caused by the bullwhip effect or by some other behavioral phenomena.

Turning to our final institutional change, Croson and Donohue (1999b) examine what impact sharing inventory information has on reducing the bullwhip effect. In this study, the participants knew the distribution of demand, which was stationary, and again faced a four-echelon, computerized supply chain. Five groups of four subjects participated in the baseline condition (without inventory-information sharing), and seven groups of four subjects participated in the inventory-sharing condition.

Their results suggest that making the inventory position of all supply-chain members known significantly reduced oscillation of orders at all levels of the supply chain, but particularly at higher levels (distributor and manufacturer). This additional information also reduced amplification, particularly between the distributor and wholesaler roles.

Croson and Donohue again replicate Sterman's results that players give too little weight to the supply line when they know the demand distribution and share inventory information. The persistence of this behavior when they shared inventory information makes one question the cause of performance improvement. After all, if the behavioral causes of the bullwhip effect, such as this underweighting, remain, why do oscillation and amplification decrease? Results suggest that although participants did not use inventory information to adjust their supply lines, they did use it to anticipate downstream members' orders. This anticipation of future orders from downstream customers allowed upstream players to adjust their own orders in advance (that is, in preparation for incoming orders). This use counteracted (but did not eliminate) their underweighting of the supply line and improved performance.

Conclusions and lessons for managers

Controlled experimental settings allow one to both demonstrate behavioral biases that cause empirically observed outcomes like the bullwhip effect and to identify the actions managers can take to reduce the impact of these biases. Such experiments can even offer insight into how best to implement institutional changes. For example, Croson and Donohue's results on the impact of inventory information suggest that when inventory information is shared across the supply chain, order oscillations decrease because upstream chain members have information about downstream members' inventory positions, rather than the other way around. The critical part of an inventory-sharing information system thus is not communicating the inventory position of the manufacturer to the retailer but instead communicating the inventory position of the retailer to the manufacturer. The biggest bang for the buck may lie in tracking and sharing downstream inventory information. Since the cost of tracking inventory is quite high, particularly at manufacturing sites, this result suggests that instituting tracking systems at the retail and wholesale levels will provide the greatest returns, with the returns diminishing for inventory sharing further up the supply chain. Similar implications can be inferred from the other experiments reviewed and (we hope) from future research in this field.

This survey suggests the types of benefits that experimental research can bring to supply-chain management. We trust that future researchers will examine other important institutional changes that show promise for improving supply-chain performance. Examples include collaborative forecasting and planning systems in which supply-chain members work together to create a chain-level ordering strategy and other information-technology-enabled systems designed to improve efficiency. More work is also needed to understand the relationship between individual characteristics (such as patience, risk-neutrality, and abstract thinking) and performance of supply-chain tasks. Finally, additional work is needed to discover the type of training managers need to improve their performance in these complex settings. We believe that experiments like these can illuminate the difficulties of managing supply chains and provide specific, behavioral suggestions for easing the task.

Professional Words and Expressions

Supply Chain Management	供应链管理
Supply Chain Partner	供应链合作伙伴
Inventory Cost	库存成本
Operations Management	运作管理
Stochastic Modeling	统计建模
Simulation	仿真
Math Programming	数学规划
rational	理性的
Objective Function	目标函数,目标方程
Individual Preference	个人偏好
Cognitive Ability	认知能力
Operational Cause	运作因素
Behavioral Factor	行为参数,行为因素
Experimental Economics	实验经济学
Beer Distribution Game	啤酒分销游戏
Bullwhip Effect	长鞭效应,牛鞭效应
Exponential Smoothing	指数平滑(预测方法)
Simple Moving Average	简单移动平均(预测方法)
Retailer	零售商
Wholesaler	批发商
Distributor	分销商
Manufacturer	制造商
Holding Cost	库存成本
Backlog Cost	缺货成本
Ordering Cost	订购成本
Setup Cost	生产准备成本
Inventory Allocation	存货分配
Infinite Manufacturing Capacity	无限制造能力,无限生产能力
Order Batching	批量订购
Setup time	生产准备时间
Price Fluctuation	价格浮动
Incentive Scheme	激励机制
POS Data	销售点数据
n-echelon	*n* 级,*n* 阶
subject	实验参加者,实验主体

Notes

1. For example, over 50 percent of the presentations sponsored by the Manufacturing and Service Operations Management Society (MSOM) at the INFORMS 1998 and 1999 meetings were dedicated to supply-chain-related topics.
   INFORMS 是运筹学与管理科学学会(The Institute for Operations Research and the Management Sciences)的简写。该学会旨在促进运筹学和管理科学(Operations Research and the Management Sciences,OR/MS)领域的发展和传播。其愿景是能够促进 OR/MS 的实践、研究、方法和应用。详见 http://www. informs. org
   可翻译为:例如,在 1998 和 1999 年的由制造和服务运作管理会赞助的 INFORMS 会议上,有超过一半的演讲主题是与供应链相关的。
2. The effect itself is described by two regularities; oscillations of orders at each level of the supply chain and amplification of these oscillations as one moves farther up the chain.
   牛鞭效应本身可以用两个规则来描述:一是订货数量在供应链的各个阶段处于摆动状态;二是随着订单信息从供应链的下游向上游的传递摆动的幅度逐渐增大。
3. A second operational cause is rationing, where suppliers allocate limited resources, such as inventory, across several customers. This practice encourages customers to game the system by inflating their orders to gain a bigger slice of the pie.
   引起牛鞭效应的第二个运作原因是定量配给,即供应商将有限的资源如存货等分配给几个客户。定量配给鼓励客户进行博弈,即试图通过扩充订单以期能从有限的蛋糕中分得较大的一块。
4. First, experiments allow us to gauge the extent to which behavioral factors cause empirical regularities, such as the bullwhip effect.
   首先,通过实验可以确定行为因素引发经验规律如牛鞭效应的程度。
5. The beer distribution game mimics the mechanics of a decentralized, serial supply chain operating under a periodic-review order system.
   啤酒分销游戏模仿在定期盘点和订货方式下分散的串行供应链结构。
6. As in most economics experiments, participants are typically paid according to their performance in order to induce preferences similar to those observed in the field.
   同多数的经济学实验类似,为了能够产生与现实生活中观察到的类似的偏好,实验参加者通常要根据其表现被给予一定的报酬。
7. Once biases in individual decision making have been identified, one can use experiments to test candidate institutions to counteract or ameliorate these biases.
   一旦个体在指定决策时的偏好被识别出来,就可以通过实验来测试各种能够抵消或减轻这些偏好的游戏规则。
8. The biggest bang for the buck may lie in tracking and sharing downstream inventory information.
   最大的收益也许能够通过跟踪和共享供应链下游的库存信息来得到。

编者注

实验经济学是研究人类行为的经济学。其价值不仅体现在实验方法的运用对传统经济学理论的验证上，更重要的是方法论上的意义。它将进一步加强经济学在行为研究层面上的发展与深化，赋予经济学"科学性"。实验经济学的发展有待于演进博弈论、社会经济学、经济心理学等学科的共同发展。实验经济学揭示了传统新古典经济学的缺陷，指出了以后经济学的前进方向。而弗农·史密斯因为通过实验测试和修正有关预测领域的经济学理论，创立实验经济学而获得了2002年诺贝尔经济学奖，成为继蒙代尔、斯彭斯之后的第三位诺贝尔经济学奖获得者，被誉为"实验经济学之父"。

2003年12月4日，史密斯教授偕同夫人莅临华南理工大学工商管理学院，作了一场题为《如何将经济学和实验相结合》的专题学术报告。作为报告现场的同声翻译，编者不仅有幸和史密斯教授合作，而且亲身领略到了新世纪最前沿的经济学说的精髓，并感受到了世界经济学顶级大师的风采。

第五篇

工业工程展望

19 The Evolution of Information Systems and Business Organization Structures 信息系统与企业组织结构的衍变

Introduction

This article looks at ways in which computerized information systems have impacted modern business organizations. While the influence of these systems on organizations in general has been both powerful and wide ranging, this article focuses primarily on how organization structures have specifically been impacted. To properly frame the various issues that are addressed, this article briefly traces early computers, and mentions their development by generations. Over the decades, both computer systems and organization structures have moved from a centralized to a decentralized design. This movement has had major implications in what organizations are capable of doing in the face of a turbulent environment by adopting organic and network like structures. These organizational metamorphoses have been possible, in large part, by the support provided by information technology that allowed autonomy and distribution of responsibility. A review of information system architecture and organizational form is made to underscore a natural compatibility or fit between information systems and organization structures. In conclusion, attention is drawn to the ways information systems are likely to create organizational interfaces between an organization's suppliers and customers, and how this may result in radically new structures.

Early developments

Modern computers, as we understand them, were essentially designed and developed in the USA around half a century ago. While punched card based unit record machines (URMs) were widely used for limited business data processing in the 1930s, the world's first fully automatic computer is considered to be the MARK I which was set in operation in 1944. This was followed by the ENIAC (1946), short for Electronic Numerical Integrator and Calculator, the EDSAC (1949), the Electronic Delayed Storage Automatic Computer, and by the EDVAC (1952), the Electronic Discrete Variable Automatic Computer. All these machines had been designed and built for military, scientific, or mathematical purposes. Von Neumann, an early pioneer, who developed the concept of the stored program, was convinced that computers could solve many important unsolved problems in applied mathematics.

Some time during the 1950s, the potential of computers in the realm of business was recognized, and a powerful impetus was now given to marry technology with commerce. The first commercial computer, a UNIVAC 1, manufactured by Rand Corporation, was delivered to the US Bureau of the Census in 1951, while the first non-government installation, also a UNIVAC 1, was installed at General Electric's appliance plant in Louisville, Kentucky. According to Lynch and Rice, the period from 1956 to 1958 saw three significant developments in computing. These were:

- breakthroughs in increased core memories;
- development of more standardized and higher level languages;
- the development of a system for operating a computer or the operating system (OS).

Computers in business

Computer development by generations

The field of computers developed by what is now recognized as generations, starting with the first generation half a century ago onto the end of the fourth generation today. The concept of generations is both artificial and arbitrary, but is a useful framework for understanding developments in this field. Commonly, generations are associated with levels of computer technology and processing speeds. The first generation computers, up to the mid-1950s, were associated with valves and electric relays. The second generation computers, developed in the late 1950s, used transistors instead of vacuum tubes. They occupied far less space than their predecessors, were faster in operation, required less maintenance, and were more reliable.

Third generation computers of the 1960s and early 1970s were characterized by large scale integration (LSI) of integrated circuits. Introduced with the third generation machines was the concept of the family of computers, and users could move upward adding computing power, storage capacity, and peripheral capability — without costly conversions. Each generation was characterized by a marked improvement in performance, capability, and a fall in prices. Fourth generation computers, from the early 1970s, were characterized by very large scale integration (VLSI), and the use of semiconductor memory and sophisticated software. Computers of this generation, apart from high speed and massive computing power, were characterized by the use of microprocessors, virtual memory, and highly developed communication and database facilities.

They not only became powerful and fascinating, but their usage in business generally accelerated the possibilities and potentialities of growth.

Computer installations in business

The combination of increased computing power, powerful software, and continuously falling hardware prices became a very attractive proposition for business organizations, and from the mid-1960s onwards installations in businesses increased rapidly. From an installed base of ten computers in 1950 valued at $0.01 billion, a total of 138,000 computers valued at $53.0 billion were installed by 1980.

The transformation of the US economy took place in the 1950s when the information age overtook the industrial age. Sprague and McNurlin (1993) mention, "It was in 1957 that the USA passed from the industrial era to the information era. In that year, the number of employees in the country whose jobs were primarily handling information surpassed the number of industrial workers". This was important not only in the service or information industry, but also in the manufacturing industry owing to the dramatic effect of computers and information. Computers have been used to systematize and solve problems in diverse areas of business including planning, R&D, engineering, marketing, procurement, production, storage, distribution, operations and service, and management. Very simply, computers allowed the development of planning techniques hitherto too complex to develop, compute, or control. These included the development of systems planning like PERT/CPM models, planned program budgeting, and simulations, as well as developments in areas like production, automation, and other planning and control systems. Other contributions of computers were in the areas of high volume and repetitive computations, measures for operations control, and as an information and decision tool. There is no doubt that the contributions of computers are numerous and well-known, and US industry has, on the whole, been radically and beneficially affected by these contributions.

Growth of information systems and business organizations

Over the last three decades, computer-based information systems and business organizations developed in unique and special ways. As far as computers are concerned, the manner of hardware and software development resulted in unique architectures evolving over time. At the same time organization structures developed special forms to suit and fit their specific environmental and strategic requirements.

Development of information systems

Computer based information systems are categorized by their architecture or topology, which are a set of interconnections or nodes in a network. Categorizing information systems architecturally is appealing since it is not idiosyncratic to particular settings, and further, these architectures are fairly well established and accepted. This section briefly discusses the four main types of information systems architectures or typologies consisting of centralized, distributed, decentralized, and stand-alone systems.

The combination of hardware, software, data, and communication formed the core of information systems. As each of these dimensions developed and integrated, the concept, design, and capability of information systems underwent massive changes. The earliest systems were the classic centralized systems typically characterized by a mainframe host computer supported by an array of peripherals, including "dumb" terminals, which allowed interactive, information processing activities mostly of a transactional nature. These centralized systems were modest in size in the earlier generation computers, but grew from small, medium to large centralized mainframe systems over time. This was the trend up to the 1970s, and for the first 20 years discussions on data and systems were about techniques to manage data in a centralized environment.

In the early 1960s, the main concern among hardware manufacturers and data processing managers was achieving machine efficiency. With increasing demands and sophistication of users of information, and with the availability of powerful personal computers (PCs), data processing activities became more distributed. This gradual shift from information availability in report form to information becoming available on demand, and forming a part of a decision support system (DSS), accelerated the trend from centralized to distributed systems, consisting of clusters of minicomputers networked through LANs, or local area networks at the intra-organizational level, and the later WANs or wide area networks at the inter-organizational level. The growth and importance of minicomputers, so fundamental to this trend, can be gauged from Table 1.

Table 1. Minicomputers installed 1970 – 1980; purchase price $ billions

Year	Number	Value
1970	31,000	1.9
1975	202,000	6.0
1980	840,000	19.3
Source: Kanter(1982)		

Distributed systems are defined as "peer-to-host systems", and are designed as "spokes" or terminals around a central processor or mainframe. Spokes might have their own processor, storage device, and terminals that have their own computing facilities and databases. Distributed systems are now giving way to decentralized information systems, and the role of the user is becoming paramount. This trend is continuing through the 1990s. Decentralized systems are referred to as "peer networks" and have no central processor through which communications must pass, and hence there are more degrees of freedom in communication, and communication constraints are substantially less than for distributed systems.

A fourth kind, though less common, are stand-alone systems, typically PCs, used in individual departments or as information systems in small organizations. Because of their limited capabilities and low cost, most large organizations do not plan for them, and their effect is on the work of individuals rather than on the organization as a whole.

Changes in organization structures

Businesses in the USA have changed in many different ways during the course of this century. The earlier trends were essentially the development of single businesses that preferred to retain overall control through vertical integration, and Chandler (1990) has observed that US organizations have invariably stressed the ascendancy and development of functional areas. In the 1960s, there were a spate of acquisitions and mergers primarily as a response to anti-trust laws. Companies went into unrelated businesses and formed huge conglomerates. In the 1980s, this trend changed through a process of readjustment, disinvestment, and restructuring, and the degree of unrelatedness was reduced somewhat, and large diversified businesses were formed. Many structural changes have taken place during the last 30 to 40 years, and the direction of these changes has been to move from centralized to decentralized organizations through various stages. These stages started with the earlier centralized single business organizations which were vertically integrated, and then moved onto the divisionalized structures used at Du Pont, and later at General Motors.

This basically was a movement away from functional control to divisionalized control. This was typical of the M-form of organizations where a division would be given complete autonomy and each division would have its functional areas under its control. The head or corporate office would have an essentially coordinating role, and each division would function with its divisional level corporate setup. These changes took place in order to handle changes more appropriately in the environment, and to have more effective responses to competition. Organizations found that a decentralized setup was in many cases better suited to cope with an environment marked with rapid changes. Perhaps the one key reason decentralization could meaningfully take place is by the support provided by information systems that allowed decentralized communication and control.

Decentralization has moved further, and later structures have been in the form of matrix, hybrid, and network organizations. Each of these structures has been found to be a more appropriate response to cope with increasing turbulence in the external environment. In modern business organizations, effectively handling a complex and turbulent environment has been the fundamental problem that top management and organizational administrators must cope with. Again, new structures to cope with new environmental realities have been possible in large part due to the possibilities of information and control provided by computers.

An important view of evolving organizations has been the five typology structure provided by Mintzberg (1979, 1981, 1983), and similar typologies have also been suggested by Daft

(2001). These typologies are based in part on organizational life cycle, type of business, and the competitive environment. The five part typology of organization structures consists of the following:

- Simple structures. These are characteristic of both young, start-up, entrepreneurial organizations as well as well entrenched autocracies. They are usually small, operating in a market niche within a dynamic environment with few rules;
- Machine bureaucracies. These are characterized by standardization, functional structural design, and large size. These structures are generally differentiated both horizontally and vertically, and are normally associated with standardized, routine, mass production technologies in a stable environment;
- Professional bureaucracies. These rely on standardization of skills as a basis for coordination, and have a high informational component. These organizations are decentralized down to the level of those professionals responsible for carrying out the organizations' tasks;
- Divisionalized forms. These are integrated sets of semi-autonomous entities loosely joined by an administrative framework. The semi-autonomous entities, often referred to as strategic business units (SBUs), determine the strategic portfolio of the organization. They may be decentralized from the perspective of the total organization, but can be centralized from within the division, or may exist in any other combination;
- Adhocracy. These can be construed as divisionalized forms, held together by a strong culture. These are usually small and have the characteristics of a young organization (without necessarily being young). Mutual coordination and cooperation are critical which cause these organizations to behave like project teams. They are essentially highly organic with little formalization.

Integrating computer architectures and organization structures

It is interesting to note, based on the earlier discussion on computer systems and organizations, that evolving computer architectures and changing organization structures bore a similarity of form, in that both evolved from a centralized to a decentralized design. This shift in both cases can be understood as a distribution of power from one central node to a number of decentralized sources because of the many advantages that accrued from such a shift. In both computers and organizations, such a shift was characterized by a significant reduction in formality, or in computer terms, a reduction in "protocol."

In the computer or information system environment, such a shift from a centralized controller or "authority" had many implications. From a relatively rigid system of a single central processor servicing requirements of peripheral units, and handling requests on a rigid set of heuristic or algorithms, distributed systems distribute both data and processing to multiple machines and results are exchanged. While both centralized and distributed systems required varying degrees of central control and authority, distributed systems had far higher levels of communication and task accomplishment at relatively lower levels. With decentralized systems, there is no central controller, and both communication and task responsibilities have been devolved to independently be able to communicate and share resources with relatively high degrees of freedom. Although terminals or other systems communicate through bridges or gateways and require rules for connectivity, these constraints are substantially less than for distributed systems, and this flexibility gives decentralized systems the capability to cope with a wide variety of information requirements. In other words, the power of decentralized systems is maximum when protocol or rules are at a minimum. Electronic mail, local area networks, telecommunication systems, group decision-making systems, etc., allow messages to be sent through the network in an interactive mode which results in an increase in the quality, quantity, reliability, and capability of the system to process information.

Organizations, in the last half century, have undergone extensive structural changes, in large part due to changes in the operating environment, and also due to advances in management and organization theory. To be highly efficient through a machine bureaucracy like structure was the requirement of an earlier age. Such a structure is still viable in an environment characterized by stability and reduced complexity. Such structures are relatively uncommon today as business organizations have moved from the criteria of efficiency to that of effectiveness, and such moves have seen machine bureaucracies evolving into more organic structures.

Many scholars, including Mintzberg (1983) and Daft (2001), have highlighted that different types of structures are more appropriate for different types of environments. Effectiveness was provided better by divisionalized organizations operating in hybrid or matrix like structures, as is common today, compared to the earlier centralized structures. According to Snow *et al.* (1992), today's competitive pressures demand both efficiency and effectiveness, and firms must adapt with increasing speed to market pressures and competitors' innovations, while simultaneously controlling or even lowering product or service costs. Under these conditions, they suggest that by using a network structure, a firm can operate an ongoing business both efficiently and innovatively, focusing on those things that it does well and contracting with other firms for the remaining resources.

It is quite clear from the above discussion that the move from centralized to decentralized information architectures, coupled with a similar move in organization structures, should be associated with each other because of the way both have such close similarities in their evolution. It must be remembered that both computers and organizations evolved and changed form for different reasons. Computers architectures evolved, at least in the earlier era, due to the pressure and impact of communication technology, while organization structures evolved as they were impacted by a multitude of forces, including the environment, competition, and technology. How is it possible to evaluate and separate this relationship, between computers and organizations, into cause and effect? This is hard to do except to understand that evolving computer architectures impacted and enabled newer organizational forms, and over time changing organizational requirements impacted the shape and design of computer systems and architectures.

Our discussion so far has been to examine the evolution of computer architectures and organization structures separately. In the following sections we combine the separate evolutions and discuss the impact of the relationship between computers and organizations in two ways.

The impact of computers on organizations

One of the earliest and more well known studies of the impact of computers on organizations was undertaken by Whisler in the late 1960s. In a study of 23 large insurance firms, the study revealed a number of interesting effects, some contrary to what were expected from computer-based information systems. Perhaps the kind of results highlighted in the study (Table 2) were due to the earlier stress on data processing as opposed to the later emphasis of using computers primarily as communication and decision support systems.

Table 2. Early impact of computers on organizations

Organization structure	Decision making	Authority and control	Job content
Decline in clerks and supervisors	Consolidation of separate decision systems	Centralization of control	Routinization at lower levels and broadening at upper levels
Increase in upper-level managers	Upward shift in decision making	Increase in machine control	Decline in interpersonal communication after computers
Decline in number of levels	Rational and quantified decision making	Control over individual behavior	Increase in communication during system development
Consolidation of departments	Rigidity and inflexibility in decision making	Blurring of traditional lines of authority and control	Decline of skill levels at lower and middle levels increase in skill levels at upper levels

The study indicated a decline in the number of levels in the organization structure, greater consolidation and rigidity in decision making, increased centralization of authority, and routinization in the content of lower level jobs. The impact of computers created shifts in power that were not anticipated before. In the initial stages of its introduction, the power of information was in the hands of the departments in which computers were installed, which was typically the accounting department. "Information is power" has become a maxim, and with it the realization that power devolves upon those who gather, process, disseminate, or simply possess information. According to them, the increasing value of information as a commodity brings with it the potential to change the bases of power and create new ones. Over the years, the availability of decentralized information systems allowed organizations to go ahead and attempt to decentralize their structures to more effectively cope with their environments. Organic structures such as hybrid, matrix, and network organizations were possible in large part because of distributed and decentralized decision-making powers made possible from new information architectures.

Mintzberg, (1983) has provided extremely compelling illustrations of how inadequacies in the machine bureaucracy structure led to formations of more effective structures, and how management information system (MIS) capabilities were used to form new structures. He mentioned that as the environment remained stable, the machine bureaucracy had no great difficulty in adaptation. As environments changed, generating new non-routine problems, managers at the strategic apex quickly became overloaded due to the high degree of centralization inherent in such structures. One of the ways to overcome these information bottlenecks was to restructure, distribute authority, and decentralize management. A combination of environmental turbulence associated with information systems' capabilities provided a strong impetus and capability for organization structures to constantly reshape.

Phases of computerization in organizations

In many organizations, computers were initially introduced as a part or a section in the accounting department, usually under the title of electronic data processing (EDP), and, for administrative purposes, was also under the control of the accounting department. At this stage, computers were generally centralized systems consisting of low capacity mainframes. As the need, usage, and capabilities of data processing increased, the data processing section in the accounting department became an independent department of its own, usually called the EDP and later the management information system (MIS) department. This department then serviced various departments in the entire organization, and became an information hub. This stage is still characterized by centralized computer systems, but they were generally high capacity mainframes that could take on the increased load. The current state of development in organizations is indicative of a situation where every department is networked into an information and communication system supported by the MIS/IS department. This is the stage of distributed and decentralized systems that are typical of a network environment. The three stages in the evolution of information systems are given in Figure 1.

The network environment presented in Figure 1. is suggestive of an information system that primarily operates as a decision support system (DSS). Here, users or user departments drive the system, communicate with each other, share resources including databases, take greater responsibility for the data and the supporting information system, and use the MIS/IS department mainly for technical and software support. According to Wiseman (1985), over the years information system technologies have evolved from MIS, to DSS, to strategic information systems (SIS), and now serve the purpose of combining with organization structures to serve as competitive weapons.

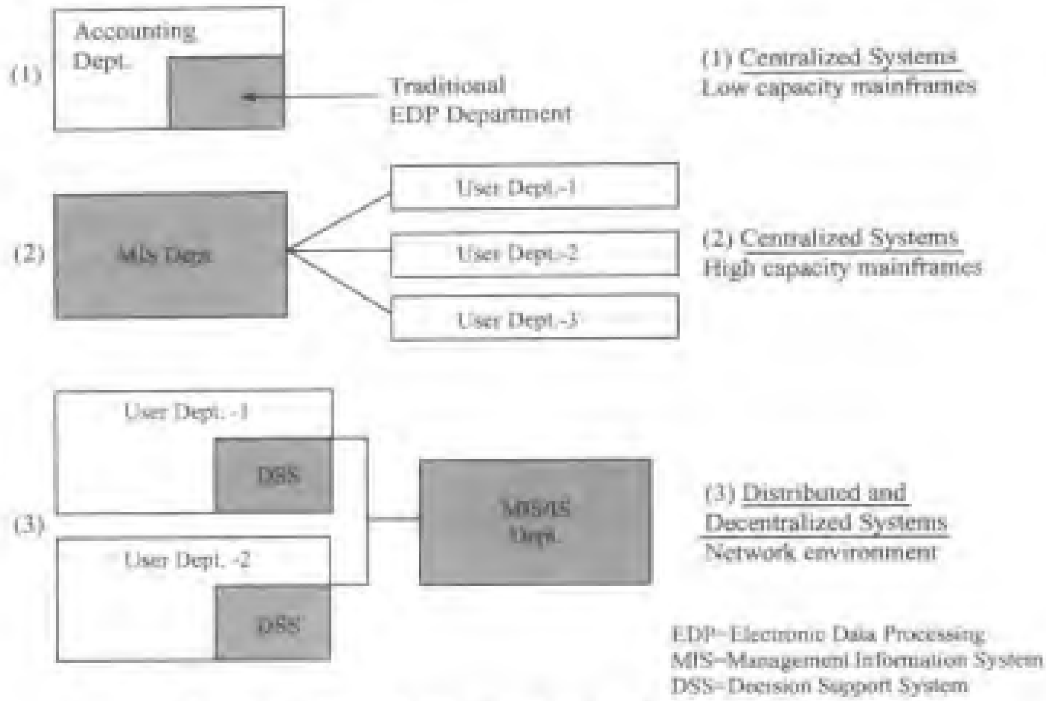

Figure 1. Three-part evolution of early information systems

Another view of the growth, evolution, and impact of computers on organizations is given by Gibson and Nolan (1974). These researchers have provided an excellent four stage framework (Table 3), covering the evolution and growth of EDP departments as computers were introduced into the organization. These four stages were:

- initiation;
- expansion;
- formalization;
- maturity.

Table 3. Four-stage growth of companies in organizations

	Initiation	Expansion	Formalization	Maturity
Applications	Cost reduction	Proliferation of applications	Emphasis on control	Database applications
Growth of personnel	Specialization for computer efficiency	Specialization to develop variety of programs	Specialization for control and effectiveness assurance	Specialization for database technology and tele-processing
Management techniques applied	Lax management	Sales oriented management	Control-oriented management	Resource-oriented planning and control
Source: Gibson and Nolan (1974)				

At each stage they have looked at three specific dimensions, namely, growth of applications, growth of specialized personnel, and management techniques applied.

Linkages between computers and organization structures

While organizations evolve to adapt to their environments, the purpose behind such evolutions and transformation is essentially a question of strategy, that is to do with the organization's adaptation, survival, growth, and improved performance. Organization structures, therefore, serve a function which essentially suggests that an organization can function best when it assumes certain forms.

In a conceptual study by Leifer (1988), there were certain ideal matches between the four information architectures discussed earlier and the Mintzberg typologies. Leifer suggests that certain organization structures are more compatible with certain information architectures. A mismatch, according to him, would result in inferior performance, unless a change was effected onto either the architecture or the structure, or both.

It will be noticed from Table 4 that bureaucracies are matched with centralized systems, while professional bureaucracies use both centralized and distributed systems. This is because such organizations need access to mainframe processing capabilities, as well as local processing linked to specialized databases. Divisionalized organizations use centralized, distributed, and decentralized systems because divisionalized structures may take many forms. Some may be loosely coupled, while others may be tightly coupled. The coupling may be by way of formal controls, or through a strong culture. The division may have a centralized or decentralized relationship with its corporate office, and the structure within the division may be centralized or decentralized. Divisions, therefore, depending on the way they are organized, will have unique and different types of information architectures. Adhocracies, on the other hand, are linked with decentralized systems as these are small autonomous structures that are highly organic and behave like project teams.

Table 4. Linkage between organization structure and information architecture

Types of organization structure	**Type of information architecture**
Simple structure	Stand-alone PCs
Machine bureaucracy	Centralized systems
Professional bureaucracy	Centralized and distributed systems
Divisionalized form	Centralized, distributed and decentralized systems
Adhocracy	Decentralized systems
Source: Leifer(1988)	

Implications for emerging and future organizations

What are emerging and future organizations going to be like? And, what is the role of information systems in shaping future organizations? Many scholars have suggested that environmental factors, managerial attitudes, workforce sophistication, and numerous other factors are likely to affect the form, structure, and functioning of future organizations. According to Galbraith and Lawler

(1993), emerging and future organizations are more likely to be characterized by decentralization of decision making, and in order to facilitate this, they are likely to be designed as distributed organizations. The newer structures are likely to have extremely close links, especially through computer based information systems, with their suppliers and customers. Enhanced coordination is likely to result, as is happening with electronic data interchange (EDI) being increasingly used to integrate the operations of two or more organizations that do business with each other. Network organizations with their internal and external networks, high performance work teams, flexible work groups, centrality of customers, close coordination with suppliers and contractors, and the ability to respond quickly to changes are perhaps the shape of organizations of the future.

The Internet, stand-alone computers and small businesses

With the advent of the Internet, the greatest impact has been on the role and operations of small businesses. Traditionally, small businesses with simple structures (Mintzberg, 1983) used stand-alone computers. Small businesses were constrained to using relatively simple off-the-shelf software packages that provided standardized solutions for typical business problems. Prior to the Internet, small businesses were neither networked nor were they capable of interorganizational communications using computers. However, the Internet has changed all that and has created completely new dynamics in the way small businesses can leverage the World Wide Web to overcome the disadvantage of size and accessibility.

A recent study (1999) indicated that consumers and businesses equipped with personal computers (PCs) and Internet access were poised to bypass paper transactions in favor of electronic information exchange. Studies have indicated that 60-67 per cent of small businesses were equipped with a computer and modem, were using online banking functions, and had their own Web pages. Another survey revealed that about 61 per cent of small businesses operate some kind of computer network, and 20 per cent of those that do not plan to do so within the next 12 months, and nearly 40 per cent of the survey respondents plan to update their networks within a year (1999). An IBM survey in 1994 indicated that less than half of small business executives were aware of the Internet's existence, while in 1999 the Internet has become an integral part of the daily business operations of small businesses. The next Internet growth spurt is expected to be among small- and mid-size businesses, and by about 2006, about 50 per cent of the US workforce will have jobs at Internet-related businesses.

What is of great interest is how small businesses with stand-alone computers can, on account of the Internet, have the same global reach and impact as the largest businesses. The potential for small businesses to take advantage of the Web and leverage it for business purposes is enormous. In practical terms, the Internet is rapidly becoming a primary channel for conducting transactions known in business as purchasing, and in government primarily as procurement. The use of electronic procurement and purchasing, which was previously dominated by larger companies, is one that has been heavily impacted by the Internet and has been of great benefit to small businesses. As one can see, not only have computers impacted structures in organizations over the years, but computer related developments have completely altered the commercial viability of small businesses and their usage of stand-alone computers.

Professional Words and Expressions

Information System	信息系统
Organization Structure	组织结构
Centralized Design	集中式设计
Decentralized Design	分布式设计
Punched Card	穿孔卡片
Unit Record Machines (URMs)	单元记录机
Electronic Numerical Integrator and Calculator	电子数字集成器和计算器
Electronic Delayed Storage Automatic Computer	电子延迟储存自动计算机
Electronic Discrete Variable Automatic Computer	电子离散变量自动计算机
Stored Program	存储程序
Memory	内存
Standardized Language	标准计算机语言
Higher Level Language	高级计算机语言
Operating System (OS)	操作系统
Valve	电子管
Electric Relay	电子继电器
Transistor	晶体管
Vacuum Tube	真空管
Large Scale Integration (LSI)	大型集成器
Integrated Circuit	集成电路
Computing Power	计算能力
Storage Capacity	存储能力
Peripheral Capability	外设(外部设备)能力
Very Large Scale Integration (VLSI)	超大规模集成器
Semiconductor Memory	半导体存储器
Software	软件
Microprocessor	微处理器

Virtual Memory	虚拟内存
Communication Facility	通讯设备
Database Facility	数据库设备
Information Age/Era	信息时代
Industrial Age/Era	工业时代
Program Evaluation and Review Technique (PERT)	计划评审技术
Critical Path Method (CPM)	关键路线法
Centralized System	集中式系统
Distributed System	分布式系统
Decentralized System	分散式系统
Stand-alone System	单机系统
Mainframe Host Computer	大型主机
Personal Computers (PCs)	个人电脑
Data Processing	数据处理
Decision Support System (DSS)	决策支持系统
Minicomputer	小型机
Local Area Network (LAN)	局域网
Wide Area Network (WAN)	广域网
Processor	处理器
Storage Device	存储设备
Terminal	终端
Degree of Unrelatedness	不相关度
Centralized Single Business Organization	集中式的单一企业组织
Vertically Integrated Structure	纵向集成式结构
Horizontally Integrated Structure	横向集成式结构
Divisionalized Structure	事业部式结构
Matrix Organization	矩阵式组织
Hybrid Organization	混合型组织
Network Organization	网络型组织
Formality	形式化
Protocol	协议
Simple Structure	简单结构
Machine Bureaucracies	机械官僚机构
Professional Bureaucracies	专业官僚机构
Divisionalized Form	事业部形式

Strategic Business Unit (SBU)	战略业务单元
Gateway	网关
Organic Structure	有机结构
Electronic Data Processing (EDP)	电子数据处理
Management Information System (MIS)	管理信息系统
Strategic Information System (SIS)	战略信息系统
Electronic Data Interchange (EDI)	电子数据交换

Notes

1. Very simply, computers allowed the development of planning techniques hitherto too complex to develop, compute, or control.
   简言之,计算机使得人们能够开发那些在此之前由于太复杂而不能开发、计算和控制的规划技术。
2. Categorizing information systems architecturally is appealing since it is not idiosyncratic to particular settings, and further, these architectures are fairly well established and accepted.
   根据信息系统的结构对其进行分类是有吸引力的,因为这种分类方法不因某些系统的特定设置(配置)而不同,并且根据这种分类方法所得到的各种系统结构很成熟并被广泛接受。
3. In the 1960s, there were a spate of acquisitions and mergers primarily as a response to anti-trust laws.
   20 世纪 60 年代,(美国企业)基本上针对《反信任法》而出现了收购和合并狂潮。
4. This is hard to do except to understand that evolving computer architectures impacted and enabled newer organizational forms, and over time changing organizational requirements impacted the shape and design of computer systems and architectures.
   评价计算机和企业组织结构演化直接的因果关系是一件困难的事情,但二者之间的关系可以理解为:计算机结构的演化影响了企业的组织结构并使得企业能够尝试新的组织结构形式;随着时间的推移,不断变化的组织需求又反过来对计算机系统及其结构的设计产生影响。

20 Information Technology and Business Process Redesign
信息技术与业务流程再造

Those aspiring to improve the way work is done must begin to apply the capabilities of information technology to redesign business processes. Business process design and information technology are natural partners, yet industrial engineers have never fully exploited their relationship. The authors argue, in fact, that it has barely been exploited at all. But the organizations that have used IT to redesign boundary-crossing, customer-driven processes have benefited enormously.

At the turn of the century, Frederick Taylor revolutionized the workplace with his ideas on work organization, task decomposition, and job measurement. Taylor's basic aim was to increase organizational productivity by applying to human labor the same engineering principles that had proven so successful in solving the technical problems in the work environment. The same approaches that had transformed mechanical activity could also be used to structure jobs performed by people. Taylor came to symbolize the practical realizations in industry that we now call industrial engineering (IE), or the scientific school of management. In fact, though work design remains a contemporary IE concern, no subsequent concept or tool has rivaled the power of Taylor's mechanizing vision.

As we enter the 1990s, however, two newer tools are transforming organizations to the degree that Taylorism once did. These are information technology — the capabilities offered by computers, software applications, and telecommunications — and business process redesign — the analysis and design of work flows and processes within and between organizations. Working together, these tools have the potential to create a new type of industrial engineering, changing the way the discipline is practiced and the skills necessary to practice it.

IT in business process redesign

The importance of both information technology and business process redesign is well known to industrial engineers, albeit as largely separate tools for use in specific, limited environments. IT is used in industrial engineering as an analysis and modeling tool, and IEs have often taken the lead in applying information technology to manufacturing environments. Well-known uses of IT in manufacturing include process modeling, production scheduling and control, materials management information systems, and logistics. In most cases where IT has been used to redesign work, the redesign has most likely been in the manufacturing function, and industrial engineers are the most likely individuals to have carried it out.

IEs have begun to analyze work activities in non-manufacturing environments, but their penetration into offices has been far less than in factories. IT has certainly penetrated the office and services environments — in 1987 Business Week reported that almost 40 percent of all U. S. capital spending went to information systems, some \$97 billion a year — but IT has been used in most cases to hasten office work rather than to transform it. With few exceptions, IT's role in the redesign of nonmanufacturing work has been disappointing; few firms have achieved major productivity gains. Aggregate productivity figures for the United States have shown no increase since 1973.

Given the growing dominance of service industries and office work in the Western economies, this type of work is as much in need of analysis and redesign as the manufacturing environments to which IT has already been applied. Many firms have found that this analysis requires taking a broader view of both IT and business activity, and of the relationships between them. Information technology should be viewed as more than an automating or mechanizing force; it can fundamentally reshape the way business is done. Business activities should be viewed as more than a collection of individual or even functional tasks; they should be broken down into processes that can be designed for maximum effectiveness, in both manufacturing and service environments.

Our research suggests that IT can be more than a useful tool in business process redesign. In leading edge practice, information technology and BPR have a recursive relationship. Each is the key to thinking about the other. Thinking about information technology should be in terms of how it supports new or redesigned business processes, rather than business functions or other organizational entities. And business processes and process improvements should be considered in terms of the capabilities information technology can provide. We refer to this broadened, recursive view of IT and BPR as the new industrial engineering.

Taylor could focus on workplace rationalization and individual task efficiency because he confronted a largely stable business environment; today's corporations do not have the luxury of such stability. Individual tasks and jobs change faster than they can be redesigned. Today, responsibility for an outcome is more often spread over a group, rather than assigned to an individual as in the past. Companies increasingly find it necessary to develop more flexible, team-oriented, coordinative, and communication-based work capability. In short, rather than maximizing the performance of particular individuals or business functions, companies must maximize interdependent activities within and across the entire organization. Such business processes are a new approach to coordination across the firm; information technology's promise — and perhaps its ultimate impact — is to be the most powerful tool in the twentieth century for reducing the costs of this coordination.

Redesigning business processes with IT: five steps

Assuming that a company has decided its processes are inefficient or ineffective, and therefore in need of redesign, how should it proceed? This is a straightforward activity, but five major steps are involved: develop the business vision and process objectives, identify the processes to be redesigned, understand and measure the existing process, identify IT levers, and design and build a prototype of the new process. We observed most or all of these steps being performed in companies that were succeeding with BPR. Each step is described in greater detail below.

Develop business vision and process objectives

In the past, process redesign was typically intended simply to "rationalize" the process, in other words, to eliminate obvious bottlenecks and inefficiencies. It did not involve any particular business vision or context. This was the approach of the "work simplification" aspect of industrial engineering, an important legacy of Taylorism.

Our research suggests strongly that rationalization is not an end in itself, and is thus insufficient as a process redesign objective. Furthermore, rationalization of highly decomposed tasks may lead to a less efficient overall process. Instead of task rationalization, redesign of entire processes should be undertaken with a specific business vision and related objectives in mind.

In most successful redesign examples we studied, the company's senior management had developed a broad strategic vision into which the process redesign activity fit. The most likely objectives are the following:

- Cost reduction. This objective was implicit in the "rationalization" approach. Cost is an important redesign objective in combination with others, but insufficient in itself. Excessive attention to cost reduction results in tradeoffs that are usually unacceptable to process stakeholders. While optimizing on other objectives seems to bring costs into line, optimizing on cost rarely brings about other objectives;
- Time reduction. Time reduction has been only a secondary objective of traditional industrial engineering. Increasing numbers of companies, however, are beginning to compete on the basis of time. Processes, as we have defined them, are the ideal unit for a focused time reduction analysis. One common approach to cutting time from product design is to make the steps begin simultaneously, rather than sequentially, using IT to coordinate design directions among the various functional participants. This approach has been taken in the design of computers, telephone equipment, automobiles, and copiers;
- Output quality. All processes have outputs, be they physical — such as in manufacturing a tangible product — or informational — such as in adding data to a customer file. Output quality is frequently the focus of process improvement in manufacturing environments; it is just as important in service industries. The specific measure of output quality may be uniformity, variability, or freedom from defects; this should be defined by the customer of

the process;

- Quality of worklife (QWL)/learning/empowerment. IT can lead either to greater empowerment of individuals, or to greater control over their output. Zuboff points out that IT-intensive processes are often simply automated, and that the "informating" or learning potential of IT in processes is often ignored. Moreover, Schein notes that organizations often do not provide a supportive context for individuals to introduce or innovate with IT. Of course, it is rarely possible to optimize all objectives simultaneously, and in most firms, the strongest pressures are to produce tangible benefits. Yet managers who ignore this dimension risk failure of redesigned processes for organizational and motivational factors.

Some firms have been able to achieve multiple objectives in redesigning processes with IT. Finally, all firms found it was important to set specific objectives, even to the point of quantification. Though it is difficult to know how much improvement is possible in advance of a redesign, "reach should exceed grasp." Setting goals that will stretch the organization will also provide inspiration and stimulate creative thinking.

Identify processes to be redesigned

Most organizations could benefit from IT-enabled redesign of critical (if not all) business processes. However, the amount of effort involved creates practical limitations. Even when total redesign was the ultimate objective, the companies we studied selected a few key processes for initial efforts. Moreover, when there was insufficient commitment to total redesign, a few successful examples of IT-enhanced processes became a powerful selling tool.

The means by which processes to be redesigned are identified and prioritized is a key issue. This is often difficult because most managers do not think about their business operations in terms of processes. There are two major approaches. The exhaustive approach attempts to identify all processes within an organization and then prioritize them in order of redesign urgency. The high-impact approach attempts to identify only the most important processes or those most in conflict with the business vision and process objectives.

The exhaustive approach is often associated with "information engineering", in which an organization's use of data dictates the processes to be redesigned. The alternative is to focus quickly on high-impact processes. Most organizations have some sense of which business areas or processes are most crucial to their success, and those most "broken" or inconsistent with the business vision. If not, these can normally be identified using senior management workshops, or through extensive interviewing.

Companies that employed the high-impact approach generally considered it sufficient. Companies taking the exhaustive approach, on the other hand, have not had the resources to address all the identified processes; why identify them if they cannot be addressed? As a rough rule of thumb, most companies we studied were unable to redesign and support more than ten to fifteen major processes per year (i. e. one to three per major business unit); there was simply not enough management attention to do more. And some organizations have abandoned the exhaustive approach.

Whichever approach is used, companies have found it useful to classify each redesigned process in terms of beginning and end points, interfaces, and organization units (functions or departments) involved, particularly including the customer unit. Thinking in these terms usually broadens the perceived scope of the process.

Understand and measure existing processes

There are two primary reasons for understanding and measuring processes before redesigning them. First, problems must be understood so that they are not repeated. Second, accurate measurement can serve as a baseline for future improvements. If the objective is to cut time and cost, the time and cost consumed by the untouched process must be measured accurately. Westinghouse Productivity and Quality Center consultants found that simply graphing the incremental cost and time consumed by process tasks can often suggest initial areas for redesign. These graphs look like "step functions" showing the incremental contribution of each major task.

This step can easily be overemphasized, however. In several firms, the "stretch" goal was less to eliminate problems or bottlenecks than to create radical improvements. Designers should be informed by past process problems and errors, but they should work with a clean slate. Similarly, the process should not be measured for measurement's sake. Only the specific objectives of the redesign should be measured. As with the high-impact process identification approach, an 80-20 philosophy is usually appropriate.

Identify IT levers

Until recently, even the most sophisticated industrial engineering approaches did not consider IT capabilities until after a process had been designed. The conventional wisdom in IT usage has always been to first determine the business requirements of a function, process, or other business entity, and then to develop a system. The problem is that an awareness of IT capabilities can — and should — influence process design. Knowing that product development teams can exchange computer-aided designs over large distances, for example, might affect the structure of a product development process. The role of IT in a process should be considered in the early stages of its redesign.

Several firms accomplished this using brainstorming sessions, with the process redesign objectives and existing process measures in hand. It was also useful to have a list of IT's generic capabilities in improving business processes. In the broadest sense, all of IT's capabilities involve improving coordination and information access across organizational units, thereby allowing for more effective management of task interdependence.

Design and build a prototype of the process

For most firms, the final step is to design the process. This is usually done by the same team that performed the previous steps, getting input from constituencies and using brainstorming workshops. A key point is that the actual design is not the end of the process. Rather, it should be viewed as a prototype, with successive iterations expected and managed. Key factors and tactics to consider in process design and prototype creation include using IT as a design tool, understanding generic design criteria, and creating organizational prototypes.

- IT as a design tool. Designing a business process is largely a matter of diligence and creativity. Emerging IT technologies, however, are beginning to facilitate the "process" of process design. Some computer-aided systems engineering (CASE) products are designed primarily to draw process models. The ability to draw models rapidly and make changes suggested by process owners speeds redesign and facilitates owner buy-in. Some CASE products can actually generate computer code for the information systems application that will support a modeled business process;
- Generic design criteria. Companies used various criteria for evaluating alternative designs. Most important, of course, is the likelihood that a design will satisfy the chosen design objectives. Others mentioned in interviews included the simplicity of the design, the lack of buffers or intermediaries, the degree of control by a single individual or department (or an effective, decentralized coordinative mechanism), the balance of process resources, and the generalization of process tasks (so that they can be performed by more than one person);
- Organizational prototypes. Mutual Benefit Life's (MBL) redesign of its individual life insurance underwriting process illustrates a final, important point about process design. At MBL, underwriting a life insurance policy involved 40 steps with over 100 people in 12 functional areas and 80 separate jobs. To streamline this lengthy and complex process, MBL undertook a pilot project with the goal of improving productivity by 40 percent. To integrate the process, MBL created a new role, the case manager. This role was designed to perform and coordinate all underwriting tasks centrally, utilizing a workstation-based computer system capable of pulling data from all over the company. After a brief start-up period, the firm learned that two additional roles were necessary on some underwriting cases: specialists such as lawyers or medical directors in knowledge-intensive fields, and clerical assistance. With the new role and redesigned process, senior managers at MBL are confident of reaching the 40 percent goal in a few months. This example illustrates the value of creating organizational prototypes in IT-driven process redesign.

Defining Process Types

The five steps described above are sufficiently general to apply to most organizations and processes. Yet the specifics of redesign vary considerably according to the type of process under examination. Different types require different levels of management attention and ownership, need different forms of IT support, and have different business consequences. In this section, we present three different dimensions within which processes vary.

Three major dimensions can be used to define processes. These are the organizational entities or subunits involved in the process, the type of objects manipulated, and the type of activities taking place. We describe each dimension and resulting process type below.

Defining process entities

Processes take place between types of organizational entities. Each type has different implications for IT benefits.

"Interorganizational" processes are those taking place between two or more business organizations. Increasingly, companies are concerned with coordinating activities that extend into the next (or previous) company along the value-added chain. Several U. S. retail, apparel, and textile companies, for example, have linked their business processes to speed up reordering of apparel. When Dillard's (department store) inventory of a particular pants style falls below a specified level, Haggar (apparel manufacturer) is notified electronically. If Haggar does not have the cloth to manufacture the pants, Burlington Industries (textile manufacturer) is notified electronically. As this example of electronic data interchange (EDI) illustrates, information technology is the major vehicle by which this interorganizational linkage is executed.

A second major type of business process is "interfunctional". These processes exist within the organization, but cross several functional or divisional boundaries. Interfunctional processes achieve major operational objectives, such as new product realization, asset management, or production scheduling. Most management processes — for example, planning, budgeting, and human resource management — are interfunctional.

A major problem in redesigning interfunctional processes is that most information systems of the past were built to automate specific functional areas or parts of functions. Few third-party application software packages have been developed to support a full business process. Very few organizations have modeled existing interfunctional processes or redesigned them, and companies will run into substantial problems in building interfunctional systems without such models.

"Interpersonal" processes involve tasks within and across small work groups, typically within a function or department. Examples include a commercial loan group approving a loan, or an airline flight crew preparing for takeoff. This type of process is becoming more important as companies shift to self-managing teams as the lowest unit of organization. Information technology is increasingly capable of supporting interpersonal processes; hardware and communications companies have developed new networking-oriented products, and software companies have begun to flesh out the concept of "groupware" (e.g. local area network-based mail, conferencing, and brainstorming tools).

Defining process objects

Processes can also be categorized by the types of objects manipulated. The two primary object types are physical and informational. In physical object processes, real, tangible things are either created or manipulated; manufacturing is the obvious example. Informational object processes create or manipulate information. Processes for making a decision, preparing a marketing plan, or designing a new product are examples.

Many processes involve the combination of physical and informational objects. Indeed, adding information to a physical object as it moves through a process is a common way of adding value. Most logistical activities, for example, combine the movement of physical objects with the manipulation of information concerning their whereabouts. Success in the logistics industry is often dependent on the close integration of physical and informational outcomes; both UPS and Federal Express, for example, track package movement closely.

The potential for using IT to improve physical processes is well known. It allows greater flexibility and variety of outcomes, more precise control of the process itself, reductions in throughput time, and elimination of human labor. These benefits have been pursued for the past three decades. Still, manufacturing process flows are often the result of historical circumstance and should usually be redesigned before further automation is applied. This is particularly true in low volume, job shop manufacturing environments. Redesigners of physical processes should also consider the role of IT in providing information to improve processes.

Strangely, the proportion of informational processes already transformed by IT is probably lower than that of physical processes. True, legions of clerks have become unemployed because of computers. But the majority of information processes to which IT has been applied are those involving high volume and low complexity. Now that these processes are well known even if not fully conquered, the emphasis needs to shift to processes that incorporate semistructured and unstructured tasks and are performed by high-skill knowledge workers. Relevant IT capabilities include the storage and retrieval of unstructured and multimedia information, the capturing and routinizing of decision logic, and the application of far-flung and complex data resources. A computer vendor's advertising videotape, for example, illustrates how artificial intelligence and hypertext; or mixed-media databases, combine to lead a manager through the process of developing a departmental budget. The IT capabilities in the video are available today, but they are rarely applied to such information-intensive yet unstructured processes.

Defining process activities

Our examples of business processes have involved two types of activities: operational and managerial. Operational processes involve the day-to-day carrying out of the organization's basic business purpose. Managerial processes help to control, plan, or provide resources for operational processes. Past uses of IT to improve processes, limited as they are, have been largely operational. We will therefore focus almost entirely on managerial processes in this section.

Applying IT to management tasks is not a new idea. The potential of decision support systems, executive support systems, and other managerial tools has been discussed for over twenty years. We believe, however, that the benefits have not been realized because of the absence of systematic process thinking. Few companies have rigorously analyzed managerial activities as processes subject to redesign. Even the notion of managerial activities involving defined outcomes (a central aspect of our definition of business processes) is somewhat foreign. How would such managerial processes as deciding on an acquisition or developing the agenda for the quarterly board meeting be improved if they were treated as processes — in other words, measured, brainstormed, and redesigned with IT capabilities?

The generic capabilities of IT for reshaping management processes include improving analytic accuracy, enabling broader management participation across wider geographical boundaries, generating feedback on actions taken (the managerial version of "informating" a process), and streamlining the time and resources a specific process consumes.

Management issues in IT-enabled redesign

Companies have found that once a process has been redesigned, several key issues remain. These include the management role in redesigned activity, implications for organization structure, new skill requirements, creating a function to perform IT-enabled BPR, the proper direction for the IT infrastructure, and the need for continuous process improvement. We discuss each below.

Management roles

Perhaps the greatest difficulty in IT-driven redesign is getting and keeping management commitment. Because processes cut across various pans of the organization, a process redesign effort driven by a single business function or unit will probably encounter resistance from other pans of the organization. Both high-level and broad support for change are necessary.

To perform the five redesign steps described above, several companies created a cross-functional task force headed by a senior executive. These task forces included representatives from key staff and line groups likely to be affected by the changes, including IT and human resources. It was particularly important that the customer of the process be represented on the team, even when the customer was external. The team composition was ideal if some members had some record of process or operations innovation involving IT.

As the redesign teams selected processes and developed objectives, they needed to work closely with the managers and staff of the affected units. Managing process change is similar to managing other types of change, except that its cross-functional nature increases the number of stakeholders, thereby increasing the complexity of the effort.

It was also important to have strong, visible commitment from senior management. Employees throughout the organization needed to understand that redesign was critical, that differences of opinion would be resolved in favor of the customer of a process, and that IT would play an important role. In many cases, the CEO communicated any structural implications of the redesign effort.

Process redesign and organizational structure

A second key issue is the relationship between process orientation and organizational structure. Certainly someone must be in charge of implementing a process change, and of managing the redesigned process thereafter. But process responsibilities are likely to cut across existing organizational structures. How can process organization and traditional functional organization be reconciled?

One possible solution is to create a new organization structure along process lines, in effect abandoning altogether other structural dimensions, such as function, product, or geography. This approach presents risks, however; as business needs change, new processes will be created that cut across the previous process-based organization. This does not mean that a process-based structure cannot be useful, but only that it will have to be changed frequently.

While no firm we studied has converted wholly to a process-based structure, a few organizations have moved in this direction. For example, Apple Computer recently moved away from a functional structure to what executives describe as an IT-oriented, process-based, customer satisfaction-driven structure called "New Enterprise." The company relishes its lack of formal hierarchy; Apple managers describe their roles as highly diffuse, and team and project based.

A more conservative approach would be to create a matrix of functional and process responsibilities. However, because of the cross-functional nature of most processes, the functional manager who should have responsibility for a given process is not always easy to identify. The company may also wish to avoid traditional functional thinking, in assigning process responsibilities. For example, it may be wiser to give responsibility for redesigning supplies acquisition to a manager who uses those supplies (i. e. the customer of the process), rather than to the head of purchasing.

New skill requirements

For process management to succeed, managers must develop facilitation and influence skills. Traditional sources of authority may be of little use when process changes cut across organizational units. Managers will find themselves trying to change the behavior of employees who do not work for them. In these cases, they must learn to persuade rather than to instruct, to convince rather than to dictate. Of course, these recommendations are consistent with many other organizational maxims of the past several years; they just happen to be useful in process management as well.

Several organizations that are moving toward IT-driven process management are conducting programs intended to develop facilitation skills. These programs encourage less reliance on hierarchy, more cross-functional communication and cooperation, and more decision making by middle- and lower-level managers. Such a program at American Airlines is being used to build an organizational infrastructure at the same time a new IT infrastructure is being built.

An ongoing organization

Organizations that redesign key processes must oversee continuing redesign and organizational "tuning," as well as ensure that information systems support process flows. In most companies, the appropriate analytical skills are most likely to be found in the IT function. However, these individuals will also require a high degree of interpersonal skills to be successful as the "new industrial engineers." The ideal group would represent multiple functional areas, for example, information systems, industrial engineering, quality, process control, finance, and human resources.

Process redesign and the IT organization

Just as information technology is a powerful force in redesigning business processes, process thinking has important implications for the IT organization and for the technology infrastructure it builds. Though few IT groups have the power and influence to spearhead process redesign, they can play several important roles. First of all, the IT group may need to play a behind-the-scenes advocacy role, convincing senior management of the power offered by information technology and process redesign. Second, as demand builds for process redesign expertise, the IT group can begin to incorporate the IE-oriented skills of process measurement, analysis, and redesign, perhaps merging with the IE function if there is one. It can also develop an approach or methodology for IT-enabled redesign, perhaps using the five steps described above as a starting point.

What must the information systems function do technologically to prepare for process redesign? IT professionals must recognize that they will have to build most systems needed to support (or enable) processes, rather than buy them from software package vendors, because most application packages are designed with particular functions in mind. IT professionals will need to build robust technology platforms on which process-specific applications can be quickly constructed. This implies a standardized architecture with extensive communications capability between computing nodes, and the development of shared databases. However, like the organizational strategies for process management described above, these are appropriate technology strategies for most companies, whether or not they are redesigning processes with IT.

Continuous process improvement

The concept of process improvement, which developed in the quality movement, requires first that the existing process be stabilized. It then becomes predictable, and its capabilities become accessible to analysis and improvement. Continuous process improvement occurs when the cycle of stabilizing, assessing, and improving a given process becomes institutionalized.

IT-enabled business process redesign must generally be dynamic. Those responsible for a process should constantly investigate whether new information technologies make it possible to carry out a process in new ways. IT is continuing to evolve, and forthcoming technologies will have a substantial impact on the processes of the next decade. The IT infrastructure must be robust enough to support the new applications appropriate to a particular process.

Summary

We believe that the industrial engineers of the future, regardless of their formal title or the organizational unit that employs them, will focus increasingly on IT-enabled redesign of business processes. We have only begun to explore the implications and implementation of this concept, and only a few companies have ventured into the area. Many companies that have used IT to redesign particular business processes have done so without any conscious approach or philosophy. In short, the actual experience base with IT-enabled process redesign is limited.

Yet managing by customer-driven processes that cross organizational boundaries is an intuitively appealing idea that has worked well in the companies that have experimented with it. And few would question that information technology is a powerful tool for reshaping business processes. The individuals and companies that can master redesigning processes around IT will be well equipped to succeed in the new decade and the new century.

Professional Words and Expressions

Work Organization	工作组织
Task Decomposition	任务分解
Job Measurement	作业测量
Information Technology	信息技术
Business Process Redesign	业务流程再造
Process Modeling	过程建模
Production Scheduling and Control	生产调度和控制
Materials Management Information Systems	物料管理信息系统
Logistics	物流
Workplace Rationalization	工作现场的合理化
Accounts Payable	应付账款
Accounts Receivable	应收账款
Cross-Functional Analysis	交叉职能分析
80-20 Philosophy	80/20 哲学,80/20 原则
Computer-Aided Systems Engineering (CASE)	计算机辅助系统工程
Underwriting	保险业
Value-Added Chain	增殖链
Electronic Data Interchange (EDI)	电子数据交换
Local Area Network (LAN)	局域网
Invoice	发票
Bills of Materials	物料清单
Asset Management	资产管理
Production Scheduling	生产计划,生产调度
Human Resource Management	人力资源管理
Continuous Process Improvement	持续流程改进

Notes

1. At the turn of the century, Frederick Taylor revolutionized the workplace with his ideas on work organization, task decomposition, and job measurement.
泰勒(1856—1915):发展了工作研究(Work Study)——方法研究及工作评量(Method study and work measurement)。从 1898 年到 1901 年服务于伯利恒钢铁公司(The Bethlehem Steel Company)的期间,除了顾问的工作外,泰勒发展了各种新的制造程序,并

且获得上百件专利。泰勒著名的论文有："A Piece Rate System（1895）"，"Shop Management（1903）"，"On the Art of Cutting Metals（1906）"，之后他汇集经验及思考于1911年出版了其著作"The Principles of Scientific Management"，说明科学管理的四原则：

（1）将每一个人的工作、每一单元均以科学方法加以分析，取代以往尝试错误所得的经验法则；

（2）选择最适当的作业员，而且要训练作业员以经过研究的方法来改善；

（3）使管理员与作业员之间，发展出合作的精神；

（4）在管理者和作业员之间，将工作责任公平地划分出来，使各方均能尽其所长。

泰勒倡导科学管理最早，因此大家公认他是"科学管理之父"、"工业工程之父"、"时间研究之父"。

该句可翻译为：20世纪初，弗雷德里克·泰勒利用工作组织、任务分解和作业测量对工作现场进行了革命性变革。

2. The importance of both information technology and business process redesign is well known to industrial engineers, albeit as largely separate tools for use in specific, limited environments.

尽管工业工程师对信息技术和业务流程再造的重要性有很深入的了解，但它们通常被作为不同的工具在特定的、有限的范围内使用。

3. Our research suggests strongly that rationalization is not an end in itself, and is thus insufficient as a process redesign objective.

我们的研究明确地表明流程的合理化本身并不是流程再造的最终目的，因此将其作为流程再造的目标是不充分的。

4. While optimizing on other objectives seems to bring costs into line, optimizing on cost rarely brings about other objectives.

尽管在优化其他目标时成本也似乎得到了优化，但对成本的优化很少能使得其他目标顺便得到优化。

5. Designers should be informed by past process problems and errors, but they should work with a clean slate.

尽管应该被告知过去发现的关于流程的问题和错误，但设计人员还是应该从零做起。

6. Information technology is increasingly capable of supporting interpersonal processes; hardware and communications companies have developed new networking-oriented products, and software companies have begun to flesh out the concept of "groupware" (e.g. local area network-based mail, conferencing, and brainstorming tools).

信息技术对处理人与人之间关系的流程的支持能力越来越强；硬件和通讯公司已经开发出新的网络产品，软件公司已经逐步形成"组件"（例如基于局域网的电子邮件，网络会议和头脑风暴工具）的概念。

专业词汇汇总表

A

80-20 Philosophy	80/20 哲学,80/20 原则
Accident Proneness	事故倾向性
Accounts Payable	应付账款
Accounts Receivable	应收账款
Activity/Work Sampling	活动/工作抽样
Activity-Based Costing（ABC）	基于活动的成本分析
Advanced Information Technologies	先进信息技术
Agile Enterprise	敏捷企业
Agile Layout	敏捷布局
Agile Manufacturing	敏捷制造
Algebra	代数学
American Standard Code for Information Interchange（ASCII）	用于信息交换的美国标准编码
Analytic Solution	解析解,分析解
Anthropometry	人体测量学
Appraisal Cost	估价成本
Apprentice Position	见习职位,实习岗位
Artificial Intelligence（AI）	人工智能
Assembly Line	装配线
Asset Management	资产管理
Auditory Sense	听觉
Automated Guided Vehicle（AGV）	自动导航设备
Automated Storage and Retrieval System（AS/RS）	自动存取系统
Automated Test Equipment（ATE）	自动检测设备
Automation（ASD）	自动化
Autonomation（ADW）	员工自治(有决定停线的权利)

B

Backlog Cost	缺货成本
Beer Distribution Game	啤酒分销游戏
Behavioral Factor	行为参数，行为因素
Benchmarking	标杆超越
Bill Of Materials（BOM）	物料清单
Biomechanics	生物力学
Bound	界限
Breaking of Administrative Barriers（BAB）	打破管理界线
Breaking of Physical Barriers（BPB）	打破物理分隔
Buffer Management	缓冲器管理
Bullwhip Effect	长鞭效应，牛鞭效应
Business Planning and Development	商业规划与开发
Business Process Redesign	业务流程再造
Business Process Redesign/Reengineering（BPR）	业务流程再设计/再造

C

Calculus	微积分
Capacity Assignment	能力分配
Capacity Design	能力(产能)设计
Capacity Requirements Planning（CPR）	能力需求规划
Cash Flow	现金流
Cell	制造单元
Cellular Layout	单元式布局
Cellular Manufacturing	单元制造
Centralized Design	集中式设计
Centralized Single Business Organization	集中式的单一企业组织
Centralized System	集中式系统
Change Notice	变更通知单
Closed-Loop MRP System	闭环 MRP 系统
Coaxial Cable	同轴电缆
Code of Ethics	道德标准，职业准则
Cognitive Ability	认知能力
Cognitive Ergonomics	认知功效学
Combinatorial Optimization Problem	组合优化问题
Communication Facility	通讯设备
Computer Graphics	计算机图形学
Computer Integrated Manufacturing System	计算机集成制造系统

Computer Numerical Control (CNC)	计算机数控
Computer Science	计算机科学
Computer Simulation	计算机仿真
Computer-Aided Design (CAD)	计算机辅助设计
Computer-Aided Engineering (CAE)	计算机辅助工程
Computer-Aided Manufacturing (CAM)	计算机辅助制造
Computer-Aided Process Planning (CAPP)	计算机辅助工艺规划
Computer-Aided Software Engineering (CASE)	计算机辅助软件工程
Computer-Aided Systems Engineering (CASE)	计算机辅助系统工程
Computer-Automated Inspection (CAI)	计算机自动检测
Computer-Generated Work Standard	计算机生成的工作标准
Computer-Integrated Manufacturing/Services	计算机集成制造/服务
Computing Power	计算能力
Concurrent Engineering	并行工程
Consolidated Facility	联合设施，公用设施
Constraint Management	约束管理
Constraints	约束
Continuous Improvement (CI)	持续改进
Continuous Process Improvement	持续流程改进
Continuous Simulation Model	连续仿真模型
Continuous System	连续系统
Contract Manufacturing	契约制造
Controller	控制器
Coordinate Transformation	坐标变换
Corporate Quality Culture	企业质量文化
Critical Path Method (CPM)	关键路线法
Cross-Functional Analysis	交叉职能分析
Current Reality Tree (CRT)	当前现实树
Customer Focus	以客户为中心
Customer Involvement	顾客参与
Customer Needs	顾客需求

D

Data Collector	数据收集器
Data Processing	数据处理
Database Facility	数据库设施
Decentralized Design	分布式设计
Decentralized System	分散式系统
Decision Support System (DSS)	决策支持系统

Decision Theory	决策理论
Defective Part	次品
Degree of Unrelatedness	不相关度
Delayed Product Differentiation	产品延迟差异化
Department of Defense (DoD)	美国国防部
Dependent Variable	非独立变量
Design for Assembly/Manufacturability	面向装配/制造的设计
Design for Maintainability	面向维护的设计
Design for Reliability	面向可靠性的设计
Design for Reusability	面向可重复使用的设计
Design Priority	设计优先级
Deterministic Simulation Model	确定型仿真模型
Direct Labor Cost	直接劳动力成本
Direct Numerical Control (DNC)	直接数控
Directed Grap	有向图
Discrete Event Stochastic System (DESS)	离散事件随机系统
Discrete Optimization	离散优化
Discrete Simulation Model	离散仿真模型
Discrete System	离散系统
Distributed Layout	分布式布局
Distributed Numerical Control (DNC II)	分布式数控
Distributed System	分布式系统
Distributor	分销商
Divisionalized Form	事业部形式
Divisionalized Structure	事业部式结构
Drum-Buffer-Rope (DBR)	鼓－缓冲器－绳子
Dynamic Simulation Model	动态仿真模型

E

Electric Relay	电子继电器
Electrically-powered	电动的
Electro-Magnetic Interference (EMI)	电磁干涉
Electronic Commerce	电子商务
Electronic Data Interchange (EDI)	电子数据交换
Electronic Data Processing (EDP)	电子数据处理
Electronic Delayed Storage Automatic Computer	电子延迟储存自动计算机
Electronic Discrete Variable Automatic Computer	电子离散变量自动计算机
Electronic Numerical Integrator and Calculator	电子数字集成器和计算器
Employee Empowerment	员工授权

Employee Involvement	员工参与
Employee Relations	员工关系
Empowered Employee	被授权的员工
End-Effector	执行件
Engineering Economics	工程经济学
Engineering Management	工程管理
Engineering Psychology	工程心理学
Engineering Services	工程服务
Enhanced Communication	强化沟通
Enterprise Integration	企业集成
Enterprise Resource Planning (ERP)	企业资源规划
Entrepreneurship Management	企业家管理
Equipment Obsolescence	设备老化
Ergonomics	人因学、功效学
Estimate	估算
Evaporating Cloud (EC)	消雾法
Experimental Economics	实验经济学
Experimental Psychology	实验心理学
Expert System	专家系统
Exponential Smoothing	指数平滑
Extended Binary-Coded-Decimal Interchange Code (ECDIC)	扩展的十进制二元编码交换码

F

Factory Automation	工厂自动化
Factory Layout	工厂布局
Failure Cost	失败成本
Feedback Loops	反馈回路
Fiber-Optic Cable	光纤电缆
Financial Management	金融/财务管理
Flexible Automation	柔性自动化
Flexible Manufacturing Cell (FMC)	柔性制造单元
Flexible Manufacturing Systems (FMS)	柔性制造系统
Flow-of-Products-oriented Layout (FPL)	面向产品流动的布局
Force Sensor	压力传感器
Forecasting	预测
Formality	形式化
Foundation Element	基本要素
Functional Layout	功能式布局

Future Reality Tree (FRT)	未来现实树

G

Gateway	网关
Generative CAPP	生成式计算机辅助工艺规划
Group Technology (GT)	成组技术

H

Hard Automation	刚性自动化
Higher Level Language	高级计算机语言
Histogram	直方图
Historical Data	历史数据
Holding Cost	库存成本
Horizontally Integrated Structure	横向集成式结构
Hub-and-Spoke Layout	轮辐式布局
Human Centered Design	面向人类的设计
Human Factors	人因学,功效学
Human Factors Engineering	人因工程
Human Perception	人类感知
Human Reliability	人类可靠性
Human Resource Management	人力资源管理
Human-Computer Interaction	人机交互
Hybrid Organization	混合型组织
Hydraulically- powered	液动的
Hypercube Queueing Model	超立方排队模型

I

Idiosyncratic Variable	特征变量
Important Factor	关键因素
Incentive Scheme	激励机制
Independent Variable	独立变量
Indirect Cost	间接成本
Individual Preference	个人偏好
Industrial Age/Era	工业时代
Industrial Engineer	工业工程师
Industrial Engineering	工业工程
Industrial Psychology	工业心理学
Infinite Manufacturing Capacity	无限制造能力,无限生产能力
Information Age/Era	信息时代

Information Processing	信息处理
Information System	信息系统
Information Technology (IT)	信息技术
Innovation Management	创新管理
Intangible Cost	无形成本
Integer Optimization	整数优化
Integrated Circuit Board	集成电路板
Interactive Expert System	交互式专家系统
Interchangeable Part	可互换零件
Intermediate/Short-Term Scheduling	中/短期规划，调度
Internal Rates of Return (IRR)	内部收益率
Inventory	库存
Inventory Allocation	存货分配
Inventory Cost	库存成本
Inventory Management	库存管理
Investment Analysis	投资分析
Invoice	发票
Irreducible Cost	既约成本
Iterative Process	反复/迭代过程

J

Japanese Management	日式管理
Job Design	作业设计
Job Measurement	作业测量
Job Rotation (JR)	工作轮换，轮岗
Just-In-Time (JIT)	准时生产

K

Kanban	看板

L

Lagrange Multiplier	拉格朗日乘数
Lagrangian Relaxation	拉格朗日松弛法
Large Scale Integration (LSI)	大型集成器
Layout/Facility Design	布局/设施设计
Linear Programming	线性规划
Local Area Network (LAN)	局域网
Location	选址
Logical Relationship	逻辑关系

Logistics	物流

M

Machine Bureaucracies	机械官僚机构
Machine Utilization	设备利用率
Macroergonomics	宏观功效学
Mainframe Host Computer	大型主机
Maintainability	可维护性
Maintenance	维护
Management Commitment	管理承诺
Management Information System (MIS)	管理信息系统
Management Science	管理科学
Management Services	管理服务
Management Support	管理层支持
Manipulators	操作件
Man-Machine Systems	人机系统
Manual Response	手动响应
Manufacturer	制造商
Manufacturing Automation Protocol (MAP)	制造自动化协议
Manufacturing Line Balancing	生产线平衡
Manufacturing Management	制造管理
Manufacturing Resources Planning (MRP II)	制造资源规划
Manufacturing System	制造系统
Manufacturing/Service Strategy	制造/服务战略
Markov Decision Process	马尔可夫决策过程
Mass Customization	大规模订制
Mass Production	大规模生产
Mass Production of Mixed Models (MMP)	混合型号产品的大规模生产
Master Standard Data (MSD)	主时间数据法
Material Handling	物料搬运
Material Requirement Planning (MRP)	物料需求规划
Materials Management Information Systems	物料管理信息系统
Mathematical Model	数学模型
Mathematical Programming	数学规划
Mathematical Relationship	数学关系
Matrix Organization	矩阵式组织
Maynard Operation Sequence Technique (MOST)	梅纳德操作排序技术
Mechatronics	机械电子学
Memory	内存

Methods Time Measurement (MTM)	方法时间测量法
Microprocessor	微处理器
Minicomputer	小型机
Model	模型
Modular Arrangement	模块化安排法
Modular Layout	模块式布局
Monte Carlo Model	蒙特卡罗模型
Motion Analysis	动作分析
Motion Standard Times (MST)	动作标准时间法
Motion Study	动作研究
Moving Average Approach	移动平均法
Multichannel Manufacturing	多通道制造
Multi-Machine Manning Working System (MMM)	多设备配员工作系统
Multiobjective Optimization	多目标优化
Musculoskeletal Disorder	肌骨失调，肌骨紊乱

N

n-echelon	*n* 级，*n* 阶
Negative Branches	负效应枝条
Net Present Value (NPV)	净现值
Net Profit	净利润
Network organization	网络型组织
Network Problem	网络问题
Network Queueing Model	网络排队模型
New Product Development	新产品开发
Nonconvex	非凸的
Nonlinear Optimization	非线性优化
Nonsparse Matrix	非稀疏矩阵
Numerical Control (NC) Machine	数控机床
Numerical Control Part Programming	数控零件编程

O

Objective Function	目标函数，目标方程
Occupational Hazards	职业危险
On-the-Job Training (OJT)	在线培训，在岗培训
Open Systems Interconnection (OSI)	开放系统互联
Operating Expenses	运作费用
Operating System (OS)	操作系统
Operational Cause	运作因素

Operations Management	运作管理
Operations Research	运筹学
Opportunity Cost	机会成本
Optimized Production Technology (OPT)	最优生产技术
Order Batching	批量订购
Ordering Cost	订购成本
Organic Structure	有机结构
Organization Structure	组织结构
Organizational Theory	组织理论
Original Equipment Manufacturer (OEM)	原始设备制造商
Outsourcing	外包
Overhead	企业一般管理费

P

Performance Improvement Engineering	绩效改善工程
Performance Measure	绩效测量
Peripheral Capability	外设(外部设备)能力
Perishability	易逝性
Personal Computers (PCs)	个人电脑
Personnel Selection	职员甄选
Physical/Iconic Model	物理模型
Physiological Arousal	生理干扰
Planning and Scheduling	规划和调度
Plastic Injection-Molding Machine	塑料注塑机
Pneumatically- powered	气动的
Point-To-Point (PTP) robot	点到点机器人
Poka Yoke or Automatic Stopping Device	自动停线设施
Polynomial Algorithm	多项式算法
Portable Machine	便携式机器
POS Data	销售点数据
Pre-determined Motion Times System (PMTS)	预定动作时间系统
Predetermined Time Standards (PTS)	预定时间标准法
Prerequisite Tree (PrT)	必备树
Prevention Cost	预防成本
Price Fluctuation	价格浮动
Primitives	基本构图要素
Printed-Circuit Board	印刷电路板
Probability Theory	概率论
Process Design	工艺设计

Process Layout	工艺式布局
Process Management	流程管理
Process Modeling	过程建模
Processor	处理器
Product Concept	产品概念
Product Concept Statement	产品概念陈述
Product Definition	产品定义
Product Feature and Function	产品特征和功能
Product Layout	产品式布局
Product Life Cycle	产品生命周期
Product Portfolio	产品汇总表
Product Strategy	产品策略
Product/Service Design	产品/服务设计
Production Lead Time	生产提前期
Production Scheduling and Control	生产调度和控制
Professional Bureaucracies	专业官僚机构
Profile Estimation	轮廓评估
Program Evaluation and Review Technique (PERT)	计划评审技术
Programmable Logic Controller (PLC)	可编程逻辑控制器
Project Audit	项目审计
Project Justification	项目论证
Project Management	项目管理
Project Plan	项目计划
Project Planning	项目规划
Project Priority	项目优先级
Projected Resource Requirement	资源需求预估
Project-Specific Element	项目特有要素
Protocol	协议
Prototyping	原型
Punched Card	穿孔卡片

Q

Quality Control	质量控制
Quality Control Circle	质量控制圈
Quality Cost	质量成本
Quality Function Deployment	质量功能展开
Quality Improvement Engineering	质量改善工程
Quality Management	质量管理
Quality Movement	质量运动

Quality Policy	质量政策
Quantitative Management	定量化管理
Quick Set-Up	快速启动

R

Rapid Prototyping	快速原型
Rate of Return	收益率
Rating or Leveling Factor	评比因子
rational	理性的
Real Cost	实际成本
Reconfigurability	可重组性,可重塑性
Reliability	可靠性
Research and Development (R&D)	研究与开发,研发
Research and Development Management	研发管理
Resource Constraint	资源限制
Response	响应,反应
Retailer	零售商
Return-On-Investment (ROI)	投资收益率
Risk Analysis	风险分析
Robotics	机器人
Robotics Programming	机器人编程
Routing and Dispatching	路径规划和调度

S

Scalable Machine	可扩展的机器
Semiconductor Memory	半导体存储器
Sensitivity Analysis	灵敏度分析
Sensor	传感器
Service Intangibility	服务的无形性
Service/Product Design	服务/产品设计
Setup Cost	生产准备成本
Setup time	生产准备时间
Shop Floor Reduction (SFR)	车间缩减
Shop-Floor Activities	车间活动
Shop-Floor Control (SFC)	车间控制
Simple Moving Average	简单移动平均
Simple Structure	简单结构
Simplex Algorithm	单纯形(算)法
Simulation	仿真

Simulation Model	仿真模型
Simulation Modeling	仿真建模
Simultaneity of Production	生产的同时性
Sketch	草图
Software	软件
Software Engineering	软件工程
Speed-Accuracy Trade-Off (SATO)	速度和精度的平衡
Stand-alone System	单机系统
Standard Operations (SO)	操作标准化
Standardization	标准化
Standardized Language	标准计算机语言
Star Layout	星型布局
State Variable	状态变量
Static Simulation Model	静态仿真模型
Statistical Process Control (SPC)	随机过程控制
Statistics	统计学
Steering Committee	控制委员会,指导委员会
Stochastic Modeling	统计建模
Stochastic Network Analysis	随机网络分析
Stochastic Service System	随机服务系统
Stochastic Simulation Model	随机仿真模型
Storage Capacity	存储能力
Storage Device	存储设备
Stored Program	存储程序
Strategic Business Unit (SBU)	战略业务单元
Strategic Information System (SIS)	战略信息系统
Strategic Quality Management	战略质量管理
Stress Analysis	应力分析
Subject	实验参加者,实验主体
Suggestions System (SS)	建议系统
Supplier Development	供应商开发
Supplier Partnership	与供应商的伙伴关系
Supplier Quality Management	供应商质量管理
Supply Chain Management (SCM)	供应链管理
Supply Chain Partner	供应链合作伙伴
Supply-Chain Partnering	供应链结盟
Support Cost	辅助成本
System Cost	系统成本
System/Product Life Cycle	系统/产品生命周期

Systems Design and Operations	系统设计和运作
Systems Engineering	系统工程
Systems Integration	系统集成

T

Tactile Sensor	触觉传感器
Taguchi Methods	田口法
Tangible Cost	有形成本
Tangible Product	实物产品
Target Market Segment	目标市场部分
Task	任务
Task Decomposition	任务分解
Team Building	团队建设
Teamwork	团队合作
Technical and Office Protocol (TOP)	技术和办公协议
Technological Cost	技术成本
Technological Innovation	技术创新,技术革新
Technological Risk Management	技术风险管理
Terminal	终端
The Institute for Defense Analysis(IDA)	防御分析研究所
Theory of Constraints (TOC)	约束理论
Thinking Process (TP)	思维流程
Three-Dimensional Model	三维模型
Threshold Value	阀值
Throughput	生产量,生产率
Throughput	产销率(约束理论)
Time Study	时间研究
Time-and-Motion Study	时间和动作研究
Total Preventive Maintenance (TPM)	全面预防性维护
Total Quality Management (TQM)	全面质量管理
Total Quality Service (TQS)	全面质量服务
Training	培训
Transistor	晶体管
Transition Tree (TrT)	转变树
Transportation Problem	运输问题

U

U. S. Army Missile Command (MICOM)	美国战术导弹指挥部
U-formed Processing Line (UPL)	U 形生产线

Unconstrained Optimization	无约束优化
Underwriting	保险业
Undesirable Effects (UDEs)	不良效果
Unit Record Machines (URMs)	单元记录机
Usability Study	使用性研究

V

Vacuum Tube	真空管
Value-Added Chain	增殖链
Valve	电子管
Variant CAPP	变异式计算机辅助工艺规划
V-A-T process structure analysis	(企业的)VAT 流程结构分析
Verbal Response	语音响应
Vertically Integrated Structure	纵向集成式结构
Very Large Scale Integration (VLSI)	超大规模集成器
Virtual Enterprise	虚拟企业
Virtual Manufacturing/Services	虚拟制造/服务
Virtual Memory	虚拟内存
Virtual Reality	虚拟现实
Vision Sensor	视觉传感器
Visual Sense	视觉

W

Waste-Disposal Facility	废物处理设施
Wholesaler	批发商
Wide Area Network (WAN)	广域网
Work Center	工作中心
Work Organization	工作组织
Work Physiology	工作生理学
WorkFactor	工作要素法
Work-In-Process (WIP)	半制品、在制品
Work-Measured Labor Standards	作业测量的劳动力标准
Workpiece	工件
Workplace Rationalization	工作现场的合理化

Z

Zero Defects	零缺陷
Zero Inventories	零库存

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