

# Engineering Management

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# Introduction

**Engineering management** is a specialized form of management, related to industrial engineering, that is concerned with the application of engineering principles to business practice.

Example areas of engineering are product development, manufacturing, construction, design engineering, industrial engineering, technology, production, or any other field that employs personnel who perform an engineering function.

Successful engineering managers typically require training and experience in business and engineering. Technically inept managers tend to be deprived of support by their technical team, and non-commercial managers tend to lack commercial acumen to deliver in a market economy. Largely, engineering managers manage engineers who are driven by non-entrepreneurial thinking, thus require the necessary people skills to coach, mentor and motivate technical professionals. Engineering professionals joining manufacturing companies sometimes become engineering managers by default after a period of time. They are required to learn how to manage once they are on the job, though this is usually an ineffective way to develop managerial abilities.

## History

### Departments

The first university department titled "Engineering Management" was founded at the Missouri University of Science and Technology (Missouri S&T, formerly the University of Missouri-Rolla) in 1967. Stevens Institute of Technology is believed to have the oldest EM department, established as the School of Business Engineering in 1907. This was later called the Bachelor of Engineering in Engineering Management (BEEM) program and moved into the School of Systems and Enterprises.

### Graduate

Missouri S&T is credited with awarding the first Ph.D. in Engineering Management in 1984. The National Institute of Industrial Engineering based in Mumbai has been

awarding degrees in the field of Post Graduate Diploma in Industrial Engineering since 1973 and the Fellowship (Doctoral) degrees are being awarded since 1980.

## **Education**

Engineering Management programs typically include instruction in accounting, economics, finance, project management, systems engineering, mathematical modeling and optimization, management information systems, quality control & six sigma, operations research, human resources management, industrial psychology, safety and health.

There are many options for entering into engineering management, albeit that the foundation requirement is an engineering degree (or other computer science, mathematics or science degree) and a business degree.

### **Undergraduate Degrees**

Although most engineering management programs are geared for graduate studies, there are a few elite institutions that teach EM at the undergraduate level. Some of the ones that are accredited and/or recognized by ASEM include: WestPoint (United States Military Academy), Stevens Institute of Technology, Rensselaer Polytechnic Institute, George Washington University

### **Graduate Degrees**

Some educational institutions in both developing and established economies are now offering post graduate courses in engineering management, helping students understand the unique requirements of applying leadership abilities and management knowledge in the technology and engineering organizations. These include:

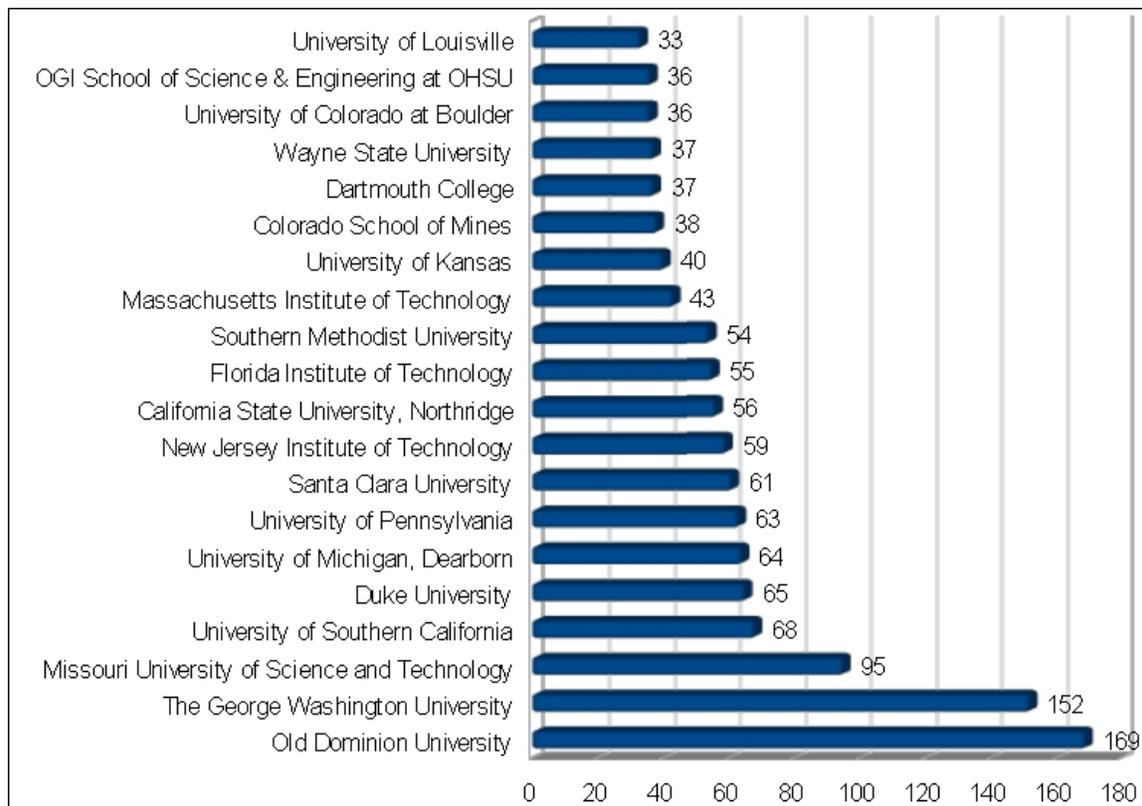
- Bachelors of Engineering and Bachelors of Law, 6.5 year degree
- Bachelors of Engineering and Bachelors of Commerce, 6 year degree
- Bachelors of Engineering with Bachelors of Law and Bachelors of Commerce, 8 year degree
- Bachelors of Engineering followed by a Masters of Business Administration, 7 year degree
- Bachelors of Engineering followed by a Master of Engineering Management, technical-based alternative to MBA
- Bachelors of Engineering followed by professional certification as a Certified Management Consultant - 8 years
- Bachelors of Engineering followed by licensing as a Professional Engineer - 10 years

It is generally recognized a Ph.D in Engineering may also be necessary to be competitive. In addition, professional association recognition may be achieved through certification programs that validate managerial skill.

The University of Waterloo offers a 4-year undergraduate degree (5 years including co-op education) in the field of Management Engineering. This is the first program of its kind in Canada.

### ***Largest EM Programs***

According to the American Society for Engineering Education (ASEE) PRISM Magazine (March 2008) the largest Master's of Engineering Management (MEM) programs (in terms of degrees awarded for 2005 -2006) are shown in the following chart.



### ***Engineering management consultants***

As engineering firms are usually small partnerships, they cannot afford in-house management, therefore giving rise to the need for engineering management consultancy. It involves providing management consulting advice that is specific to engineering. Indifferent from the traditional focus of the Boston Consulting Group and McKinsey, science and engineering requires a particularly holistic approach involving art and science. There are many branches of engineering management consultancy (commerce), including law, accounting, human resources, marketing, politics, economics, finance, public affairs, and communication. Commonly, engineering management consultants are also used when firms require special technical knowledge, though many prefer to use engineering educational consultants for such a task, to upgrade organizational knowledge and in able to keep the intellectual property confidential. Though many firms opt to use

traditional management consulting firms, many lack the know-how to tailor the traditional theories to accommodate technical workers.

### ***Professional organizations***

There are a number of societies and organizations dedicated to the field of engineering management. One of the largest societies is a division of IEEE, the Engineering Management Society, which regularly publishes a trade magazine. Another prominent professional organization in the field is the American Society of Engineering Management, which was founded in 1979 by a group of 20 engineering managers from industry. The Master of Engineering Management Programs Consortium is a newly formed consortium of prominent universities intended to raise the value and visibility of the MEM degree. The Engineering Management Certification International, is a part of American Society of Mechanical Engineers, provides a very comprehensive guide on Engineering Management, known as EMC-BOK Guide. EMCI also provides two levels of Engineering Management Certification; EMCF & EMCP. Also, engineering management university programs have the possibility of being accredited by ABET or ATMAE.

## Chapter 1

# New Product Development

In business and engineering, **new product development** (NPD) is the term used to describe the complete process of bringing a new product or service to market. There are two parallel paths involved in the NPD process: one involves the idea generation, product design and detail engineering; the other involves market research and marketing analysis. Companies typically see new product development as the first stage in generating and commercializing new products within the overall strategic process of product life cycle management used to maintain or grow their market share.

### ***The process***

1. **Idea Generation** is often called the "fuzzy front end" of the NPD process
  - Ideas for new products can be obtained from basic research using a SWOT analysis (Strengths, Weaknesses, Opportunities & Threats), Market and consumer trends, company's R&D department, competitors, focus groups, employees, salespeople, corporate spies, trade shows, or Ethnographic discovery methods (searching for user patterns and habits) may also be used to get an insight into new product lines or product features.
  - Lots of ideas are being generated about the new product. Out of these ideas many ideas are being implemented. The ideas use to generate in many forms and their generating places are also various. Many reasons are responsible for generation of an idea.
  - Idea Generation or Brainstorming of new product, service, or store concepts - idea generation techniques can begin when you have done your OPPORTUNITY ANALYSIS to support your ideas in the **Idea Screening Phase** (shown in the next development step).
2. **Idea Screening**
  - The object is to eliminate unsound concepts prior to devoting resources to them.
  - The screeners should ask several questions:
    - Will the customer in the target market benefit from the product?
    - What is the size and growth forecasts of the market segment/target market?

- What is the current or expected competitive pressure for the product idea?
  - What are the industry sales and market trends the product idea is based on?
  - Is it technically feasible to manufacture the product?
  - Will the product be profitable when manufactured and delivered to the customer at the target price?
3. **Concept Development and Testing**
- Develop the marketing and engineering details
    - Investigate intellectual property issues and search patent data bases
    - Who is the target market and who is the decision maker in the purchasing process?
    - What product features must the product incorporate?
    - What benefits will the product provide?
    - How will consumers react to the product?
    - How will the product be produced most cost effectively?
    - Prove feasibility through virtual computer aided rendering, and rapid prototyping
    - What will it cost to produce it?
  - Testing the Concept by asking a sample of prospective customers what they think of the idea. Usually via Choice Modelling.
4. **Business Analysis**
- Estimate likely selling price based upon competition and customer feedback
  - Estimate sales volume based upon size of market and such tools as the Fourt-Woodlock equation
  - Estimate profitability and break-even point
5. **Beta Testing and Market Testing**
- Produce a physical prototype or mock-up
  - Test the product (and its packaging) in typical usage situations
  - Conduct focus group customer interviews or introduce at trade show
  - Make adjustments where necessary
  - Produce an initial run of the product and sell it in a test market area to determine customer acceptance
6. **Technical Implementation**
- New program initiation
  - Finalize Quality management system
  - Resource estimation
  - Requirement publication
  - Publish technical communications such as data sheets
  - Engineering operations planning
  - Department scheduling
  - Supplier collaboration
  - Logistics plan
  - Resource plan publication
  - Program review and monitoring

- Contingencies - what-if planning
- 7. **Commercialization** (often considered post-NPD)
  - Launch the product
  - Produce and place advertisements and other promotions
  - Fill the distribution pipeline with product
  - Critical path analysis is most useful at this stage
- 8. **New Product Pricing**
  - Impact of new product on the entire product portfolio
  - Value Analysis (internal & external)
  - Competition and alternative competitive technologies
  - Differing value segments (price, value, and need)
  - Product Costs (fixed & variable)
  - Forecast of unit volumes, revenue, and profit

These steps may be iterated as needed. Some steps may be eliminated. To reduce the time that the NPD process takes, many companies are completing several steps at the same time (referred to as **concurrent engineering** or **time to market**). Most industry leaders see new product development as a *proactive* process where resources are allocated to identify market changes and seize upon new product opportunities before they occur (in contrast to a *reactive strategy* in which nothing is done until problems occur or the competitor introduces an innovation). Many industry leaders see new product development as an ongoing process in which the entire organization is always looking for opportunities.

For the more innovative products indicated on the diagram above, great amounts of uncertainty and change may exist, which makes it difficult or impossible to plan the complete project before starting it. In this case, a more flexible approach may be advisable.

Because the NPD process typically requires both engineering and marketing expertise, cross-functional teams are a common way of organizing projects. The team is responsible for all aspects of the project, from initial idea generation to final commercialization, and they usually report to senior management (often to a vice president or Program Manager). In those industries where products are technically complex, development research is typically expensive, and product life cycles are relatively short, strategic alliances among several organizations helps to spread the costs, provide access to a wider skill set, and speeds the overall process.

Also, notice that because engineering and marketing expertise are usually both critical to the process, choosing an appropriate blend of the two is important.

People respond to new products in different ways. The adoption of a new technology can be analyzed using a variety of diffusion theories such as the Diffusion of innovations theory.

A new product pricing process is important to reduce risk and increase confidence in the pricing and marketing decisions to be made. Bernstein and Macias describe an integrated process that breaks down the complex task of new product pricing into manageable elements.

### ***Fuzzy Front End***

The Fuzzy Front End is the messy "getting started" period of new product development processes. It is in the front end where the organization formulates a concept of the product to be developed and decides whether or not to invest resources in the further development of an idea. It is the phase between first consideration of an opportunity and when it is judged ready to enter the structured development process (Kim and Wilemon, 2002; Koen et al., 2001). It includes all activities from the search for new opportunities through the formation of a germ of an idea to the development of a precise concept. The Fuzzy Front End ends when an organization approves and begins formal development of the concept.

Although the Fuzzy Front End may not be an expensive part of product development, it can consume 50% of development time, and it is where major commitments are typically made involving time, money, and the product's nature, thus setting the course for the entire project and final end product. Consequently, this phase should be considered as an essential part of development rather than something that happens "before development," and its cycle time should be included in the total development cycle time.

Koen et al. (2001, pp. 47–51) distinguish five different front-end elements (not necessarily in a particular order):

1. Opportunity Identification
2. Opportunity Analysis
3. Idea Genesis
4. Idea Selection
5. Concept and Technology Development

The first element is the opportunity identification. In this element, large or incremental business and technological chances are identified in a more or less structured way. Using the guidelines established here, resources will eventually be allocated to new projects... which then lead to a structured NPPD (New Product & Process Development) strategy. The second element is the opportunity analysis. It is done to translate the identified opportunities into implications for the business and technology specific context of the company. Here extensive efforts may be made to align ideas to target customer groups and do market studies and/or technical trials and research. The third element is the idea genesis, which is described as evolutionary and iterative process progressing from birth to maturation of the opportunity into a tangible idea. The process of the idea genesis can be made internally or come from outside inputs, e.g. a supplier offering a new material/technology, or from a customer with an unusual request. The fourth element is the idea selection. Its purpose is to choose whether to pursue an idea by analyzing its

potential business value. The fifth element is the concept and technology development. During this part of the front-end, the business case is developed based on estimates of the total available market, customer needs, investment requirements, competition analysis and project uncertainty. Some organizations consider this to be the first stage of the NPPD process (i.e., Stage 0).

The Fuzzy Front End is also described in literature as "Front End of Innovation", "Phase 0", "Stage 0" or "Pre-Project-Activities".

A universally acceptable definition for Fuzzy Front End or a dominant framework has not been developed so far. In a glossary of PDMA, it is mentioned that the Fuzzy Front End generally consists of three tasks: strategic planning, concept generation, and, especially, pre-technical evaluation. These activities are often chaotic, unpredictable, and unstructured. In comparison, the subsequent new product development process is typically structured, predictable, and formal. The term *Fuzzy Front End* was first popularized by Smith and Reinertsen (1991). R.G.Cooper (1988) describes the early stages of NPPD as a four step process in which ideas are generated (I), subjected to a preliminary technical and market assessment(II) and merged to coherent product concepts(III) which are finally judged for their fit with existing product strategies and portfolios (IV). In a more recent paper, Cooper and Edgett (2008) affirm that vital predevelopment activities include:

1. Preliminary market assessment.
2. Technical assessment.
3. Source-of-supply-assessment:suppliers and partners or alliances.
4. Market research : market size and segmentation analysis,VoC (voice of the customer) research.
5. Product concept testing
6. Value-to-the customer assessment
7. Product definition
8. Business and financial analysis.

These activities yield vital information to make a Go/No-Go to Development decision.

In the in-depth study by Khurana and Rosenthal front-end activities include:

- product strategy formulation and communication,
- opportunity identification and assessment,
- idea generation,
- product definition,
- project planning, and
- executive reviews.

Economical analysis, benchmarking of competitive products,and modeling and prototyping are also important activities during the front-end activities.

The outcomes of FFE are the

- mission statement
- customer needs
- details of the selected concept
- product definition and specifications
- economic analysis of the product
- the development schedule
- project staffing and the budget, and a
- business plan aligned with corporate strategy.

In a paper by Husig, Kohn and Huskela (2005) was proposed a conceptual model of Front-End Process which includes early Phases of Innovation Process. This model is structured in three phases and three gates:

- Phase 1: Environmental screening or opportunity identification stage in which external changes will be analysed and translated into potential business opportunities.
- Phase 2: Preliminary definition of an idea or concept.
- Phase 3: Detailed product, project or concept definition, and Business planning.

The gates are:

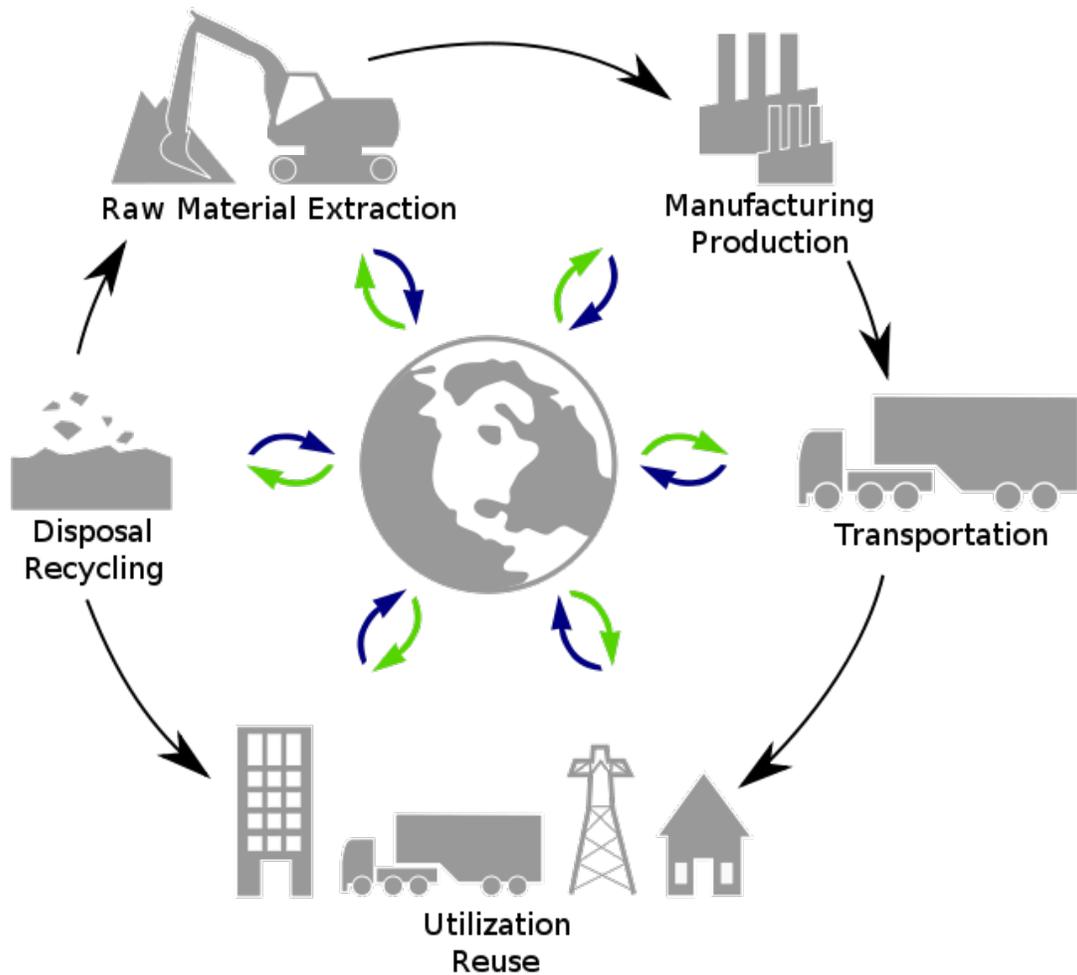
- Opportunity screening;
- Idea evaluation;
- Go/No-Go for development.

The final gate leads to a dedicated new product development project . Many professionals and academics consider that the general features of Fuzzy Front End (fuzziness,,ambiguity, and uncertainty) make difficult to see the FFE as a structured process,but rather as a set of interdependent activities ( e.g.Kim and Wilemon ,2002). However, Husig et al.,2005 argue that front-end not need to be fuzzy,but can be handled in a structured manner. Peter Koen argue that in the FFE for incremental,platform and radical projects,three separate strategies and processes are typically involved. The traditional Stage Gate (TM) process was designed for incremental product development,namely for a single product.The FFE for developing a new platform must start out with a strategic vision of where the company wants to develop products and this will lead to a family of products. Projects for breakthrough products start out with a similar strategic vision,but are associated with technologies which require new discoveries.It is worth mentioning what are incremental,platform and breakthrough products. *Incremental products* are considered to be cost reductions, improvements to existing product lines,additions to existing platforms and repositioning of existing products introduced in markets. *Breakthrough products* are new to the company or new to the world and offer a 5-10 times or greater improvement in performance combined with a 30-50% or greater reduction in costs. *Platform products* establish a basic

architecture for a next generation product or process and are substantially larger in scope and resources than incremental projects.

## Chapter 2

# Manufacturing





Assembly of Section 41 of a Boeing 787 Dreamliner.

**Manufacturing** is the use of machines, tools and labor to produce goods for use or sale. The term may refer to a range of human activity, from handicraft to high tech, but is most commonly applied to industrial production, in which raw materials are transformed into finished goods on a large scale. Such finished goods may be used for manufacturing other, more complex products, such as aircraft, household appliances or automobiles, or sold to wholesalers, who in turn sell them to retailers, who then sell them to end users – the "consumers".

Manufacturing takes turns under all types of economic systems. In a free market economy, manufacturing is usually directed toward the mass production of products for sale to consumers at a profit. In a collectivist economy, manufacturing is more frequently directed by the state to supply a centrally planned economy. In free market economies, manufacturing occurs under some degree of government regulation.

Modern manufacturing includes all intermediate processes required for the production and integration of a product's components. Some industries, such as semiconductor and steel manufacturers use the term *fabrication* instead.

The manufacturing sector is closely connected with engineering and industrial design. Examples of major manufacturers in the North America include General Motors Corporation, General Electric, and Pfizer. Examples in Europe include Volkswagen Group, Siemens, and Michelin. Examples in Asia include Toyota, Samsung, and Bridgestone.

## ***History and development***

- In its earliest form, manufacturing was usually carried out by a single skilled artisan with assistants. Training was by apprenticeship. In much of the pre-industrial world the guild system protected the privileges and trade secrets of urban artisans.
- Before the Industrial Revolution, most manufacturing occurred in rural areas, where household-based manufacturing served as a supplemental subsistence strategy to agriculture (and continues to do so in places). Entrepreneurs organized a number of manufacturing households into a single enterprise through the putting-out system.
- Toil manufacturing is an arrangement whereby a first firm with specialized equipment processes raw materials or semi-finished goods for a second firm.

## **Manufacturing systems: The changing methods of manufacturing**

- Craft or Guild system
- Putting-out system
- English system of manufacturing
- American system of manufacturing
- Soviet collectivism in manufacturing
- Mass production
- Just In Time manufacturing
- Lean manufacturing
- Flexible manufacturing
- Mass customization
- Agile manufacturing
- Rapid manufacturing
- Prefabrication
- Packaging and labeling
- Ownership
- Fabrication
- Publication

## ***Economics of manufacturing***

According to some economists, manufacturing is a wealth-producing sector of an economy, whereas a service sector tends to be wealth-consuming. Emerging technologies have provided some new growth in advanced manufacturing employment opportunities in the Manufacturing Belt in the United States. Manufacturing provides important material support for national infrastructure and for national defense.

On the other hand, most manufacturing may involve significant social and environmental costs. The clean-up costs of hazardous waste, for example, may outweigh the benefits of a product that creates it. Hazardous materials may expose workers to health risks. Developed countries regulate manufacturing activity with labor laws and environmental

laws. In the U.S, manufacturers are subject to regulations by the Occupational Safety and Health Administration and the United States Environmental Protection Agency. In Europe, pollution taxes to offset environmental costs are another form of regulation on manufacturing activity. Labor Unions and craft guilds have played a historic role in the negotiation of worker rights and wages. Environment laws and labor protections that are available in developed nations may not be available in the third world. Tort law and product liability impose additional costs on manufacturing.

Manufacturing requires huge amounts of fossil fuels. The construction of a single car in the United States requires, on average, at least 20 barrels of oil.

### ***Manufacturing and investment around the world***

Surveys and analyses of trends and issues in manufacturing and investment around the world focus on such things as:

- the nature and sources of the considerable variations that occur cross-nationally in levels of manufacturing and wider industrial-economic growth;
- competitiveness; and
- attractiveness to foreign direct investors.

In addition to general overviews, researchers have examined the features and factors affecting particular key aspects of manufacturing development. They have compared production and investment in a range of Western and non-Western countries and presented case studies of growth and performance in important individual industries and market-economic sectors.

On June 26, 2009, Jeff Immelt, the CEO of General Electric, called for the United States to increase its manufacturing base employment to 20% of the workforce, commenting that the U.S. has outsourced too much in some areas and can no longer rely on the financial sector and consumer spending to drive demand. A total of 3.2 million – one in six U.S. manufacturing jobs – have disappeared between 2000 and 2007.

### ***Taxonomy of manufacturing processes***

- Taxonomy of manufacturing processes
- Manufacturing Process Management

### ***Manufacturing categories***

- Chemical industry
  - Pharmaceutical
- Construction
- Electronics

- Semiconductor
- Engineering
  - Manufacturing engineering
  - Production engineering
  - Process Engineering
  - Industrial Engineering
  - Biotechnology
  - Emerging technologies
  - Nanotechnology
  - Synthetic biology, Bioengineering
- Energy industry
- Food and Beverage
  - Agribusiness
  - Brewing industry
  - Food processing
- Industrial design
  - Interchangeable parts
- Metalworking
  - Smith
  - Machinist
  - Machine tools
  - Cutting tools (metalworking)
  - Free machining
  - Tool and die maker
  - Global steel industry trends
  - Steel production
- Metalcasting
- Plastics
- Telecommunications
- Textile manufacturing
  - Clothing industry
  - Sailmaker
  - Tentmaking
- Transportation
  - Aerospace manufacturing
  - Automotive industry
  - Bus manufacturing
  - Tire manufacturing

## **Theories**

- Taylorism
- Fordism
- Scientific management

## ***Control***

- Management
  - List of management topics
  - Total Quality Management
- Quality control
  - Six Sigma

## Chapter 3

# Construction



In large construction projects, such as this skyscraper in Melbourne, cranes are essential.

In the fields of architecture and civil engineering, **construction** is a process that consists of the **building** or assembling of infrastructure. Far from being a single activity, large scale construction is a feat of human multitasking. Normally, the job is managed by a project manager, and supervised by a construction manager, design engineer, construction engineer, or project architect.

For the successful execution of a project, effective planning is essential. Those involved with the design and execution of the infrastructure in question must consider the environmental impact of the job, the successful scheduling, budgeting, construction site safety, availability of building materials, logistics, inconvenience to the public caused by construction delays, and bidding, etc.

### ***Types of construction projects***



Construction of a prefabricated home

In general, there are three types of construction:

1. Building construction
2. Heavy / civil construction
3. Industrial construction

Each type of construction project requires a unique team to plan, design, construct, and maintain the project.

## Building construction



A building site for a row of riverside apartment blocks in Cambridge



A large unfinished building

Building construction is the process of adding structure to real property. The vast majority of building construction projects are small renovations, such as addition of a room, or renovation of a bathroom. Often, the owner of the property acts as laborer, paymaster, and design team for the entire project. However, all building construction projects include some elements in common - design, financial, and legal considerations. Many projects of varying sizes reach undesirable end results, such as structural collapse, cost overruns, and/or litigation reason, those with experience in the field make detailed plans and maintain careful oversight during the project to ensure a positive outcome.

Building construction is procured privately or publicly utilizing various delivery methodologies, including hard bid, negotiated price, traditional, management contracting, construction management-at-risk, design & build and design-build bridging.

Residential construction practices, technologies, and resources must conform to local building authority regulations and codes of practice. Materials readily available in the area generally dictate the construction materials used (e.g. brick versus stone, versus timber). Cost of construction on a per square metre (or per square foot) basis for houses can vary dramatically based on site conditions, local regulations, economies of scale (custom designed homes are always more expensive to build) and the availability of

skilled tradespeople. As residential (as well as all other types of construction) can generate a lot of waste, careful planning again is needed here.

The most popular method of residential construction in the United States is wood framed construction. As efficiency codes have come into effect in recent years, new construction technologies and methods have emerged. University Construction Management departments are on the cutting edge of the newest methods of construction intended to improve efficiency, performance and reduce construction waste.

## **Industrial construction**

Industrial construction, though a relatively small part of the entire construction industry, is a very important component. Owners of these projects are usually large, for-profit, industrial corporations. These corporations can be found in such industries as medicine, petroleum, chemical, power generation, manufacturing, etc. Processes in these industries require highly specialized expertise in planning, design, and construction. As in building and heavy/highway construction, this type of construction requires a team of individuals to ensure a successful project. Industrial construction is very important.

## ***Construction processes***

### **Design team**



Shasta Dam under construction in June 1942

In the modern industrialized world, construction usually involves the translation of designs into reality. A formal design team may be assembled to plan the physical proceedings, and to integrate those proceedings with the other parts. The design usually consists of drawings and specifications, usually prepared by a design team including surveyors, civil engineers, cost engineers (or quantity surveyors), mechanical engineers, electrical engineers, structural engineers, and fire protection engineers. The design team is most commonly employed by (i.e. in contract with) the property owner. Under this system, once the design is completed by the design team, a number of construction companies or construction management companies may then be asked to make a bid for the work, either based directly on the design, or on the basis of drawings and a bill of quantities provided by a quantity surveyor. Following evaluation of bids, the owner will typically award a contract to the most cost efficient bidder.

The modern trend in design is toward integration of previously separated specialties, especially among large firms. In the past, architects, interior designers, engineers, developers, construction managers, and general contractors were more likely to be entirely separate companies, even in the larger firms. Presently, a firm that is nominally an "architecture" or "construction management" firm may have experts from all related fields as employees, or to have an associated company that provides each necessary skill. Thus, each such firm may offer itself as "one-stop shopping" for a construction project, from beginning to end. This is designated as a "design Build" contract where the contractor is given a performance specification, and must undertake the project from design to construction, while adhering to the performance specifications.

Several project structures can assist the owner in this integration, including design-build, partnering, and construction management. In general, each of these project structures allows the owner to integrate the services of architects, interior designers, engineers, and constructors throughout design and construction. In response, many companies are growing beyond traditional offerings of design or construction services alone, and are placing more emphasis on establishing relationships with other necessary participants through the design-build process.

The increasing complexity of construction projects creates the need for design professionals trained in all phases of the project's life-cycle and develop an appreciation of the building as an advanced technological system requiring close integration of many sub-systems and their individual components, including sustainability. **Building engineering** is an emerging discipline that attempts to meet this new challenge.

## Financial advisors

### Trump International Hotel and Tower (Chicago)



May 23, 2006



September 14, 2007 (3 months before completion)

Construction projects can suffer from preventable financial problems. **Underbids** ask for too little money to complete the project. Cash flow problems exist when the present amount of funding cannot cover the current costs for labour and materials, and because they are a matter of having sufficient funds at a specific time, can arise even when the overall total is enough. Fraud is a problem in many fields, but is notoriously prevalent in the construction field. Financial planning for the project is intended to ensure that a solid plan, with adequate safeguards and contingency plans, is in place before the project is started, and is required to ensure that the plan is properly executed over the life of the project.

Mortgage bankers, accountants, and cost engineers are likely participants in creating an overall plan for the financial management of the building construction project. The presence of the mortgage banker is highly likely even in relatively small projects, since the owner's equity in the property is the most obvious source of funding for a building project. Accountants act to study the expected monetary flow over the life of the project, and to monitor the payouts throughout the process. Cost engineers apply expertise to relate the work and materials involved to a proper valuation. Cost overruns with government projects have occurred when the contractor was able to identify change orders or changes in the project resulting in large increases in cost, which are not subject to competition by other firm as they have already been eliminated from consideration after the initial bid.

Large projects can involve highly complex financial plans. As portions of a project are completed, they may be sold, supplanting one lender or owner for another, while the logistical requirements of having the right trades and materials available for each stage of the building construction project carries forward. In many English-speaking countries, but not the United States, projects typically use quantity surveyors.

### **Legal considerations**



Construction along Ontario Highway 401, widening the road from six to twelve travel lanes.

A construction project must fit into the legal framework governing the property. These include governmental regulations on the use of property, and obligations that are created in the process of construction.

The project must adhere to zoning and building code requirements. Constructing a project that fails to adhere to codes will not benefit the owner. Some legal requirements come from *malum in se* considerations, or the desire to prevent things that are indisputably bad - bridge collapses or explosions. Other legal requirements come from *malum prohibitum* considerations, or things that are a matter of custom or expectation, such as isolating businesses to a business district and residences to a residential district. An attorney may seek changes or exemptions in the law governing the land where the building will be built, either by arguing that a rule is inapplicable (the bridge design will not collapse), or that the custom is no longer needed (acceptance of live-work spaces has grown in the community).

A construction project is a complex net of contracts and other legal obligations, each of which must be carefully considered. A contract is the exchange of a set of obligations between two or more parties, but it is not so simple a matter as trying to get the other side to agree to as much as possible in exchange for as little as possible. The time element in construction means that a delay costs money, and in cases of bottlenecks, the delay can be extremely expensive. Thus, the contracts must be designed to ensure that each side is capable of performing the obligations set out. Contracts that set out clear expectations and clear paths to accomplishing those expectations are far more likely to result in the project flowing smoothly, whereas poorly drafted contracts lead to confusion and collapse.

Legal advisors in the beginning of a construction project seek to identify ambiguities and other potential sources of trouble in the contract structure, and to present options for preventing problems. Throughout the process of the project, they work to avoid and resolve conflicts that arise. In each case, the lawyer facilitates an exchange of obligations that matches the reality of the project.

## Interaction of expertise



Apartment complex under construction in Daegu, South Korea

Design, finance, and legal aspects overlap and interrelate. The design must be not only structurally sound and appropriate for the use and location, but must also be financially possible to build, and legal to use. The financial structure must accommodate the need for building the design provided, and must pay amounts that are legally owed. The legal structure must integrate the design into the surrounding legal framework, and enforce the financial consequences of the construction process.

## Procurement

**Procurement describes the merging** of activities undertaken by the client to obtain a building. There are many different methods of construction procurement; however the three most common types of procurement are:

1. Traditional (Design-bid-build)
2. Design and Build
3. Management Contracting

There is also a growing number of new forms of procurement that involve relationship contracting where the emphasis is on a co-operative relationship between the principal

and contractor and other stakeholders within a construction project. New forms include partnering such as Public-Private Partnering (PPPs) aka Private Finance Initiatives (PFIs) and alliances such as "pure" or "project" alliances and "impure" or "strategic" alliances. The focus on co-operation is to ameliorate the many problems that arise from the often highly competitive and adversarial practices within the construction industry.

## **Traditional**

This is the most common method of construction procurement and is well established and recognized. In this arrangement, the architect or engineer acts as the project coordinator. His or her role is to design the works, prepare the specifications and produce construction drawings, administer the contract, tender the works, and manage the works from inception to completion. There are direct contractual links between the architect's client and the main contractor. Any subcontractor will have a direct contractual relationship with the main contractor.

## **Design and build**





Construction of the *Phase-I* (first two towers) of the Havelock City Project, Sri Lanka.

This approach has become more common in recent years and includes an entire completed package, including fixtures, fittings and equipment where necessary, to produce a completed fully functional building. In some cases, the Design and Build (D & B) package can also include finding the site, arranging funding and applying for all necessary statutory consents.

The owner produces a list of requirements for a project, giving an overall view of the project's goals. Several D&B contractors present different ideas about how to accomplish these goals. The owner selects the ideas he likes best and hires the appropriate contractor. Often, it is not just one contractor, but a consortium of several contractors working together. Once a contractor (or a consortium/consortia) has been hired, they begin building the first phase of the project. As they build phase 1, they design phase 2. This is in contrast to a design-bid-build contract, where the project is completely designed by the owner, then bid on, then completed.

Kent Hansen, director of engineering for the National Asphalt Pavement Association (NAPA), pointed out that state departments of transportation (DOTs) usually use design build contracts as a way of getting projects done when states don't have the resources. In DOTs, design build contracts are usually used for very large projects.

## **Management procurement systems**

In this arrangement the client plays an active role in the procurement system by entering into separate contracts with the designer (architect or engineer), the construction manager, and individual trade contractors. The client takes on the contractual role, while the construction or project manager provides the active role of managing the separate trade contracts, and ensuring that they all work smoothly and effectively together.

Management procurement systems are often used to speed up the procurement processes, allow the client greater flexibility in design variation throughout the contract, the ability to appoint individual work contractors, separate contractual responsibility on each individual throughout the contract, and to provide greater client control.

## ***Authority having jurisdiction***



Construction on a building in Kansas City, Missouri

In construction, the **authority having jurisdiction** (AHJ) is the governmental agency or sub-agency which regulates the construction process. In most cases, this is the municipality in which the building is located. However, construction performed for supra-municipal authorities are usually regulated directly by the owning authority, which becomes the AHJ.

During the planning of a building, the zoning and planning boards of the AHJ will review the overall compliance of the proposed building with the municipal General Plan and zoning regulations. Once the proposed building has been approved, detailed civil, architectural, and structural plans must be submitted to the municipal **building department** (and sometimes the public works department) to determine compliance with the building code and sometimes for fit with existing infrastructure. Often, the municipal fire department will review the plans for compliance with fire-safety ordinances and regulations.

Before the foundation can be dug, contractors are typically required to notify utility companies, either directly or through a company such as Dig Safe to ensure that underground utility lines can be marked. This lessens the likelihood of damage to the existing electrical, water, sewage, phone, and cable facilities, which could cause outages and potentially hazardous situations. During the construction of a building, the municipal building inspector inspects the building periodically to ensure that the construction adheres to the approved plans and the local **building code**. Once construction is complete and a final inspection has been passed, an **occupancy permit** may be issued.

An operating building must remain in compliance with the **fire code**. The fire code is enforced by the local fire department.

Changes made to a building that affect safety, including its use, expansion, structural integrity, and fire protection items, usually require approval of the AHJ for review concerning the building code.

## ***Construction careers***



Ironworkers erecting the steel frame of a new building at Massachusetts General Hospital, Boston

There are many routes to the different careers within the construction industry which vary by country. However, there are three main tiers of careers based on educational background which are common internationally:

- Unskilled and Semi-Skilled - General site labour with little or no construction qualifications.
- Skilled - On-site managers whom possess extensive knowledge and experience in their craft or profession.

- Technical and Management - Personnel with the greatest educational qualifications, usually graduate degrees, trained to design, manage and instruct the construction process.

Skilled occupations in the UK require further education qualifications, often in vocational subject areas. These qualifications are either obtained directly after the completion of compulsory education or through "on the job" apprenticeship training. In the UK, 8500 construction-related apprenticeships were commenced in 2007.

Technical and specialised occupations require more training as a greater technical knowledge is required. These professions also hold more legal responsibility. A short list of the main careers with an outline of the educational requirements are given below:

- Architect - Typically holds 1, Undergraduate 3 year degree in architecture + 1, Post-Graduate 2 year degree (DipArch or BArch) in architecture plus 24 months experience within the industry. To use the title "architect" the individual must be registered on the Architects Registration Board register of Architects.
- Civil Engineer - Typically holds a degree in a related subject. The Chartered Engineer qualification is controlled by the Institution of Civil Engineers. A new university graduate must hold a master's degree to become chartered, persons with bachelor's degrees may become an Incorporated Engineer.
- Building Services Engineer - Often referred to as an "M&E Engineer" typically holds a degree in mechanical or electrical engineering. Chartered Engineer status is governed by the Chartered Institution of Building Services Engineers.
- Project Manager - Typically holds a 4-year or greater higher education qualification, but are often also qualified in another field such as quantity surveying or civil engineering.
- Quantity Surveyor - Typically holds a master's degree in quantity surveying. Chartered status is gained from the Royal Institution of Chartered Surveyors.
- Structural Engineer - Typically holds a bachelors or master's degree in structural engineering, new university graduates must hold a master's degree to gain chartered status from the Institution of Structural Engineers.

## ***History***

The first buildings were huts and shelters, constructed by hand or with simple tools. As cities grew during the Bronze Age, a class of professional craftsmen, like bricklayers and carpenters, appeared. Occasionally, slaves were used for construction work. In the Middle Ages, these were organized into guilds. In the 19th century, steam-powered machinery appeared, and later diesel- and electric powered vehicles such as cranes, excavators and bulldozers. Modern-day Construction involves creating awesome structures that can show the beauty and creativity of the human intellect.

## Chapter 4

# Technology

**Technology** is the usage and knowledge of tools, techniques, crafts, systems or methods of organization in order to solve a problem or serve some purpose. The word *technology* comes from Greek *τεχνολογία* (*technología*); from *τέχνη* (*téchnē*), meaning "art, skill, craft", and *-λογία* (*-logía*), meaning "study of-". The term can either be applied generally or to specific areas: examples include *construction technology*, *medical technology*, and *information technology*.

Technologies significantly affect human as well as other animal species' ability to control and adapt to their natural environments. The human species' use of technology began with the conversion of natural resources into simple tools. The prehistorical discovery of the ability to control fire increased the available sources of food and the invention of the wheel helped humans in travelling in and controlling their environment. Recent technological developments, including the printing press, the telephone, and the Internet, have lessened physical barriers to communication and allowed humans to interact freely on a global scale. However, not all technology has been used for peaceful purposes; the development of weapons of ever-increasing destructive power has progressed throughout history, from clubs to nuclear weapons.

Technology has affected society and its surroundings in a number of ways. In many societies, technology has helped develop more advanced economies (including today's global economy) and has allowed the rise of a leisure class. Many technological processes produce unwanted by-products, known as pollution, and deplete natural resources, to the detriment of the Earth and its environment. Various implementations of technology influence the values of a society and new technology often raises new ethical questions. Examples include the rise of the notion of efficiency in terms of human productivity, a term originally applied only to machines, and the challenge of traditional norms.

Philosophical debates have arisen over the present and future use of technology in society, with disagreements over whether technology improves the human condition or worsens it. Neo-Luddism, anarcho-primitivism, and similar movements criticise the

pervasiveness of technology in the modern world, opining that it harms the environment and alienates people; proponents of ideologies such as transhumanism and techno-progressivism view continued technological progress as beneficial to society and the human condition. Indeed, until recently, it was believed that the development of technology was restricted only to human beings, but recent scientific studies indicate that other primates and certain dolphin communities have developed simple tools and learned to pass their knowledge to other generations.

### ***Definition and usage***



The invention of the printing press made it possible for scientists and politicians to communicate their ideas with ease, leading to the Age of Enlightenment; an example of technology as a cultural force.

The use of the term *technology* has changed significantly over the last 200 years. Before the 20th century, the term was uncommon in English, and usually referred to the description or study of the useful arts. The term was often connected to technical education, as in the Massachusetts Institute of Technology (chartered in 1861). "Technology" rose to prominence in the 20th century in connection with the second industrial revolution. The meanings of technology changed in the early 20th century when American social scientists, beginning with Thorstein Veblen, translated ideas from the German concept of *Technik* into "technology." In German and other European languages, a distinction exists between *Technik* and *Technologie* that is absent in English, as both terms are usually translated as "technology." By the 1930s, "technology" referred not to the study of the industrial arts, but to the industrial arts themselves. In 1937, the American sociologist Read Bain wrote that "technology includes all tools, machines, utensils, weapons, instruments, housing, clothing, communicating and transporting devices and the skills by which we produce and use them." Bain's definition remains common among scholars today, especially social scientists. But equally prominent is the definition of technology as applied science, especially among scientists and engineers, although most social scientists who study technology reject this definition. More recently, scholars have borrowed from European philosophers of "technique" to extend the meaning of technology to various forms of instrumental reason, as in Foucault's work on technologies of the self ("techniques de soi").

Dictionaries and scholars have offered a variety of definitions. The Merriam-Webster dictionary offers a definition of the term: "the practical application of knowledge especially in a particular area" and "a capability given by the practical application of knowledge". Ursula Franklin, in her 1989 "Real World of Technology" lecture, gave another definition of the concept; it is "practice, the way we do things around here". The term is often used to imply a specific field of technology, or to refer to high technology or just consumer electronics, rather than technology as a whole. Bernard Stiegler, in *Technics and Time, 1*, defines technology in two ways: as "the pursuit of life by means other than life", and as "organized inorganic matter."

Technology can be most broadly defined as the entities, both material and immaterial, created by the application of mental and physical effort in order to achieve some value. In this usage, technology refers to tools and machines that may be used to solve real-world problems. It is a far-reaching term that may include simple tools, such as a crowbar or wooden spoon, or more complex machines, such as a space station or particle accelerator. Tools and machines need not be material; virtual technology, such as computer software and business methods, fall under this definition of technology.

The word "technology" can also be used to refer to a collection of techniques. In this context, it is the current state of humanity's knowledge of how to combine resources to produce desired products, to solve problems, fulfill needs, or satisfy wants; it includes technical methods, skills, processes, techniques, tools and raw materials. When combined with another term, such as "medical technology" or "space technology", it refers to the state of the respective field's knowledge and tools. "State-of-the-art technology" refers to the high technology available to humanity in any field.

Technology can be viewed as an activity that forms or changes culture. Additionally, technology is the application of math, science, and the arts for the benefit of life as it is known. A modern example is the rise of communication technology, which has lessened barriers to human interaction and, as a result, has helped spawn new subcultures; the rise of cyberculture has, at its basis, the development of the Internet and the computer. Not all technology enhances culture in a creative way; technology can also help facilitate political oppression and war via tools such as guns. As a cultural activity, technology predates both science and engineering, each of which formalize some aspects of technological endeavor.

## ***Science, engineering and technology***

The distinction between science, engineering and technology is not always clear. Science is the reasoned investigation or study of phenomena, aimed at discovering enduring principles among elements of the phenomenal world by employing formal techniques such as the scientific method. Technologies are not usually exclusively products of science, because they have to satisfy requirements such as utility, usability and safety.

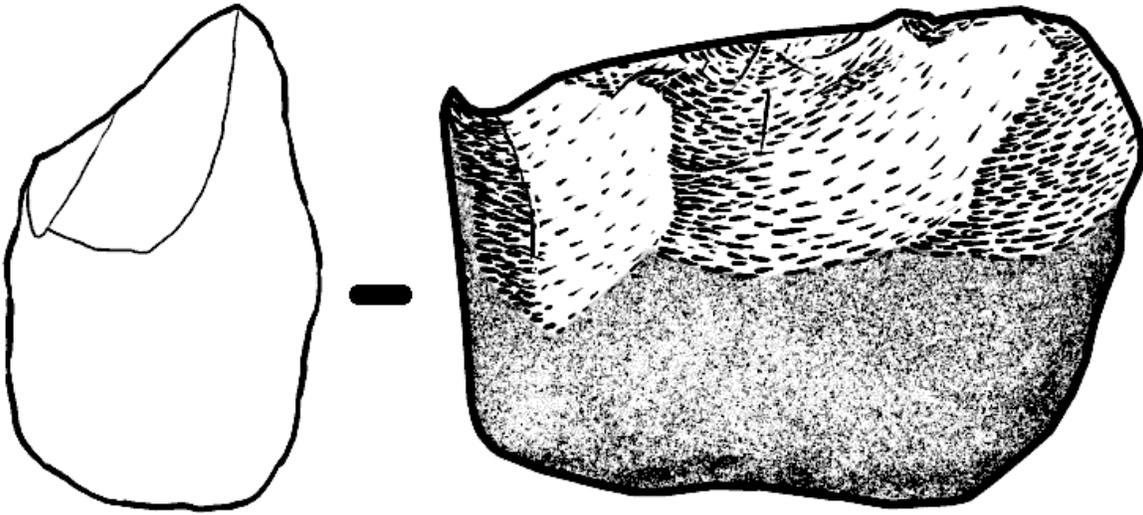
Engineering is the goal-oriented process of designing and making tools and systems to exploit natural phenomena for practical human means, often (but not always) using results and techniques from science. The development of technology may draw upon many fields of knowledge, including scientific, engineering, mathematical, linguistic, and historical knowledge, to achieve some practical result.

Technology is often a consequence of science and engineering — although technology as a human activity precedes the two fields. For example, science might study the flow of electrons in electrical conductors, by using already-existing tools and knowledge. This new-found knowledge may then be used by engineers to create new tools and machines, such as semiconductors, computers, and other forms of advanced technology. In this sense, scientists and engineers may both be considered technologists; the three fields are often considered as one for the purposes of research and reference.

The exact relations between science and technology in particular have been debated by scientists, historians, and policymakers in the late 20th century, in part because the debate can inform the funding of basic and applied science. In the immediate wake of World War II, for example, in the United States it was widely considered that technology was simply "applied science" and that to fund basic science was to reap technological results in due time. An articulation of this philosophy could be found explicitly in Vannevar Bush's treatise on postwar science policy, *Science—The Endless Frontier*: "New products, new industries, and more jobs require continuous additions to knowledge of the laws of nature... This essential new knowledge can be obtained only through basic scientific research." In the late-1960s, however, this view came under direct attack, leading towards initiatives to fund science for specific tasks (initiatives resisted by the scientific community). The issue remains contentious—though most analysts resist the model that technology simply is a result of scientific research.

## ***History***

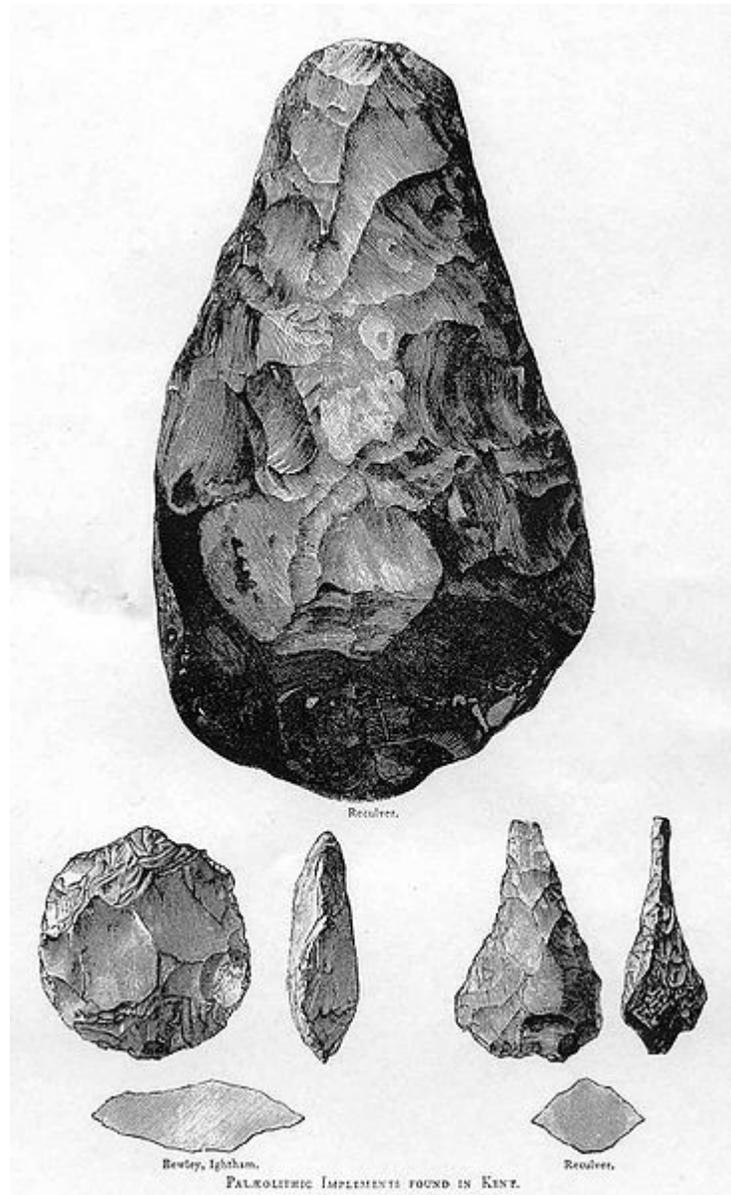
**Paleolithic (2.5 million – 10,000 BC)**



A primitive chopper

The use of tools by early humans was partly a process of discovery, partly of evolution. Early humans evolved from a species of foraging hominids which were already bipedal, with a brain mass approximately one third that of modern humans. Tool use remained relatively unchanged for most of early human history, but approximately 50,000 years ago, a complex set of behaviors and tool use emerged, believed by many archaeologists to be connected to the emergence of fully modern language.

## Stone tools



Hand axes from the Acheulian period



A Clovis point, made via pressure flaking

Human ancestors have been using stone and other tools since long before the emergence of *Homo sapiens* approximately 200,000 years ago. The earliest methods of stone tool making, known as the Oldowan "industry", date back to at least 2.3 million years ago, with the earliest direct evidence of tool usage found in Ethiopia within the Great Rift Valley, dating back to 2.5 million years ago. This era of stone tool use is called the *Paleolithic*, or "Old stone age", and spans all of human history up to the development of agriculture approximately 12,000 years ago.

To make a stone tool, a "core" of hard stone with specific flaking properties (such as flint) was struck with a hammerstone. This flaking produced a sharp edge on the core stone as well as on the flakes, either of which could be used as tools, primarily in the form of choppers or scrapers. These tools greatly aided the early humans in their hunter-gatherer lifestyle to perform a variety of tasks including butchering carcasses (and breaking bones to get at the marrow); chopping wood; cracking open nuts; skinning an animal for its hide; and even forming other tools out of softer materials such as bone and wood.

The earliest stone tools were crude, being little more than a fractured rock. In the Acheulian era, beginning approximately 1.65 million years ago, methods of working these stone into specific shapes, such as hand axes emerged. The Middle Paleolithic, approximately 300,000 years ago, saw the introduction of the prepared-core technique, where multiple blades could be rapidly formed from a single core stone. The Upper Paleolithic, beginning approximately 40,000 years ago, saw the introduction of pressure flaking, where a wood, bone, or antler punch could be used to shape a stone very finely.

## **Fire**

The discovery and utilization of fire, a simple energy source with many profound uses, was a turning point in the technological evolution of humankind. The exact date of its

discovery is not known; evidence of burnt animal bones at the Cradle of Humankind suggests that the domestication of fire occurred before 1,000,000 BC; scholarly consensus indicates that Homo erectus had controlled fire by between 500,000 BC and 400,000 BC. Fire, fueled with wood and charcoal, allowed early humans to cook their food to increase its digestibility, improving its nutrient value and broadening the number of foods that could be eaten.

## **Clothing and shelter**

Other technological advances made during the Paleolithic era were clothing and shelter; the adoption of both technologies cannot be dated exactly, but they were a key to humanity's progress. As the Paleolithic era progressed, dwellings became more sophisticated and more elaborate; as early as 380,000 BC, humans were constructing temporary wood huts. Clothing, adapted from the fur and hides of hunted animals, helped humanity expand into colder regions; humans began to migrate out of Africa by 200,000 BC and into other continents, such as Eurasia.

## **Neolithic through Classical Antiquity (10,000BC – 300AD)**



An array of Neolithic artifacts, including bracelets, axe heads, chisels, and polishing tools.

Man's technological ascent began in earnest in what is known as the Neolithic period ("New stone age"). The invention of polished stone axes was a major advance because it allowed forest clearance on a large scale to create farms. The discovery of agriculture

allowed for the feeding of larger populations, and the transition to a sedentist lifestyle increased the number of children that could be simultaneously raised, as young children no longer needed to be carried, as was the case with the nomadic lifestyle. Additionally, children could contribute labor to the raising of crops more readily than they could to the hunter-gatherer lifestyle.

With this increase in population and availability of labor came an increase in labor specialization. What triggered the progression from early Neolithic villages to the first cities, such as Uruk, and the first civilizations, such as Sumer, is not specifically known; however, the emergence of increasingly hierarchical social structures, the specialization of labor, trade and war amongst adjacent cultures, and the need for collective action to overcome environmental challenges, such as the building of dikes and reservoirs, are all thought to have played a role.

## **Metal tools**

Continuing improvements led to the furnace and bellows and provided the ability to smelt and forge native metals (naturally occurring in relatively pure form). Gold, copper, silver, and lead, were such early metals. The advantages of copper tools over stone, bone, and wooden tools were quickly apparent to early humans, and native copper was probably used from near the beginning of Neolithic times (about 8000 BC). Native copper does not naturally occur in large amounts, but copper ores are quite common and some of them produce metal easily when burned in wood or charcoal fires. Eventually, the working of metals led to the discovery of alloys such as bronze and brass (about 4000 BC). The first uses of iron alloys such as steel dates to around 1400 BC.

## **Energy and Transport**



The wheel was invented circa 4000 BC.

Meanwhile, humans were learning to harness other forms of energy. The earliest known use of wind power is the sailboat. The earliest record of a ship under sail is shown on an Egyptian pot dating back to 3200 BC. From prehistoric times, Egyptians probably used the power of the Nile annual floods to irrigate their lands, gradually learning to regulate much of it through purposely built irrigation channels and 'catch' basins. Similarly, the early peoples of Mesopotamia, the Sumerians, learned to use the Tigris and Euphrates rivers for much the same purposes. But more extensive use of wind and water (and even human) power required another invention.

According to archaeologists, the wheel was invented around 4000 B.C. probably independently and nearly-simultaneously in Mesopotamia (in present-day Iraq), the Northern Caucasus (Maykop culture) and Central Europe. Estimates on when this may have occurred range from 5500 to 3000 B.C., with most experts putting it closer to 4000 B.C. The oldest artifacts with drawings that depict wheeled carts date from about 3000 B.C.; however, the wheel may have been in use for millennia before these drawings were made. There is also evidence from the same period of time that wheels were used for the production of pottery. (Note that the original potter's wheel was probably not a wheel, but rather an irregularly shaped slab of flat wood with a small hollowed or pierced area near the center and mounted on a peg driven into the earth. It would have been rotated by repeated tugs by the potter or his assistant.) More recently, the oldest-known wooden wheel in the world was found in the Ljubljana marshes of Slovenia.

The invention of the wheel revolutionized activities as disparate as transportation, war, and the production of pottery (for which it may have been first used). It didn't take long to discover that wheeled wagons could be used to carry heavy loads and fast (rotary) potters' wheels enabled early mass production of pottery. But it was the use of the wheel as a transformer of energy (through water wheels, windmills, and even treadmills) that revolutionized the application of nonhuman power sources.

## **Medieval and Modern history (300 AD —)**

Innovations continued through the Middle Ages with new innovations such as silk, the horse collar and horseshoes in the first few hundred years after the fall of the Roman Empire. Medieval technology saw the use of simple machines (such as the lever, the screw, and the pulley) being combined to form more complicated tools, such as the wheelbarrow, windmills and clocks. The Renaissance brought forth many of these innovations, including the printing press (which facilitated the greater communication of knowledge), and technology became increasingly associated with science, beginning a cycle of mutual advancement. The advancements in technology in this era allowed a more steady supply of food, followed by the wider availability of consumer goods.

Starting in the United Kingdom in the 18th century, the Industrial Revolution was a period of great technological discovery, particularly in the areas of agriculture, manufacturing, mining, metallurgy and transport, driven by the discovery of steam power. Technology later took another step with the harnessing of electricity to create such innovations as the electric motor, light bulb and countless others. Scientific

advancement and the discovery of new concepts later allowed for powered flight, and advancements in medicine, chemistry, physics and engineering. The rise in technology has led to the construction of skyscrapers and large cities whose inhabitants rely on automobiles or other powered transit for transportation. Communication was also improved with the invention of the telegraph, telephone, radio and television.

The second half of the 20th century brought a host of new innovations. In physics, the discovery of nuclear fission has led to both nuclear weapons and nuclear energy. Computers were also invented and later miniaturized utilizing transistors and integrated circuits. These advancements subsequently led to the creation of the Internet. Humans have also been able to explore space with satellites (later used for telecommunication) and in manned missions going all the way to the moon. In medicine, this era brought innovations such as open-heart surgery and later stem cell therapy along with new medications and treatments. Complex manufacturing and construction techniques and organizations are needed to construct and maintain these new technologies, and entire industries have arisen to support and develop succeeding generations of increasingly more complex tools. Modern technology increasingly relies on training and education — their designers, builders, maintainers, and users often require sophisticated general and specific training. Moreover, these technologies have become so complex that entire fields have been created to support them, including engineering, medicine, and computer science, and other fields have been made more complex, such as construction, transportation and architecture.

## ***Technology and philosophy***

### **Technicism**

Generally, technicism is a reliance or confidence in technology as a benefactor of society. Taken to extreme, technicism is the belief that humanity will ultimately be able to control the entirety of existence using technology. In other words, human beings will someday be able to master all problems and possibly even control the future using technology. Some, such as Stephen V. Monsma, connect these ideas to the abdication of religion as a higher moral authority.

### **Optimism**

Optimistic assumptions are made by proponents of ideologies such as transhumanism and singularitarianism, which view technological development as generally having beneficial effects for the society and the human condition. In these ideologies, technological development is morally good. Some critics see these ideologies as examples of scientism and techno-utopianism and fear the notion of human enhancement and technological singularity which they support. Some have described Karl Marx as a techno-optimist.

## Skepticism and Critics of Technology

On the somewhat skeptical side are certain philosophers like Herbert Marcuse and John Zerzan, who believe that technological societies are inherently flawed. They suggest that the inevitable result of such a society is to become evermore technological at the cost of freedom and psychological health.

Many, such as the Luddites and prominent philosopher Martin Heidegger, hold serious, although not entirely deterministic reservations, about technology. According to Heidegger scholars Hubert Dreyfus and Charles Spinoza, "Heidegger does not oppose technology. He hopes to reveal the essence of technology in a way that 'in no way confines us to a stultified compulsion to push on blindly with technology or, what comes to the same thing, to rebel helplessly against it.' Indeed, he promises that 'when we once open ourselves expressly to the essence of technology, we find ourselves unexpectedly taken into a freeing claim.'" What this entails is a more complex relationship to technology than either techno-optimists or techno-pessimists tend to allow.

Some of the most poignant criticisms of technology are found in what are now considered to be dystopian literary classics, for example Aldous Huxley's *Brave New World* and other writings, Anthony Burgess's *A Clockwork Orange*, and George Orwell's *Nineteen Eighty-Four*. And, in *Faust* by Goethe, Faust's selling his soul to the devil in return for power over the physical world, is also often interpreted as a metaphor for the adoption of industrial technology. More recently, modern works of science fiction, such as those by Philip K. Dick and William Gibson, and films (e.g. *Blade Runner*, *Ghost in the Shell*) project highly ambivalent or cautionary attitudes toward technology's impact on human society and identity.

The late cultural critic Neil Postman distinguished tool-using societies from technological societies and, finally, what he called "technopolies," that is, societies that are dominated by the ideology of technological and scientific progress, to the exclusion or harm of other cultural practices, values and world-views.

Darin Barney has written about technology's impact on practices of citizenship and democratic culture, suggesting that technology can be construed as (1) an object of political debate, (2) a means or medium of discussion, and (3) a setting for democratic deliberation and citizenship. As a setting for democratic culture, Barney suggests that technology tends to make ethical questions, including the question of what a good life consists in, nearly impossible, because they already give an answer to the question: a good life is one that includes the use of more and more technology.

Nikolas Kompridis has also written about the dangers of new technology, such as genetic engineering, nanotechnology, synthetic biology and robotics. He warns that these technologies introduce unprecedented new challenges to human beings, including the possibility of the permanent alteration of our biological nature. These concerns are shared by other philosophers, scientists and public intellectuals who have written about similar issues (e.g. Francis Fukuyama, Jürgen Habermas, William Joy, and Michael Sandel).

Another prominent critic of technology is Hubert Dreyfus, who has published books *On the Internet* and *What Computers Still Can't Do*.

Another, more infamous anti-technological treatise is *Industrial Society and Its Future*, written by Theodore Kaczynski (aka The Unabomber) and printed in several major newspapers (and later books) as part of an effort to end his bombing campaign of the techno-industrial infrastructure.

### **Appropriate technology**

The notion of appropriate technology, however, was developed in the 20th century (e.g., see the work of Jacques Ellul) to describe situations where it was not desirable to use very new technologies or those that required access to some centralized infrastructure or parts or skills imported from elsewhere. The eco-village movement emerged in part due to this concern.

### **Other animal species**



This adult gorilla uses a branch as a walking stick to gauge the water's depth; an example of technology usage by primates.

The use of basic technology is also a feature of other animal species apart from humans. These include primates such as chimpanzees, some dolphin communities, and crows. Considering a more generic perspective of technology as ethology of active

environmental conditioning and control, we can also refer to animal examples such as beavers and their dams, or bees and their honeycombs.

The ability to make and use tools was once considered a defining characteristic of the genus Homo. However, the discovery of tool construction among chimpanzees and related primates has discarded the notion of the use of technology as unique to humans. For example, researchers have observed wild chimpanzees utilising tools for foraging: some of the tools used include leaf sponges, termite fishing probes, pestles and levers. West African chimpanzees also use stone hammers and anvils for cracking nuts, as do capuchin monkeys of Boa Vista, Brazil.

### ***Future technology***

Theories of technology often attempt to predict the future of technology based on the high technology and science of the time. This process is difficult if not impossible. Referring to the sheer velocity of technological innovation, Arthur C. Clarke said "Any sufficiently advanced technology is indistinguishable from magic."

## Chapter 5

# Management

**Management** in all business and organizational activities is the act of getting people together to accomplish desired goals and objectives using available resources efficiently and effectively. Management comprises planning, organizing, staffing, leading or directing, and controlling an organization (a group of one or more people or entities) or effort for the purpose of accomplishing a goal. Resourcing encompasses the deployment and manipulation of human resources, financial resources, technological resources, and natural resources.

Because organizations can be viewed as systems, management can also be defined as human action, including design, to facilitate the production of useful outcomes from a system. This view opens the opportunity to 'manage' oneself, a pre-requisite to attempting to manage others.

### ***History***

The verb *manage* comes from the Italian *maneggiare* (to handle — especially tools), which in turn derives from the Latin *manus* (hand). The French word *mesnagement* (later *ménagement*) influenced the development in meaning of the English word *management* in the 17th and 18th centuries.

Some definitions of management are:

- Organization and coordination of the activities of an enterprise in accordance with certain policies and in achievement of clearly defined objectives. Management is often included as a factor of production along with machines, materials, and money. According to the management guru Peter Drucker (1909–2005), the basic task of a management is twofold: marketing and innovation.
- Directors and managers have the power and responsibility to make decisions to manage an enterprise. As a discipline, management comprises the interlocking functions of formulating corporate policy and organizing, planning, controlling,

and directing the firm's resources to achieve the policy's objectives. The size of management can range from one person in a small firm to hundreds or thousands of managers in multinational companies. In large firms the board of directors formulates the policy which is implemented by the chief executive officer.

## **Theoretical scope**

At the beginning, one thinks of management functionally, as the action of measuring a quantity on a regular basis and of adjusting some initial plan; or as the actions taken to reach one's intended goal. This applies even in situations where planning does not take place. From this perspective, Frenchman Henri Fayol(1841–1925) considers management to consist of six functions: forecasting, planning, organizing, commanding, coordinating, controlling. He was one of the most influential contributors to modern concepts of management.

Another way of thinking, Mary Parker Follett (1868–1933), who wrote on the topic in the early twentieth century, defined management as "the art of getting things done through people". She described management as philosophy.

Some people, however, find this definition, while useful, far too narrow. The phrase "management is what managers do" occurs widely, suggesting the difficulty of defining management, the shifting nature of definitions, and the connection of managerial practices with the existence of a managerial cadre or class.

One habit of thought regards management as equivalent to "business administration" and thus excludes management in places outside commerce, as for example in charities and in the public sector. More realistically, however, every organization must manage its work, people, processes, technology, etc. in order to maximize its effectiveness. Nonetheless, many people refer to university departments which teach management as "business schools." Some institutions (such as the Harvard Business School) use that name while others (such as the Yale School of Management) employ the more inclusive term "management."

English speakers may also use the term "management" or "the management" as a collective word describing the managers of an organization, for example of a corporation. Historically this use of the term was often contrasted with the term "Labor" referring to those being managed.

## ***Nature of managerial work***

In for-profit work, management has as its primary function the satisfaction of a range of stakeholders. This typically involves making a profit (for the shareholders), creating valued products at a reasonable cost (for customers), and providing rewarding employment opportunities (for employees). In nonprofit management, add the importance of keeping the faith of donors. In most models of management/governance, shareholders vote for the board of directors, and the board then hires senior management. Some

organizations have experimented with other methods (such as employee-voting models) of selecting or reviewing managers; but this occurs only very rarely.

In the public sector of countries constituted as representative democracies, voters elect politicians to public office. Such politicians hire many managers and administrators, and in some countries like the United States political appointees lose their jobs on the election of a new president/governor/mayor.

### ***Historical development***

Difficulties arise in tracing the history of management. Some see it (by definition) as a late modern (in the sense of late modernity) conceptualization. On those terms it cannot have a pre-modern history, only harbingers (such as stewards). Others, however, detect management-like-thought back to Sumerian traders and to the builders of the pyramids of ancient Egypt. Slave-owners through the centuries faced the problems of exploiting/motivating a dependent but sometimes unenthusiastic or recalcitrant workforce, but many pre-industrial enterprises, given their small scale, did not feel compelled to face the issues of management systematically. However, innovations such as the spread of Arabic numerals (5th to 15th centuries) and the codification of double-entry book-keeping (1494) provided tools for management assessment, planning and control.

Given the scale of most commercial operations and the lack of mechanized record-keeping and recording before the industrial revolution, it made sense for most owners of enterprises in those times to carry out management functions by and for themselves. But with growing size and complexity of organizations, the split between owners (individuals, industrial dynasties or groups of shareholders) and day-to-day managers (independent specialists in planning and control) gradually became more common.

### **Early writing**

While management has been present for millennia, several writers have created a background of works that assisted in modern management theories.

#### **Sun Tzu's *The Art of War***

Written by Chinese general Sun Tzu in the 6th century BC, *The Art of War* is a military strategy book that, for managerial purposes, recommends being aware of and acting on strengths and weaknesses of both a manager's organization and a foe's.

#### **Chanakya's *Arthashastra***

Chanakya wrote the *Arthashastra* around 300BC in which various strategies, techniques and management theories were written which gives an account on the management of empires, economy and family. The work is often compared to the later works of Machiavelli.

## **Niccolò Machiavelli's *The Prince***

Believing that people were motivated by self-interest, Niccolò Machiavelli wrote *The Prince* in 1513 as advice for the city of Florence, Italy. Machiavelli recommended that leaders use fear—but not hatred—to maintain control.

## **Adam Smith's *The Wealth of Nations***

Written in 1776 by Adam Smith, a Scottish moral philosopher, *The Wealth of Nations* aims for efficient organization of work through Specialization of labor. Smith described how changes in processes could boost productivity in the manufacture of pins. While individuals could produce 200 pins per day, Smith analyzed the steps involved in manufacture and, with 10 specialists, enabled production of 48,000 pins per day.

## **19th century**

Classical economists such as Adam Smith (1723–1790) and John Stuart Mill (1806–1873) provided a theoretical background to resource-allocation, production, and pricing issues. About the same time, innovators like Eli Whitney (1765–1825), James Watt (1736–1819), and Matthew Boulton (1728–1809) developed elements of technical production such as standardization, quality-control procedures, cost-accounting, interchangeability of parts, and work-planning. Many of these aspects of management existed in the pre-1861 slave-based sector of the US economy. That environment saw 4 million people, as the contemporary usages had it, "managed" in profitable quasi-mass production.

By the late 19th century, marginal economists Alfred Marshall (1842–1924), Léon Walras (1834–1910), and others introduced a new layer of complexity to the theoretical underpinnings of management. Joseph Wharton offered the first tertiary-level course in management in 1881.

## **20th century**

By about 1900 one finds managers trying to place their theories on what they regarded as a thoroughly scientific basis. Examples include Henry R. Towne's *Science of management* in the 1890s, Frederick Winslow Taylor's *The Principles of Scientific Management* (1911), Frank and Lillian Gilbreth's *Applied motion study* (1917), and Henry L. Gantt's charts (1910s). J. Duncan wrote the first college management textbook in 1911. In 1912 Yoichi Ueno introduced Taylorism to Japan and became first management consultant of the "Japanese-management style". His son Ichiro Ueno pioneered Japanese quality assurance.

The first comprehensive theories of management appeared around 1920. The Harvard Business School invented the Master of Business Administration degree (MBA) in 1921. People like Henri Fayol (1841–1925) and Alexander Church described the various branches of management and their inter-relationships. In the early 20th century, people

like Ordway Tead (1891–1973), Walter Scott and J. Mooney applied the principles of psychology to management, while other writers, such as Elton Mayo (1880–1949), Mary Parker Follett (1868–1933), Chester Barnard (1886–1961), Max Weber (1864–1920), Rensis Likert (1903–1981), and Chris Argyris (1923 - ) approached the phenomenon of management from a sociological perspective.

Peter Drucker (1909–2005) wrote one of the earliest books on applied management: *Concept of the Corporation* (published in 1946). It resulted from Alfred Sloan (chairman of General Motors until 1956) commissioning a study of the organisation. Drucker went on to write 39 books, many in the same vein.

H. Dodge, Ronald Fisher (1890–1962), and Thornton C. Fry introduced statistical techniques into management-studies. In the 1940s, Patrick Blackett combined these statistical theories with microeconomic theory and gave birth to the science of operations research. Operations research, sometimes known as "management science" (but distinct from Taylor's scientific management), attempts to take a scientific approach to solving management problems, particularly in the areas of logistics and operations.

Some of the more recent developments include the Theory of Constraints, management by objectives, reengineering, Six Sigma and various information-technology-driven theories such as agile software development, as well as group management theories such as Cog's Ladder.

As the general recognition of managers as a class solidified during the 20th century and gave perceived practitioners of the art/science of management a certain amount of prestige, so the way opened for popularised systems of management ideas to peddle their wares. In this context many management fads may have had more to do with pop psychology than with scientific theories of management.

Towards the end of the 20th century, business management came to consist of six separate branches, namely:

- Human resource management
- Operations management or production management
- Strategic management
- Marketing management
- Financial management
- Information technology management responsible for management information systems

## **21st century**

In the 21st century observers find it increasingly difficult to subdivide management into functional categories in this way. More and more processes simultaneously involve several categories. Instead, one tends to think in terms of the various processes, tasks, and objects subject to management.

Branches of management theory also exist relating to nonprofits and to government: such as public administration, public management, and educational management. Further, management programs related to civil-society organizations have also spawned programs in nonprofit management and social entrepreneurship.

Note that many of the assumptions made by management have come under attack from business ethics viewpoints, critical management studies, and anti-corporate activism.

As one consequence, workplace democracy has become both more common, and more advocated, in some places distributing all management functions among the workers, each of whom takes on a portion of the work. However, these models predate any current political issue, and may occur more naturally than does a command hierarchy. All management to some degree embraces democratic principles in that in the long term workers must give majority support to management; otherwise they leave to find other work, or go on strike. Despite the move toward workplace democracy, command-and-control organization structures remain commonplace and the *de facto* organization structure. Indeed, the entrenched nature of command-and-control can be seen in the way that recent layoffs have been conducted with management ranks affected far less than employees at the lower levels of organizations. In some cases, management has even rewarded itself with bonuses when lower level employees have been laid off.

## Topics



The photo shows a training meeting with factory workers in a stainless steel ecodesign company from Rio de Janeiro, Brazil. Endomarketing is a part of the management and is very important to motivate the work force

## Basic Functions

Management operates through various functions, often classified as planning, organizing, staffing, leading/directing, and controlling/monitoring.i.e

- **Planning:** Deciding what needs to happen in the future (today, next week, next month, next year, over the next 5 years, etc.) and generating plans for action.
- **Organizing:** (Implementation) making optimum use of the resources required to enable the successful carrying out of plans.
- **Staffing:** Job Analyzing, recruitment, and hiring individuals for appropriate jobs.
- **Leading/Directing:** Determining what needs to be done in a situation and getting people to do it.
- **Controlling/Monitoring:** Checking progress against plans.
- **Motivation :** Motivation is also a kind of basic function of management, because without motivation, employees cannot work effectively. If motivation doesn't take place in an organization, then employees may not contribute to the other functions (which are usually set by top level management).

## Basic Roles

- **Interpersonal:** roles that involve coordination and interaction with employees.
- **Informational:** roles that involve handling, sharing, and analyzing information.
- **Decisional:** roles that require decision-making.

## Management Skills

- **Technical:** used for specialized knowledge required for work.
- **Political:** used to build a power base and establish connections.
- **Conceptual:** used to analyze complex situations.
- **Interpersonal:** used to communicate, motivate, mentor and delegate.

## Formation of the business policy

- The **mission** of the business is the most obvious purpose—which may be, for example, to make soap.
- The **vision** of the business reflects its aspirations and specifies its intended direction or future destination.
- The **objectives** of the business refers to the ends or activity at which a certain task is aimed.
- The business's **policy** is a guide that stipulates rules, regulations and objectives, and may be used in the managers' decision-making. It must be flexible and easily interpreted and understood by all employees.
- The business's **strategy** refers to the coordinated plan of action that it is going to take, as well as the resources that it will use, to realize its vision and long-term objectives. It is a guideline to managers, stipulating how they ought to allocate

and utilize the factors of production to the business's advantage. Initially, it could help the managers decide on what type of business they want to form.

## **Implementation of policies and strategies**

- All policies and strategies must be discussed with all managerial personnel and staff.
- Managers must understand where and how they can implement their policies and strategies.
- A plan of action must be devised for each department.
- Policies and strategies must be reviewed regularly.
- Contingency plans must be devised in case the environment changes.
- Assessments of progress ought to be carried out regularly by top-level managers.
- A good environment and team spirit is required within the business.
- The missions, objectives, strengths and weaknesses of each department must be analysed to determine their roles in achieving the business's mission.
- The **forecasting method** develops a reliable picture of the business's future environment.
- A **planning unit** must be created to ensure that all plans are consistent and that policies and strategies are aimed at achieving the same mission and objectives.

All policies must be discussed with all managerial personnel and staff that is required in the execution of any departmental policy.

- Organizational change is strategically achieved through the implementation of the eight-step plan of action established by John P. Kotter: Increase urgency, get the vision right, communicate the buy-in, empower action, create short-term wins, don't let up, and make change stick.

## **Policies and strategies in the planning process**

- They give mid- and lower-level managers a good idea of the future plans for each department in an organization.
- A framework is created whereby plans and decisions are made.
- Mid- and lower-level management may add their own plans to the business's strategic ones.

## **Levels of Management**

In organizations, there are generally three different levels of managers: first-level managers, middle-level managers, and top-level managers. These levels of managers are classified in a hierarchy of importance and authority, and are also arranged by the different types of management tasks that each role does. In many organizations, the number of managers in every level resembles a pyramid, in which the first-level has many more managers than middle-level and top-level managers, respectively. Each

management level is explained below in specifications of their different responsibilities and likely job titles.

- **Top-Level Managers:** typically consist of Board of Directors, President, Vice President, Chief Executive Officers etc. These individuals are mainly responsible for controlling and overseeing all the departments in the organization. They develop goals, strategic plans, and policies for the company, as well as make many decisions on the direction of the business. In addition, top-level managers play a significant role in the mobilization of outside resources and are for the most part responsible for the shareholders and general public. Top-level managers typically consist of Board of Directors, President, Vice President, Chief Executive Officers etc.
- **Middle-Level Managers:** typically consist of General Managers, Branch Managers, Department Managers, etc. These individuals are mainly responsible to the top management for the functioning of their department. They devote more time to organizational and directional functions. Their roles can be emphasized as executing plans of the organization in conformance with the company's policies and the objectives of the top management, they define and discuss information and policies from top management to lower management, and most importantly they inspire and provide guidance to lower level managers towards better performance.
- **First-Level Managers:** typically consist of Supervisors, Section Officers, Foreman, etc. These individuals focus more on the controlling and direction of management functions. For instance, they assign tasks and jobs to employees, guide and supervise employees on day-to-day activities, look after the quantity and quality of the production of the company, make recommendations, suggestions, and communicate employee problems to the higher level above, etc. In this level manager's are the "image builders" of the company considering they are the only ones who have direct contact with employees.

## **Instructional Needs at Different Management Levels**

According to Lawrence S. Kleiman, the skills mentioned below are needed at different managerial levels..

### **First-Level Managers:**

- Basic supervision.
- Motivation.
- Career planning.
- Performance feedback.

**Middle-Level Managers:**

- Designing and implementing effective group and intergroup work and information systems.
- Defining and monitoring group-level performance indicators.
- Diagnosing and resolving problems within and among work groups.
- Designing and implementing reward systems that support cooperative behavior.

**Top-Level Managers:**

- Broadening their understanding of how factors such as competition, world economies, politics, and social trends influence the effectiveness of the organization.

## Chapter 6

# Industrial Engineering & Design Engineer

## Industrial Engineering

**Industrial engineering** is a branch of engineering dealing with the optimization of complex processes or systems. It is concerned with the development, improvement, implementation and evaluation of integrated systems of people, money, knowledge, information, equipment, energy, materials, analysis and synthesis, as well as the mathematical, physical and social sciences together with the principles and methods of engineering design to specify, predict, and evaluate the results to be obtained from such systems or processes. Its underlying concepts overlap considerably with certain business-oriented disciplines such as Operations Management, but the engineering side tends to emphasize extensive *mathematical* proficiency and usage of quantitative methods.

Depending on the sub-speciality(ies) involved, industrial engineering may also be known as operations management, management science, operations research, systems engineering, or manufacturing engineering, usually depending on the viewpoint or motives of the user. Recruiters or educational establishments use the names to differentiate themselves from others. In health care, industrial engineers are more commonly known as health management engineers or health systems engineers.

While the term originally applied to manufacturing, the use of "industrial" in "industrial engineering" can be somewhat misleading, since it has grown to encompass any methodical or quantitative approach to optimizing how a process, system, or organization operates. Some engineering universities and educational agencies around the world have changed the term "industrial" to the broader term "production", leading to the typical extensions noted above. In fact, the primary U.S. professional organization for Industrial Engineers, the Institute of Industrial Engineers (IIE) has been considering changing its name to something broader (such as the Institute of Industrial & Systems Engineers), although the latest vote among membership deemed this unnecessary for the time being.

The various topics of concern to industrial engineers include management science, financial engineering, engineering management, supply chain management, process engineering, operations research, systems engineering, ergonomics, cost and value engineering, quality engineering, facilities planning, and the engineering design process. Traditionally, a major aspect of industrial engineering was planning the layouts of factories and designing assembly lines and other manufacturing paradigms. And now, in so-called lean manufacturing systems, industrial engineers work to eliminate wastes of time, money, materials, energy, and other resources.

Examples of where industrial engineering might be used include designing an assembly workstation, strategizing for various operational logistics, consulting as an efficiency expert, developing a new financial algorithm or loan system for a bank, streamlining operation and emergency room location or usage in a hospital, planning complex distribution schemes for materials or products (referred to as Supply Chain Management), and shortening lines (or queues) at a bank, hospital, or a theme park.

Industrial engineers typically use computer simulation (especially discrete event simulation), along with extensive mathematical tools and modeling and computational methods for system analysis, evaluation, and optimization.

## ***History***

Efforts to apply science to the design of processes and of production systems were made by many people in the 18th and 19th centuries. They took some time to evolve and to be synthesized into disciplines that we would label with names such as industrial engineering, production engineering, or systems engineering. For example, precursors to industrial engineering included some aspects of military science; the quest to develop manufacturing using interchangeable parts; the development of the armory system of manufacturing; the work of Henri Fayol and colleagues (which grew into a larger movement called Fayolism); and the work of Frederick Winslow Taylor and colleagues (which grew into a larger movement called scientific management). In the late 19th century, such efforts began to inform consultancy and higher education. The idea of consulting with experts about process engineering naturally evolved into the idea of teaching the concepts as curriculum.

Industrial engineering courses were taught by multiple universities in Europe at the end of the 19th century, including in Germany, France, the United Kingdom, and Spain. In the United States, the first department of industrial and manufacturing engineering was established in 1909 at the Pennsylvania State University.

The first doctoral degree in industrial engineering was awarded in the 1930s by Cornell University.

## **University programs**

Many universities have BS, MS, M.Tech and PhD programs available. *US News and World Report's* article on "America's Best Colleges 2010" lists schools offering Undergraduate engineering specialities in Industrial or Manufacturing. The Georgia Institute of Technology has been ranked as having the best Industrial Engineering program in the United States consecutively for the last twenty years according to this survey.

## **Undergraduate curriculum**

In the United States, the usual undergraduate degree earned is the Bachelor of Science or B.S. in Industrial Engineering (BSIE). Like most undergraduate engineering programs, the typical curriculum includes a broad math and science foundation spanning chemistry, physics, engineering design, calculus, differential equations, statistics, materials science, engineering mechanics, computer science, circuits and electronics, and often additional specialized courses in areas such as management, systems theory, ergonomics/safety, stochastics, advanced mathematics and computation, and economics. Some Universities require International credits to complete the BS degree.

## **Postgraduate curriculum**

The usual postgraduate degree earned is the Master of Science in Industrial Engineering, Production Engineering, Industrial Engineering & Management or Industrial Engineering & Operations Research. The typical MS curriculum includes:

- Operations research & Optimization techniques
- Engineering economics
- Supply chain management & Logistics
- Systems Simulation & Stochastic Processes
- System Dynamics & Policy Planning
- System Analysis & Techniques
- Manufacturing systems/Manufacturing engineering
- Human factors engineering & Ergonomics
- Production planning and control
- Management Sciences
- Computer aided manufacturing
- Facilities design & Work space design
- Quality Engineering
- Reliability Engineering & Life Testing
- Statistical process control or Quality control
- Time and motion study
- Operations management
- Corporate planning
- Productivity improvement
- Materials management

## ***Salaries and workforce statistics***

The total number of engineers employed in the U.S. in 2006 was roughly 1.5 million. Of these, 201,000 were industrial engineers (13.3%), the third most popular engineering specialty. The average **starting** salaries being \$55,067 with a bachelor's degree, \$64,759 with a master's degree, and \$77,364 with a doctorate degree. This places industrial engineering at 7th of 15 among engineering bachelors degrees, 3rd of 10 among masters degrees, and 2nd of 7 among doctorate degrees in average annual salary. The median annual income of industrial engineers in the U.S. workforce is \$68,620.

## **Design Engineer**

**Design engineer** is a general term that covers multiple engineering disciplines including electrical, mechanical and civil engineering, architectural engineers in the U.S. and building engineers in the U.K.

The design engineer is distinguished from the designer/drafter by virtue of the fact that a design engineer takes care of the total system as well as inner workings/engineering of a design. While industrial designers may be responsible for the conceptual aesthetic and ergonomic aspects of a design, the design engineer usually works with a team of engineers and designers to develop the conceptual, preliminary and detail design and the most critical parts. He/she may work with industrial designers and marketing to develop the product concept and specifications, and he/she may direct the design effort from that point. Products are usually designed with input from a number of sources such as marketing, manufacturing, purchasing, tool making and packaging engineering. In addition design engineers deal with much more complex technological and scientific systems (aircraft, spacecraft, rockets, trains, ships, dams, bridges, building structures, urban infrastructure, machinery, production systems, propulsion systems, oil, gas, and mining exploration systems, manufacturing processes, military systems, cars, electronics, computers, power generation systems - nuclear, fossil, wind, ocean, and power distribution systems). Industrial design deals with individual artifacts (chairs, cups, home interiors, furniture, auto interiors, electronic displays, consumer goods)

In many engineering areas, a distinction is made between the design engineer and the planning engineer in design. Planning engineers are more concerned with designing on a more systems engineering level, and overlaps onto the operational side are often necessary. Design engineers, in contrast, are more concerned with designing a particular new product or system. However in very narrowly defined areas the design process and concepts will usually start with an ideation session from the industrial designer/s. Analysis is important for planning engineers, while synthesis is paramount for design engineers.

When the design involves public safety, the design engineer is usually required to be licensed, for example a Professional Engineer in the U.S and Canada. There is usually an 'industrial exemption' for design engineers working on project internal to companies and not delivering professional services directly to the public.

## ***Design engineer tasks***

They may work in a team along with designers to create the drawings necessary for prototyping and production, or in the case of buildings, for construction. However, with the advent of CAD and solid modeling software (SolidWorks, SpaceClaim, Solid Edge, Autodesk Inventor, Pro/ENGINEER, NX, CATIA, etc, for example) the design engineers may create the drawings themselves.

The next responsibility of many design engineers is prototyping. A model of the product is created and reviewed. Prototypes are usually functional and non-functional. Functional "alpha" prototypes are used for testing and the non-functional are used for form and fit checking. Virtual prototyping software like Ansys or Comsol may also be used. This stage is where design flaws are found and corrected, and tooling, manufacturing fixtures, and packaging are developed.

Once the "alpha" prototype is finalized, after many iterations, the next step is the "beta" pre-production prototype. The design engineer, working with a manufacturing engineer and a quality engineer reviews an initial run of components and assemblies for design compliance and fabrication/manufacturing methods analysis. This is often determined through statistical process control. Variations in the product are correlated to aspects of the process and eliminated. The most common metric used is the process capability index  $C_{pk}$ . A  $C_{pk}$  of 1.0 is considered the baseline acceptance for full production go-ahead.

The design engineer may follow the product and make requested changes and corrections throughout the life of the product. This is referred to as "cradle to grave" engineering.

These duties may also be shared with industrial designers depending on who is more qualified for each task.

## Chapter 7

# Human Factors



Research subject in a human fatigue study.

**Human factors science** or **human factors technologies** is a multidisciplinary field incorporating contributions from psychology, engineering, industrial design, statistics, operations research and anthropometry. It is a term that covers:

- The science of understanding the properties of human capability (Human Factors Science).
- The application of this understanding to the design, development and deployment of systems and services (Human Factors Engineering).
- The art of ensuring successful application of Human Factors Engineering to a program (sometimes referred to as Human Factors Integration). It can also be called ergonomics.

In general, a *human factor* is a physical or cognitive property of an individual or social behavior which is specific to humans and influences functioning of technological systems as well as human-environment equilibriums.

In social interactions, the use of the term *human factor* stresses the social properties unique to or characteristic of humans.

Human factors involves the study of all aspects of the way humans relate to the world around them, with the aim of improving operational performance, safety, through life costs and/or adoption through improvement in the experience of the end user.

The terms *human factors* and *ergonomics* have only been widely used in recent times; the field's origin is in the design and use of aircraft during World War II to improve aviation safety. It was in reference to the psychologists and physiologists working at that time and the work that they were doing that the terms "applied psychology" and "ergonomics" were first coined. Work by Elias Porter, Ph.D. and others within the RAND Corporation after WWII extended these concepts. "As the thinking progressed, a new concept developed - that it was possible to view an organization such as an air-defense, man-machine system as a single organism and that it was possible to study the behavior of such an organism. It was the climate for a breakthrough."

Specialisations within this field include cognitive ergonomics, usability, human computer/ human machine interaction, and user experience engineering. New terms are being generated all the time. For instance, "user trial engineer" may refer to a human factors professional who specialises in user trials. Although the names change, human factors professionals share an underlying vision that through application of an understanding of human factors the design of equipment, systems and working methods will be improved, directly affecting people's lives for the better.

Human factors practitioners come from a variety of backgrounds, though predominantly they are psychologists (engineering, cognitive, perceptual, and experimental) and physiologists. Designers (industrial, interaction, and graphic), anthropologists, technical communication scholars and computer scientists also contribute. Though some practitioners enter the field of human factors from other disciplines, both M.S. and Ph.D. degrees in Human Factors Engineering are available from several universities worldwide.

## ***The Formal History of American Human Factors Engineering***

The formal history describes activities in known chronological order. This can be divided into 5 markers:

### **Developments prior to World War I**

Prior to WWI the only test of human to machine compatibility was that of trial and error. If the human functioned with the machine, he was accepted, if not he was rejected. There was a significant change in the concern for humans during the American civil war. The

US patent office was concerned whether the mass produced uniforms and new weapons could be used by the infantry men. The next development was when the American inventor Simon Lake tested submarine operators for psychological factors, followed by the scientific study of the worker. This was an effort dedicated to improve the efficiency of humans in the work place. These studies were designed by F W Taylor. The next step was the derivation of formal time and motion study from the studies of Frank Gilbreth, Sr. and Lillian Gilbreth.

## **Developments during World War I**

With the onset of WWI, more sophisticated equipment was developed. The inability of the personnel to use such systems led to an increase in interest in human capability. Earlier the focus of aviation psychology was on the aviator himself. But as time progressed the focus shifted onto the aircraft, in particular, the design of controls and displays, the effects of altitude and environmental factors on the pilot. The war saw the emergence of aeromedical research and the need for testing and measurement methods. Still, the war did not create a Human Factors Engineering (HFE) discipline, as such. The reasons attributed to this are that technology was not very advanced at the time and America's involvement in the war only lasting for 18 months.

## **Developments between World War I and World War II**

This period saw relatively slow development in HFE. Although, studies on driver behaviour started gaining momentum during this period, as Henry Ford started providing millions of Americans with automobiles. Another major development during this period was the performance of aeromedical research. By the end of WWI, two aeronautical labs were established, one at Brooks Airforce Base, Texas and the other at Wright field outside of Dayton, Ohio. Many tests were conducted to determine which characteristic differentiated the successful pilots from the unsuccessful ones. During the early 1930s, Edwin Link developed the first flight simulator. The trend continued and more sophisticated simulators and test equipment were developed. Another significant development was in the civilian sector, where the effects of illumination on worker productivity were examined. This led to the identification of the Hawthorne Effect, which suggested that motivational factors could significantly influence human performance.

## **Developments during World War II**

With the onset of the WW II, it was no longer possible to adopt the Tayloristic principle of matching individuals to preexisting jobs. Now the design of equipment had to take into account human limitations and take advantage of human capabilities. This change took time to come into place. There was a lot of research conducted to determine the human capabilities and limitations that had to be accomplished. A lot of this research took off where the aeromedical research between the wars had left off. An example of this is the study done by Fitts and Jones (1947), who studied the most effective configuration of control knobs to be used in aircraft cockpits. A lot of this research transcended into other equipment with the aim of making the controls and displays easier for the operators to

use. After the war, the Army Air Force published 19 volumes summarizing what had been established from research during the war.

## **Developments after World War II**

In the initial 20 years after the WW II, most activities were done by the founding fathers: Alphonse Chapanis, Paul Fitts, and Small. The beginning of cold war led to a major expansion of Defense supported research laboratories. Also, a lot of labs established during the war started expanding. Most of the research following the war was military sponsored. Large sums of money were granted to universities to conduct research. The scope of the research also broadened from small equipments to entire workstations and systems. Concurrently, a lot of opportunities started opening up in the civilian industry. The focus shifted from research to participation through advice to engineers in the design of equipment. After 1965, the period saw a maturation of the discipline. The field has expanded with the development of the computer and computer applications.

Founded in 1957, the Human Factors and Ergonomics Society is the world's largest organization of professionals devoted to the science of human factors and ergonomics. The Society's mission is to promote the discovery and exchange of knowledge concerning the characteristics of human beings that are applicable to the design of systems and devices of all kinds.

## ***The Cycle of Human Factors***

Human Factors involves the study of factors and development of tools that facilitate the achievement of these goals. In the most general sense, the three goals of human factors are accomplished through several procedures in the human factors cycle, which depicts the human operator (brain and body) and the system with which he or she is interacting. First it is necessary to diagnose or identify the problems and deficiencies in the human-system interaction of an existing system. After defining the problems there are five different approaches that can be used in order to implement the solution. These are as follows:

- *Equipment Design*: changes the nature of the physical equipment with which humans work.
- *Task Design*: focuses more on changing what operators do than on changing the devices they use. This may involve assigning part or all of tasks to other workers or to automated components.
- *Environmental Design*: implements changes, such as improved lighting, temperature control and reduced noise in the physical environment where the task is carried out.
- *Training the individuals*: better preparing the worker for the conditions that he or she will encounter in the job environment by teaching and practicing the necessary physical or mental skills.
- *Selection of individuals*: is a technique that recognizes the individual differences across humans in every physical and mental dimension that is relevant for good

system performance. Such a performance can be optimized by selecting operators who possess the best profile of characteristics for the job.

## ***Human Factors Science***

Human factors are sets of human-specific physical, cognitive, or social properties which either may interact in a critical or dangerous manner with technological systems, the human natural environment, or human organizations, or they can be taken under consideration in the design of ergonomic human-user oriented equipment. The choice or identification of human factors usually depends on their possible negative or positive impact on the functioning of human-organizations and human-machine systems.

### **The human-machine model**

The simple human-machine model is a person interacting with a machine in some kind of environment. The person and machine are both modeled as information-processing devices, each with inputs, central processing, and outputs. The inputs of a person are the senses (e.g., eyes, ears) and the outputs are effectors (e.g., hands, voice). The inputs of a machine are input control devices (e.g., keyboard, mouse) and the outputs are output display devices (e.g., screen, auditory alerts). The environment can be characterized physically (e.g., vibration, noise, zero-gravity), cognitively (e.g., time pressure, uncertainty, risk), and/or organizationally (e.g., organizational structure, job design). This provides a convenient way for organizing some of the major concerns of human engineering: the selection and design of machine displays and controls; the layout and design of workplaces; design for maintainability; and the design of the work environment.

Example: Driving an automobile is a familiar example of a simple man-machine system. In driving, the operator receives inputs from outside the vehicle (sounds and visual cues from traffic, obstructions, and signals) and from displays inside the vehicle (such as the speedometer, fuel indicator, and temperature gauge). The driver continually evaluates this information, decides on courses of action, and translates those decisions into actions upon the vehicle's controls—principally the accelerator, steering wheel, and brake. Finally, the driver is influenced by such environmental factors as noise, fumes, and temperature.

No matter how important it may be to match an individual operator to a machine, some of the most challenging and complex human problems arise in the design of large man-machine systems and in the integration of human operators into these systems. Examples of such large systems are a modern jet airliner, an automated post office, an industrial plant, a nuclear submarine, and a space vehicle launch and recovery system. In the design of such systems, human-factors engineers study, in addition to all the considerations previously mentioned, three factors: personnel, training, and operating procedures.

- *Personnel* are trained; that is, they are given appropriate information and skills required to operate and maintain the system. System design includes the development of training

techniques and programs and often extends to the design of training devices and training aids.

- *Instructions, operating procedures, and rules* set forth the duties of each operator in a system and specify how the system is to function. Tailoring operating rules to the requirements of the system and the people in it contributes greatly to safe, orderly, and efficient operations.

## **Human Factors Engineering**

Human Factors Engineering (HFE) is the discipline of applying what is known about human capabilities and limitations to the design of products, processes, systems, and work environments. It can be applied to the design of all systems having a human interface, including hardware and software. Its application to system design improves ease of use, system performance and reliability, and user satisfaction, while reducing operational errors, operator stress, training requirements, user fatigue, and product liability. HFE is distinctive in being the only discipline that relates humans to technology.

Human factors engineering focuses on how people interact with tasks, machines (or computers), and the environment with the consideration that humans have limitations and capabilities. Human factors engineers evaluate "Human to Human," "Human to Group," "Human to Organizational," and "Human to Machine (Computers)" interactions to better understand these interactions and to develop a framework for evaluation.

Human Factors engineering activities include: 1. Usability assurance 2. Determination of desired user profiles 3. Development of user documentation 4. Development of training programs.

### **Usability assurance**

Usability assurance is an interdisciplinary concept, integrating system engineering with Human Factors engineering methodologies. Usability assurance is achieved through the system or service design, development, evaluation and deployment.

- User interface design comprises physical (ergonomic) design, interaction design and layout design.
- Usability development comprises integration of human factors in project planning and management, including system specification documents: requirements, design and testing.
- Usability evaluation is a continuous process, starting with the operational requirements specification, through prototypes of the user interfaces, through usability alpha and beta testing, and through manual and automated feedback after the system has been deployed.

## **User Interface Design**

Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them. This is a well known subject of Human Factors within the Engineering field. There are many different ways to determine human computer interaction at the user interface by usability testing.

## **Human Factors Evaluation Methods**

Human Factors evaluation methods are part of Human Factors methodology, which is part of Human Factors Engineering.

Besides evaluation, Human Factors Engineering also deals with methods for usability assurance, for assessing desired user profiles, for developing user documentation and training programs, etc.

Until recently, methods used to evaluate human factors ranged from simple questionnaires to more complex and expensive usability labs.

Recently, new methods were proposed, based on analysis of logs of the activity of the system users.

Actually, the work in usability labs and that of the new methods is part of Usability Engineering, which is part of Human Factors Engineering.

## **Brief Summary of Human Factors Evaluation Methods**

**Ethnographic analysis:** Using methods derived from ethnography, this process focuses on observing the uses of technology in a practical environment. It is a qualitative and observational method that focuses on "real-world" experience and pressures, and the usage of technology or environments in the workplace. The process is best used early in the design process.

**Focus Groups:** Focus groups are another form of qualitative research in which one individual will facilitate discussion and elicit opinions about the technology or process under investigation. This can be on a one to one interview basis, or in a group session. Can be used to gain a large quantity of deep qualitative data, though due to the small sample size, can be subject to a higher degree of individual bias. Can be used at any point in the design process, as it is largely dependent on the exact questions to be pursued, and the structure of the group. Can be extremely costly.

**Iterative design:** Also known as prototyping, the iterative design process seeks to involve users at several stages of design, in order to correct problems as they emerge. As prototypes emerge from the design process, these are subjected to other forms of analysis as outlined here, and the results are then taken and incorporated into the new design.

Trends amongst users are analyzed, and products redesigned. This can become a costly process, and needs to be done as soon as possible in the design process before designs become too concrete.

**Meta-analysis:** A supplementary technique used to examine a wide body of already existing data or literature in order to derive trends or form hypotheses in order to aid design decisions. As part of a literature survey, a meta-analysis can be performed in order to discern a collective trend from individual variables.

**Subjects-in-tandem:** Two subjects are asked to work concurrently on a series of tasks while vocalizing their analytical observations. This is observed by the researcher, and can be used to discover usability difficulties. This process is usually recorded.

**Surveys and Questionnaires:** A commonly used technique outside of Human Factors as well, surveys and questionnaires have an advantage in that they can be administered to a large group of people for relatively low cost, enabling the researcher to gain a large amount of data. The validity of the data obtained is, however, always in question, as the questions must be written and interpreted correctly, and are, by definition, subjective. Those who actually respond are in effect self-selecting as well, widening the gap between the sample and the population further.

**Task analysis:** A process with roots in activity theory, task analysis is a way of systematically describing human interaction with a system or process to understand how to match the demands of the system or process to human capabilities. The complexity of this process is generally proportional to the complexity of the task being analyzed, and so can vary in cost and time involvement. It is a qualitative and observational process. Best used early in the design process.

**Think aloud protocol:** Also known as "concurrent verbal protocol", this is the process of asking a user to execute a series of tasks or use technology, while continuously verbalizing their thoughts so that a researcher can gain insights as to the users' analytical process. Can be useful for finding design flaws that do not affect task performance, but may have a negative cognitive affect on the user. Also useful for utilizing experts in order to better understand procedural knowledge of the task in question. Less expensive than focus groups, but tends to be more specific and subjective.

**User analysis:** This process is based around designing for the attributes of the intended user or operator, establishing the characteristics that define them, creating a persona for the user. Best done at the outset of the design process, a user analysis will attempt to predict the most common users, and the characteristics that they would be assumed to have in common. This can be problematic if the design concept does not match the actual user, or if the identified are too vague to make clear design decisions from. This process is, however, usually quite inexpensive, and commonly used.

**"Wizard of Oz":** This is a comparatively uncommon technique but has seen some use in mobile devices. Based upon the Wizard of Oz experiment, this technique involves an

operator who remotely controls the operation of a device in order to imitate the response of an actual computer program. It has the advantage of producing a highly changeable set of reactions, but can be quite costly and difficult to undertake.

## **Problems with Human Factors Methods**

Problems in how usability measures are employed include:

- (1) measures of learning and retention of how to use an interface are rarely employed during methods and
- (2) some studies treat measures of how users interact with interfaces as synonymous with quality-in-use, despite an unclear relation.

### ***Weakness of Usability Lab Testing***

Although usability lab testing is believed to be the most influential evaluation method, it does have some limitations. These limitations include:

- (1) Additional resources and time than other methods
- (2) Usually only examines a fraction of the entire market segment
- (3) Test scope is limited to the sample tasks chosen
- (4) Long term ease-of-use problems are difficult to identify
- (5) May reveal only a fraction of total problems
- (6) Laboratory setting excludes factors that the operational environment places on the products usability

### ***Weakness of Inspection Methods***

Inspection methods (expert reviews and walkthroughs) can be accomplished quickly, without resources from outside the development team, and does not require the research expertise that usability tests need. However, inspection methods do have limitations, which include:

- (1) Do not usually directly involve users
- (2) Often do not involve developers
- (3) Set up to determine problems and not solutions
- (4) Do not foster innovation or creative solutions
- (5) Not good at persuading developers to make product improvements

### ***Weakness of Surveys, Interviews, and Focus Groups***

These traditional human factors methods have been adapted, in many cases, to assess product usability. Even though there are several surveys that are tailored for usability and that have established validity in the field, these methods do have some limitations, which include:

- (1) Reliability of all surveys is low with small sample sizes (10 or less)
- (2) Interview lengths restricts use to a small sample size
- (3) Use of focus groups for usability assessment has highly debated value
- (4) All of these methods are highly dependent on the respondents

## ***Weakness of Field Methods***

Although field methods can be extremely useful because they are conducted in the users natural environment, they have some major limitations to consider. The limitations include:

- (1) Usually take more time and resources than other methods
- (2) Very high effort in planning, recruiting, and executing than other methods
- (3) Much longer study periods and therefore requires much goodwill among the participants
- (4) Studies are longitudinal in nature, therefore, attrition can become a problem.

## ***Application of Human Factors Engineering***

### **An Example: Human Factors Engineering Applied to the Military**

Before World War II, HFE had no significance in the design of machines. Consequently, many fatal human errors during the war were directly or indirectly related to the absence of comprehensive HFE analyses in the design and manufacturing process. One of the reasons for so many costly errors was the fact that the capabilities of the human were not clearly differentiated from those of the machine.

Furthermore, human performance capabilities, skill limitation, and response tendencies were not adequately considered in the designs of the new systems that were being produced so rapidly during the war. For example, pilots were often trained on one generation of aircraft, but by the time they got to the war zone, they were required to fly a newer model. The newer model was usually more complex than the older one and, even more detrimental, the controls may have had opposing functions assigned to them. Some aircraft required that the control stick be pulled back toward the pilot in order to pull the nose up. In other aircraft the exact opposite was required; namely, in order to ascend you would push the stick away from you. Needless to say, in an emergency situation many pilots became confused and performed the incorrect maneuver, with disastrous results.

Along the same line, pilots were subject to substitution errors due mostly to lack of uniformity of control design, inadequate separation of controls, or the lack of a coding system to help the pilot identify controls by the sense of touch alone. For example, in the early days of retractable landing gear, pilots often grabbed the wrong lever and mistakenly raised the landing gear instead of the flaps. Sensory overload also became a problem, especially in cockpit design. The 1950s brought a strong program of standardizing control shapes, locations and overload management.

The growth of human factors engineering during the mid- to late-forties was evidenced by the establishment of several organizations to conduct psychological research on equipment design. Toward the end of 1945, Paul Fitts established what came to be known as the Behavioral Sciences Laboratory at the Army Corps Aeromedical Laboratory in Dayton, Ohio. Around the same time, the U.S. Navy established the Naval Research Laboratory at Anacostia, Maryland (headed by Frank V. Taylor), and the Navy Special

Devices Center at Port Washington, New York (headed by Leonard C. Mead). The Navy Electronics Laboratory in San Diego, California, was established about a year later with Arnold M. Small as head.

In addition to the establishment of these military organizations, the human factors discipline expanded within several civilian activities. Contract support was provided by the U.S. Navy and the U.S. Air Force for research at several noted universities, specifically Johns Hopkins, Tufts, Harvard, Maryland, Holyoke, and California (Berkeley). Paralleling this growth was the establishment of several private corporate ventures. Thus, as a direct result of the efforts of World War II, a new industry known as engineering psychology or human factors engineering was born.

### **Why is HFE important to the military?**

Until today, many project managers and designers are still slow to consider Human Factors Engineering (HFE) as an essential and integral part of the design process. This is sometimes due to their lack of education on the purpose of HFE, in other instances it is due to others being perfectly capable of considering HFE related issues. Nevertheless, progress is being made as HFE is becoming more and more accepted and is now implemented in a wide variety of applications and processes. The U.S. military is particularly concerned with the implementation of HFE in every phase of the acquisition process of its systems and equipment. Just about every piece of gear, from a multi-billion dollar aircraft carrier to the boots that servicemen wear, goes at least in part through some HFE analyses before procurement and throughout its lifecycle.

Lessons learned in the aftermath of World War II prompted the U.S. War Department (now U.S. Department of Defense) to take some steps in improving safety in military operations. U.S. Department of Defense regulations require a comprehensive management and technical strategy for human systems integration (HSI) be initiated early in the acquisition process to ensure that human performance is considered throughout the system design and development process.

### **HFE applications in the U.S. Army**

In the U.S. Army, the term MANPRINT is used as the program designed to implement HSI. The program was established in 1984 with a primary objective to place the human element (functioning as individual, crew/team, unit and organization) on an equal footing with other design criteria such as hardware and software. The entry point of MANPRINT in the acquisition process is through requirements documents and studies.

### **What is MANPRINT?**

MANPRINT (Manpower and Personnel Integration) is a comprehensive management and technical program that focuses attention on human capabilities and limitations throughout the system's life cycle: concept development, test and evaluation, documentation, design, development, fielding, post-fielding, operation and modernization of systems. It was

initiated in recognition of the fact that the human is an integral part of the total system. If the human part of the system can't perform efficiently, the entire system will function sub-optimally.

MANPRINT's goal is to optimize total system performance at acceptable cost and within human constraints. This is achieved by the continuous integration of seven human-related considerations (known as MANPRINT domains) with the hardware and software components of the total system and with each other, as appropriate. The seven MANPRINT domains are: Manpower (M), Personnel (P), Training (T), Human Factors Engineering (HFE), System Safety (SS), Health Hazards (HH), Soldier Survivability (SSv). They are each expounded on below:

### **Manpower (M)**

Manpower addresses the number of military and civilian personnel required and potentially available to operate, maintain, sustain, and provide training for systems. It is the number of personnel spaces (required or authorized positions) and available people (operating strength). It considers these requirements for peacetime, conflict, and low intensity operations. Current and projected constraints on the total size of the Army/organization/unit are also considered. The MANPRINT practitioner evaluates the manpower required and/or available to support a new system and subsequently considers these constraints to ensure that the human resource demands of the system do not exceed the projected supply.

### **Personnel (P)**

Manpower and personnel are closely related. While manpower looks at numbers of spaces and people, the domain of personnel addresses the cognitive and physical characteristics and capabilities required to be able to train for, operate, maintain, and sustain materiel and information systems. Personnel capabilities are normally reflected as knowledge, skills, abilities, and other characteristics (KSAOs). The availability of personnel and their KSAOs should be identified early in the acquisition process and may result in specific thresholds. On most systems, emphasis is placed on enlisted personnel as the primary operators, maintainers, and supporters of the system. Personnel characteristics of enlisted personnel are easier to quantify since the Armed Services Vocational Aptitude Battery (ASVAB) is administered to potential enlistees.

While normally enlisted personnel are operators and maintainers; that is not always the case, especially in aviation systems. Early in the requirements determination process, identification of the target audience should be accomplished and used as a baseline for assessment. Cognitive and physical demands of the system should be assessed and compared to the projected supply. MANPRINT also takes into consideration personnel factors such as availability, recruitment, skill identifiers, promotion, and assignment.

## **Training (T)**

Training is defined as the instruction or education, on-the-job, or self development training required to provide all personnel and units with their essential job skills, and knowledge. Training is required to bridge the gap between the target audiences' existing level of knowledge and that required to effectively operate, deploy/employ, maintain and support the system. The MANPRINT goal is to acquire systems that meet the Army's training thresholds for operation and maintenance. Key considerations include developing an affordable, effective and efficient training strategy (which addresses new equipment, training devices, institutional, sustainment, and unit collective tactical training); determining the resources required to implement it in support of fielding and the most efficient method for dissemination (contractor, distance learning, exportable packages, etc.); and evaluating the effectiveness of the training.

Training is particularly crucial in the acquisition and employment of a new system. New tasks may be introduced into a duty position; current processes may be significantly changed; existing job responsibilities may be redefined, shifted, or eliminated; and/or entirely new positions may be required. It is vital to consider the total training impact of the system on both the individuals and the organization as a whole.

## **Human Factors Engineering (HFE)**

The goal of HFE is to maximize the ability of an individual or crew to operate and maintain a system at required levels by eliminating design-induced difficulty and error. Human factors engineers work with systems engineers to design and evaluate human-system interfaces to ensure they are compatible with the capabilities and limitations of the potential user population. HFE is conducted during all phases of system development, to include requirements specification, design and testing and evaluation. HFE activities during requirements specification include: evaluating predecessor systems and operator tasks; analyzing user needs; analyzing and allocating functions; and analyzing tasks and associated workload. During the design phase, HFE activities include: evaluating alternative designs through the use of equipment mockups and software prototypes; evaluating software by performing usability testing; refining analysis of tasks and workload; and using modeling tools such as human figure models to evaluate crew station and workplace design and operator procedures. During the testing and evaluation phase, HFE activities include: confirming the design meets HFE specification requirements; measuring operator task performance; and identifying any undesirable design or procedural features.

## **System Safety (SS)**

System Safety is the design features and operating characteristics of a system that serve to minimize the potential for human or machine errors or failures that cause injurious accidents. Safety considerations should be applied in system acquisition to minimize the potential for accidental injury of personnel and mission failure.

## **Health Hazards (HH)**

Health Hazards addresses the design features and operating characteristics of a system that create significant risks of bodily injury or death. Along with safety hazards, an assessment of health hazards is necessary to determine risk reduction or mitigation. The goal of the Health Hazard Assessment (HHA) is to incorporate biomedical knowledge and principles early in the design of a system to eliminate or control health hazards. Early application will eliminate costly system retrofits and training restrictions resulting in enhanced soldier-system performance, readiness and cost savings. HHA is closely related to occupational health and preventive medicine but gets its distinctive character from its emphasis on soldier-system interactions of military unique systems and operations.

Health Hazard categories include acoustic energy, biological substances, chemical substances, oxygen deficiency, radiation energy, shock, temperature extremes and humidity, trauma, vibration, and other hazards. Health hazards include those areas that could cause death, injury, illness, disability, or a reduction in job performance.

## **Organisational and Social**

The seventh domain addresses the human factors issues associated with the socio-technical systems necessary for modern warfare. This domain has been recently added to investigate issues specific to Network Enabled Capability (NEC) also known as Network Centric Warfare (NCW). Elements such as dynamic command and control structures, data assimilation across multiple platforms and its fusion into information easily understood by distributed operators are some of the issues investigated.

A soldier survivability domain was also proposed but this was never fully integrated into the MANPRINT model.

## **Domain Integration**

Although each of the MANPRINT domains has been introduced separately, in practice they are often interrelated and tend to impact on one another. Changes in system design to correct a deficiency in one MANPRINT domain nearly always impact another domain.

## ***Human Factors Integration***

Areas of interest for human factors practitioners may include: training, staffing evaluation, communication, task analyses, functional requirements analyses and allocation, job descriptions and functions, procedures and procedure use, knowledge, skills, and abilities; organizational culture, human-machine interaction, workload on the human, fatigue, situational awareness, usability, user interface, learnability, attention, vigilance, human performance, human reliability, human-computer interaction, control and display design, stress, visualization of data, individual differences, aging, accessibility, safety, shift work, work in extreme environments including virtual environments, human error, and decision making.

## ***Real World Applications of Human Factors - MultiModal Interfaces***

### **Multi-Modal Interfaces**

In many real world domains, ineffective communication occurs partially because of inappropriate and ineffective presentation of information. Many real world interfaces both allow user input and provide user output in a single modality (most often being either visual or auditory). This single modality presentation can often lead to data overload in that modality causing the user to become overwhelmed by information and cause him/her to overlook something. One way to address this issue is to use multi-modal interfaces.

### **Reasons to Use Multimodal Interfaces**

- Time Sharing – helps avoid overloading one single modality
- Redundancy – providing the same information in two different modalities helps assure that the user will see the information
- Allows for more diversity in users (blind can use tactile input; hearing impaired can use visual input and output)
- Error Prevention – having multiple modalities allows the user to choose the most appropriate modality for each task (for example, spatial tasks are best done in a visual modality and would be much harder in an olfactory modality)

### **Examples of Well Known Multi-Modality Interfaces**

- Cell Phone – The average cell phone uses auditory, visual, and tactile output through use of a phone ringing, vibrating, and a visual display of caller ID.
- ATM – Both auditory and visual outputs

### **Early Multi-Modal Interfaces by the Experts**

- Bolts “Put That There” – 1980 – used speech and manual pointing
- Cohen and Oviatt’s “Quickset” – multi user speech and gesture input

### ***Worker Safety and Health***

One of the most prevalent types of work-related injuries are musculoskeletal disorders. Work-related musculoskeletal disorders (WRMDs) result in persistent pain, loss of functional capacity and work disability, but their initial diagnosis is difficult because they are mainly based on complaints of pain and other symptoms. Every year 1.8 million U.S. workers experience WRMDs and nearly 600,000 of the injuries are serious enough to

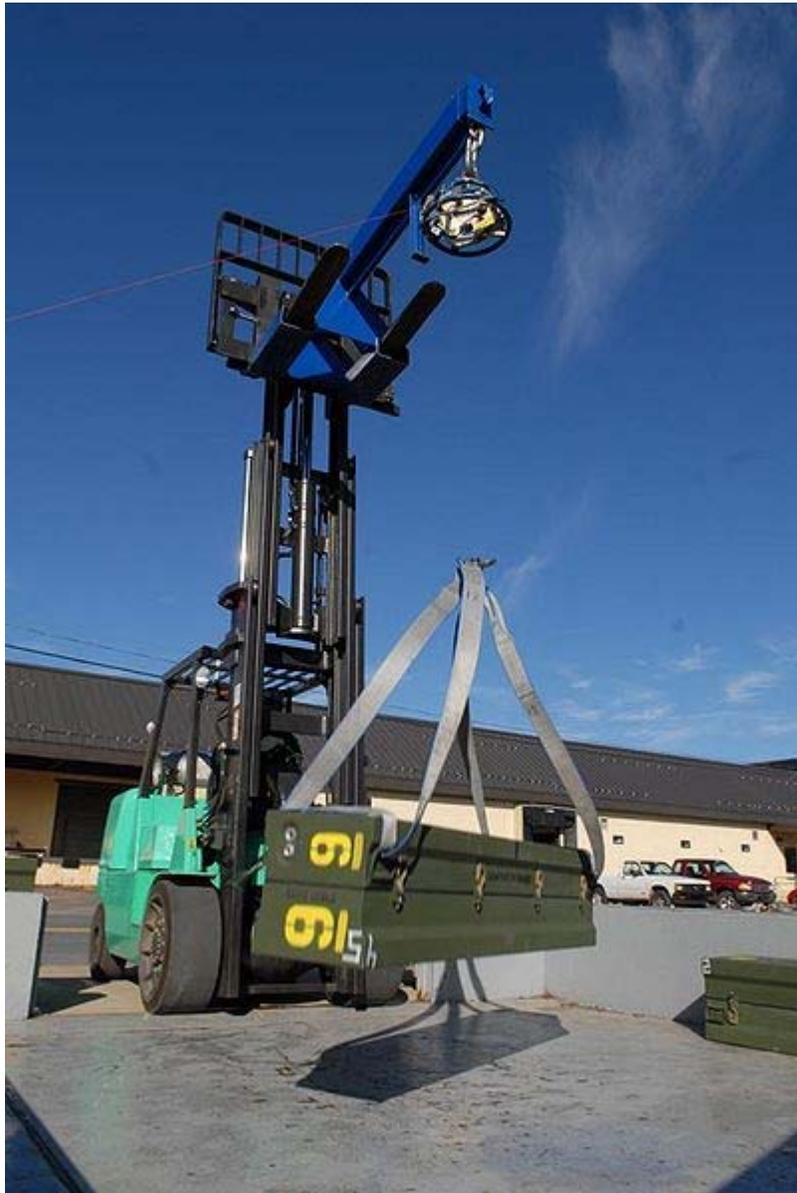
cause workers to miss work. Certain jobs or work conditions cause a higher rate worker complaints of undue strain, localized fatigue, discomfort, or pain that does not go away after overnight rest. These types of jobs are often those involving activities such as repetitive and forceful exertions; frequent, heavy, or overhead lifts; awkward work positions; or use of vibrating equipment. The Occupational Safety and Health Administration (OSHA) has found substantial evidence that ergonomics programs can cut workers' compensation costs, increase productivity and decrease employee turnover. Therefore, it is important to gather data to identify jobs or work conditions that are most problematic, using sources such as injury and illness logs, medical records, and job analyses.

Job analysis can be carried out using methods analysis, time studies, work sampling, or other established work measurement systems.

- Methods Analysis is the process of studying the tasks a worker completes using a step-by-step investigation. Each task is broken down into smaller steps until each motion the worker performs is described. Doing so enables you to see exactly where repetitive or straining tasks occur.
- Time studies determine the time required for a worker to complete each task. Time studies are often used to analyze cyclical jobs. They are considered “event based” studies because time measurements are triggered by the occurrence of predetermined events.
- Work Sampling is a method in which the job is sampled at random intervals to determine the proportion of total time spent on a particular task. It provides insight into how often workers are performing tasks which might cause strain on their bodies.
- Predetermined time systems are methods for analyzing the time spent by workers on a particular task. One of the most widely used predetermined time system is called Methods-Time-Measurement or MTM. Other common work measurement systems include MODAPTS and MOST.

## Chapter 8

# Package Testing



Military shipping container being drop tested



Testing modified atmosphere in a plastic bag of carrots

**Package testing** or **packaging testing** involves the measurement of a characteristic or property involved with packaging. This includes packaging materials, packaging components, primary packages, shipping containers, and unit loads, as well as the associated processes.

Testing measures the effects and interactions of the levels of packaging, the package contents, external forces, and end-use.

It can involve controlled laboratory experiments, subjective evaluations by people, or field testing. Documentation is important: formal test method, test report, photographs, video, etc.

Testing can be a qualitative or quantitative procedure. Package testing is often a physical test. With some types of packaging such as food and pharmaceuticals, chemical tests are conducted to determine suitability of food contact materials. Testing programs range from simple tests with little replication to more thorough experimental designs.

Package testing can extend for the full life cycle. Packages can be tested for their ability to be recycled and their ability to degrade as surface litter, in a sealed landfill or under composting conditions.

## ***Purposes***

Packaging testing might have a variety of purposes, such as:

- Determine if, or verify that, the requirements of a specification, regulation, or contract are met
- Decide if a new product development program is on track: Demonstrate proof of concept
- Provide standard data for other scientific, engineering, and quality assurance functions
- Validate suitability for end-use
- Provide a basis for technical communication
- Provide a technical means of comparison of several options
- Provide evidence in legal proceedings: product liability, patents, product claims, etc.
- Help solve problems with current packaging
- Help identify potential cost savings in packaging
- Predict in a laboratory, the performance of a package during distribution and the use by customers

## ***Importance of testing***



Testing the ability of packages to resist insect infestation

For some types of products, package testing is mandated by regulations: food, pharmaceuticals, medical devices, dangerous goods, etc. This may cover both the design qualification, periodic retesting, and control of the packaging processes. Processes may be controlled by a variety of quality management systems such as HACCP, statistical process control, validation protocols, ISO 9000, etc.

For unregulated products, testing can be required by a contract or governing specification. The degree of package testing can often be a business decision. Risk management may involve factors such as

- costs of packaging
- costs of package testing
- value of contents being shipped
- value of customer's good will
- product liability exposure
- other potential costs of inadequate packaging
- etc.

With distribution packaging, one vital packaging development consideration is to determine if a packaged-product is likely to be damaged in the process of getting to the final customer. A primary purpose of a package is to ensure the safety of a product during transportation and storage. If a product is damaged during this process, then the package has failed to accomplish a primary objective and the customer will either return the product or be unlikely to purchase the product altogether.

Package testing is often a formal part of Project management programs. Packages are usually tested when there is a new packaging design, a revision to a current design, a change in packaging material, and various other reasons. Testing a new packaging design before full scale manufacturing can save time and money.

### ***Laboratory affiliation***

Many suppliers or vendors offer limited material and package testing as a free service to customers. It is common for packagers to partner with reputable suppliers: Many suppliers have certified quality management systems such as ISO 9000 or allow customers to conduct technical and quality audits. Data from testing is commonly shared. There is sometimes a risk that supplier testing may tend to be self-serving and not completely impartial.

Large companies often have their own packaging staff and a package testing and development laboratory. Corporate engineers know their products, manufacturing capabilities, logistics system, and their customers best. Cost reduction of existing products and cost avoidance for new products have been documented.

Another option is to use paid consultants, Independent contractors, and third-party test laboratories. They are commonly chosen for specialized expertise, for access to certain test equipment, for surge projects, or where independent testing is otherwise required. Many have certifications and accreditations: ISO 9000, ISO/IEC 17025, and various governing agencies.

### ***Procedures***

Several standards organizations publish test methods for package testing. Included are:

- International Organization for Standardization, ISO
- ASTM International
- European Committee for Standardization. CEN
- TAPPI
- International Safe Transit Association
- etc.

Governments and regulators publish some packaging test methods. There are also many corporate test standards in use. A review of technical literature and patents provides good options to consider for test procedures.

Researchers are not restricted to the use of published standards but can modify existing test methods or develop procedures specific to their particular needs. If a test is conducted with a deviation from a published test method or if a new method is employed, the test report must fully disclose the procedure.

### ***Materials testing***



Materials and components are often evaluated on a universal testing machine

The basis of packaging design and performance is the component materials. The physical properties, and sometimes chemical properties, of the materials need to be communicated to packaging engineers to aid in the design process. Suppliers publish data sheets and other technical communications that include the typical or average relevant physical

properties and the test method these are based upon. Sometimes these are adequate. Other times, additional material and component testing is required by the packager or supplier to better define certain characteristics.

When a final package design is complete, the specifications for the component materials needs to be communicated to suppliers. Packaging materials testing is often needed to identify the critical material characteristics and engineering tolerances. These are used to prepare and enforce specifications.

For example, shrink film data might include: tensile strength (MD and CD), elongation, Elastic modulus, surface energy, thickness, Moisture vapor transmission rate, Oxygen transmission rate, heat seal strength, heat sealing conditions, heat shrinking conditions, etc. Average and process capability are often provided. The chemical properties related for use as Food contact materials may be necessary.

### ***Testing with People***

Some types of package testing do not use scientific instruments but use people for the evaluation.

The regulations for Child-resistant packaging require a test protocol that involves children. Samples of the test packages are given to a prescribed population of children. With specified 50 child panels, a high percentage must be unable to open a test package within 5 minutes. Adults are also tested for their ability to open a C-R package.

Consumer packages are often evaluated by Focus groups. People evaluate the package features in a room monitored by video cameras. The consumer responses are treated qualitatively for feedback into the new packaging process.

Some food packagers use organoleptic evaluations. People use their senses (taste, smell, etc.) to determine if a package component has tainted the food in the package.

A new package may be evaluated in a test market that uses people to try the packages at home. Consumers have the opportunity to buy a product, perhaps with a coupon or discount. Return post cards or internet sites provide feedback to package developers. Perhaps the most critical feedback is repeated sales items in the new package. Packaging evaluations are an important part of Marketing research.

Legibility of text on packaging and labels is always subjective due to the inherent variations of people. Efforts have been made to help better quantify this by people in a laboratory: still using people for the evaluation but also employing a test apparatus to help reduce variability.

Some laboratory tests are conducted but still result in an observation by people. Some test procedures call for a judgment by test engineers whether or not pre-established acceptance criteria has been met.

## **Relevant standards**

ASTM D7298 Test Method for Measurement of Comparative Legibility by Means of Polarizing Filter Instrumentation.  
ASTM E460 Practice for Determining Effect of Packaging on Food and Beverage Products During Storage  
ASTM E619 Practice for Evaluating Foreign Odors in Paper Packaging  
ASTM E1870 Test Method for Odor and Taste Transfer from Polymeric Packaging Film  
ASTM 2609 Test Method for Odor and Flavor Transfer from Rigid Polymeric Packaging  
ISO 16820 Sensory Analysis - Methodology - Sequential Analysis  
ISO 5495 Sensory Analysis - Methodology - Paired Comparisons  
ISO 13302 Sensory Analysis - Methods for assessing modifications to the flavour of foodstuffs due to packaging

## ***Conditioning, testing atmosphere***



Environmental chamber to simulate temperatures and humidities encountered by packages

The environmental conditions of testing are critical. The measured performance of many packages is affected by the conditioning and testing atmospheres. For example, paper based products are strongly affected by their moisture content: Relative humidity needs to be controlled. Plastic products are often strongly affected by temperature.

Conditions of 23°C (73.4°F) and 50% relative humidity are common but other standard testing conditions are also published in material and package test standards. Engineering tolerances for the conditions are also specified. Often the package is conditioned to the specified environment and tested under those conditions. This can be in a conditioned room or in a chamber enclosing the test. With some testing, the package is conditioned to a specified environment, then is removed to ambient conditions and quickly tested. The test report needs to state the actual conditions used.

Engineers have found it important to know the effects of the full range of expected conditions on package performance. This can be through investigating published technical literature, obtaining supplier documentation, or by conducting controlled tests at diverse conditions.

### **Relevant Standards**

ASTM D4332- Standard Practice for Conditioning Containers, Packages, or Packaging Components for Testing

ASTM E171- Standard Specification for Standard Atmospheres for Conditioning and Testing Flexible Barrier Materials

### ***Degradation of product***



Heat sealer used to prepare bag of lettuce for shelf life testing

Laboratory tests can help determine the expected shelf life of a package and its contents. This is particularly important for foods, pharmaceuticals, some chemicals, and a variety of products. The testing is usually product specific: the mechanisms of degradation are often different. Exposures to expected and elevated temperatures and humidities are commonly used for shelf life testing. The ability of packaging to control product degradation is frequently a subject of laboratory and field evaluations.

### **Relevant tests**

ASTM E2454 Standard Guide for Sensory Evaluation Methods to Determine the Sensory Shelf -life of Consumer Products

DoD 4140.27M Shelf Life Management Manual, 2000

ISO 11987 Ophthalmic Optics, Contact Lenses, Determination of Shelf Life

### **Barrier Properties**

Many products degrade with exposure to the atmosphere: foods, pharmaceuticals, chemicals, etc. The ability of a package to control the permeation and penetration of gasses is vital for many types of products. Tests are often conducted on the packaging materials but also on the completed packages, sometimes after being subjected to flexing, handling, vibration, or temperature.

### ***Degradation of Packages***

Packages can degrade with exposure to temperature, humidity, time, sterilization (steam, radiation, gas, etc.), sunlight, and other environmental factors. Several types of accelerated aging of packaging and materials can be accomplished in a laboratory.

Exposure to elevated temperatures accelerates some degradation mechanisms. An Arrhenius equation is often used to correlate certain chemical reactions at different temperatures, based on the proper choice of Q10 (temperature coefficient)s.

As with any laboratory testing, validating field trials are important.

### **Relevant tests**

ASTM D3045 Standard Practice for Heat Aging of Plastics without Load

ASTM F1640 Standard Guide for Packaging Materials for Foods to be Irradiated

ASTM F1980– Standard Guide for Accelerated Aging of Sterile Medical Device Packages

ASTM G151 Standard Practice for Exposing Non-metallic Materials in Accelerated Test Devices that are Laboratory Light Sources

## ***Vacuum testing***



Vacuum chamber for testing leaks in packaging component

Vacuum chambers are used to test the ability of a package to withstand low pressures. This can be to:

1. Determine the ability of packages to withstand low pressures that might be encountered. This could be in an air shipment or high altitude truck shipment.
2. A laboratory vacuum places controlled stress on a sealed package to test the strength of seals, the tendency for leakage, and the ability to retain sterility.

## **Relevant tests**

ASTM D3078- Standard Test Method for Determination of Leaks in Flexible Packaging by Bubble Emission

ASTM D4991- Standard Test Method for Leakage Testing of Empty Rigid Containers by Vacuum Method

ASTM D6653- Standard Test Methods for Determining the Effects of High Altitude on Packaging Systems by Vacuum Method

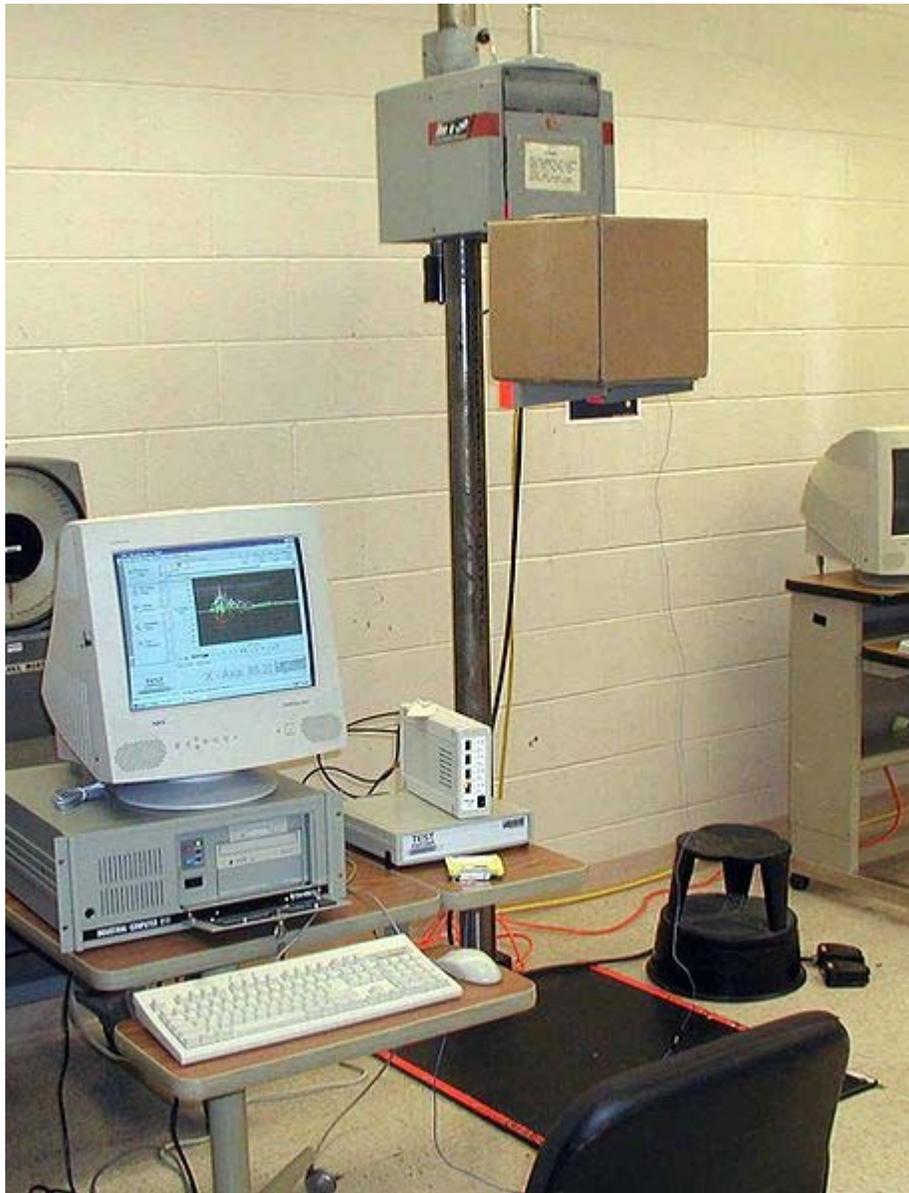
ASTM D6834- Standard Test Method for Determining Product Leakage from a Package with a Mechanical Pump Dispenser

ASTM E493- Standard Test Methods for Leaks Using the Mass Spectrometer Leak Detector in the Inside-Out Testing Mode

ASTM F2338- Standard Test Method for Nondestructive Detection of Leaks in Packages by Vacuum Decay Method

ASTM F2391- Standard Test Method for Measuring Package and Seal Integrity Using Helium as the Tracer Gas

## ***Shock and impact***



Instrumented drop test of cushioned package to measure the transmitted shock

Both primary (consumer) packages and shipping containers have a risk of being dropped or being impacted by other items. Package integrity and product protection are important packaging functions. Tests are conducted to measure the resistance of packages and products to controlled laboratory shock and impact.

Testing also determines the effectiveness of package cushioning to isolate fragile products from shock. Instrumentation is used to measure the shock transmitted to a cushioned product.

## **Relevant tests**

ASTM D880- Standard Test Method for Impact Testing for Shipping Containers and Systems  
ASTM D1596- Standard Test Method for Dynamic Shock Cushioning Characteristics of Packaging Materials  
ASTM D3332- Standard Test Methods for Mechanical-Shock Fragility of Products, Using Shock Machines  
ASTM D4003- Standard Test Methods for Programmable Horizontal Impact Test for Shipping Containers and Systems  
ASTM D5265- Standard Test Method for Bridge Impact Testing  
ASTM D5276- Standard Test Method for Drop Test of Loaded Containers by Free Fall  
ASTM D5277- Standard Test Method for Performing Programmed Horizontal Impacts Using an Inclined Impact Tester  
ASTM D5487- Standard Test Method for Simulated Drop of Loaded Containers by Shock Machines  
ASTM D6344- Standard Test Method for Concentrated Impacts to Transport Packages  
ASTM D6537- Standard Practice for Instrumented Package Shock Testing For Determination of Package Performance

## ***Package Insulation***

Many packages are used for products that are sensitive to temperature. The ability of insulated shipping containers to protect their contents from exposure to temperature fluctuations can be measured in a laboratory. The testing can be of empty containers or of full containers with appropriate jell or ice packs, contents, etc. Ovens, freezers, and environmental chambers are commonly used for this and other types of packaging.

Digital data loggers are used to measure temperatures experienced in different distribution systems. This data is sometimes used to develop unique test methods for that distribution system.

## **Relevant tests**

ASTM D3103-Standard Test Method for Thermal Insulation Performance of Distribution Packages  
ISTA Guide 5B- Focused Simulation Guide for Thermal Performance Testing of Temperature Controlled Transport Packaging

## **Vibration**



Vibration tester to simulate vibration frequencies at which packaged products are subjected during shipments

Vibration is encountered during shipping (vehicle vibration, rough roads, etc.) and movement on conveyors. Potential vibration damage may include:

- fractures and fatigue damage
- loose wires, screw caps, etc
- bruises on soft products (fruit, etc)
- surface abrasion
- etc

The ability of a package to withstand these vibrations and to protect the contents can be measured by several laboratory test procedures. Some allow searching for the particular frequencies of vibration that have potential for damage. Modal testing methodologies are sometimes employed. Others use specified bands of random vibration to better represent complex vibrations measured in field studies of distribution environments.

### **Relevant tests**

ASTM D999- Standard Test Methods for Vibration Testing of Shipping Containers

ASTM D3580-Standard Test Methods for Vibration (Vertical Linear Motion) Test of Products

ASTM D4728- Standard Test Method for Random Vibration Testing of Shipping Containers

ASTM D5112- Standard Test Method for Vibration (Horizontal Linear Sinusoidal Motion) Test of Products

ASTM D7387- Standard Test Method for Vibration Testing of Intermediate Bulk Containers (IBCs) Used for Shipping Liquid Hazardous Materials (Dangerous Goods)

## ***Compression***



Packaging compression tester to determine the stacking strength of packaging

Compression testing relates to stacking or crushing of packages, particularly shipping containers. It usually measures of the force required to crush a package, stack of packages, or a unit load. Packages can be empty or filled as for shipment. A force-deflection curve used to obtain the peak load or other desired points. Other tests use a constant load and measure the time to failure or to a critical deflection.

Dynamic compression is sometimes tested by shock or impact testing with an additional load to crush the test package. Dynamic compression also takes place in stacked vibration testing.

## ***Dangerous Goods***

Hazardous materials, dangerous goods are highly regulated. There are some material and construction requirements but also Performance testing is required. The testing is based on the packing group (hazard level) of the contents, the quantity of material, and the type of container.

## **Relevant standards**

ASTM D4919- Standard Specification for Testing of Hazardous Materials Packaging

ASTM D7387- Standard Test Method for Vibration Testing of Intermediate Bulk Containers (IBCs) Used for Shipping Liquid Hazardous Materials (Dangerous Goods)

UN Recommendations on the Transport of Dangerous Goods

ISO 16104 - 2003 Packaging - Transport packaging for dangerous goods - Test methods

## **Large loads**



Rotational corner drop test of wooden box

Large pallet loads, bulk boxes, wooden boxes, and crates can be evaluated by many of the other test procedures previously listed. In addition, some special test methods are available for these larger loads.

### **Relevant tests**

ASTM D5331- Standard Test Method for Evaluation of Mechanical Handling of Unitized Loads Secured with Stretch Wrap Films

ASTM D5414- Standard Test Method for Evaluation of Horizontal Impact Performance of Load Unitizing Stretch Wrap Films

ASTM D5415- Standard Test Method for Evaluating Load Containment Performance of Stretch Wrap Films by Vibration Testing

ASTM D5416- Standard Test Method for Evaluating Abrasion Resistance of Stretch Wrap Films by Vibration Testing

ASTM D6055- Standard Test Methods for Mechanical Handling of Unitized Loads and Large Shipping Cases and Crates

ASTM D6179- Standard Test Methods for Rough Handling of Unitized Loads and Large Shipping Cases and Crates

## ***Medical Packaging***

Medical packaging has special user requirements and is highly regulated. Barrier properties, durability, visibility, sterility and strength need to be controlled; usually with documented test results for initial designs and for production.

Often medical devices and products are sterilized in the package. The sterility must be maintained throughout distribution to allow immediate use by physicians. A series of special packaging tests is used to measure the ability of the package to maintain sterility.

### **Relevant standards**

ASTM D1585- Guide for Integrity Testing of Porous Medical Packages

ASTM F1929 - Standard Test Method for Detecting Seal strength in Porous Medical Packaging by Dye Penetration

ASTM F2096 - Standard Test Method for Detecting Gross Leaks in Medical Packaging by Internal Pressurization

ASTM F2097- Standard Guide for Design and Evaluation of Primary Flexible Packaging for Medical Products

ASTM F2228 - Standard Test Method for Non-Destructive Detection of Leaks in Medical Packaging Which Incorporates Porous Barrier Material by CO<sub>2</sub> Tracer Gas

ASTM F2391 - Standard Test Method for Measuring Package and Seal Integrity using Helium as the Tracer Gas

EN 868-1- Packaging materials and systems for medical devices which are to be sterilized. General requirements and test methods

ISO 11607-1- Packaging for terminally sterilized medical devices -- Part 1: Requirements for materials, sterile barrier systems and packaging systems

## ***Test Protocols for Shipping Containers***

Shipping containers are often subjected to sequential tests involving a combination of individual test methods. A variety of standard test schedules or protocols are available for evaluating transport packaging. They are used to help determine the ability of complete and filled shipping containers to various types of logistics systems. Some test the general ruggedness of the shipping container while others have been shown to reproduce the types of damage encountered in distribution. Some base the type and severity of testing on formal studies of the distribution environment: instrumentation, data loggers, and observation. Test cycles with these documented elements better simulate parts of certain logistics shipping environments.

ASTM International

ASTM D4169- Standard Practice for Performance Testing of Shipping Containers and Systems

ASTM D7386- Standard Practice for Performance Testing of Packages for Single Parcel Delivery Systems

ISO

ISO 4180:2009 Packaging - Complete filled transport packages - General rules for the compilation of performance test schedules

International Safe Transit Association

Procedure 1A: Packaged-Products weighing 150 lb (68 kg) or Less

Procedure 1B: Packaged-Products weighing Over 150 lb (68 kg)

Procedure 1C: Extended Testing for Individual Packaged-Products weighing 150 lb (68 kg) or Less

Procedure 1D: Extended Testing for Individual Packaged-Products weighing Over 150 lb (68 kg)

Procedure 1E: Unitized Loads

Procedure 1G: Packaged-Products weighing 150 lb (68 kg) or Less (Random Vibration)

Procedure 1H: Packaged-Products weighing Over 150 lb (68 kg) (Random Vibration)

Procedure 2A: Packaged-Products weighing 150 lb (68 kg) or Less

Procedure 2B: Packaged-Products weighing over 150 lb (68 kg)

Procedure 2C: Furniture Packages

Procedure 2D: Packaged-Products Considered Flat

Procedure 2E: Packaged-Products Considered Elongated

Procedure 2F: LTL Shipments (NMFC Item 180)

Procedure 3A: Packaged-Products for Parcel Delivery System Shipments 70kg (150 lb) or Less (standard, small, flat or elongated)

Project 3B: Packaged-Products for Less-Than-Truckload (LTL) Shipment

Procedure 3E: Unitized Loads of Same Product

Procedure 3F: Packaged Products for Distribution Center to Retail Outlet Shipment 100 lb (45 kg)

Procedure 3H: Performance Test for Products or Packaged-Products in Mechanically Handled Bulk Transport Containers

Procedure 3J: Packaged-Products for Club Store Distribution System Shipment

Procedure 7B: Closed Reusable Transport Containers for Loads of 150 lb (68 kg) or Less

Procedure 7C: Reusable Intermediate Bulk Containers

Procedure 7D: Thermal Controlled Transport Packaging for Parcel Delivery System Shipment

## **Field trials**

Laboratory testing can often help identify shipping container constructions that, in general, should perform well in the field. Of course, laboratory tests cannot fully reproduce the full range of field hazards, their magnitudes, nor their frequency. Field experiments are often conducted to help validate the laboratory testing.

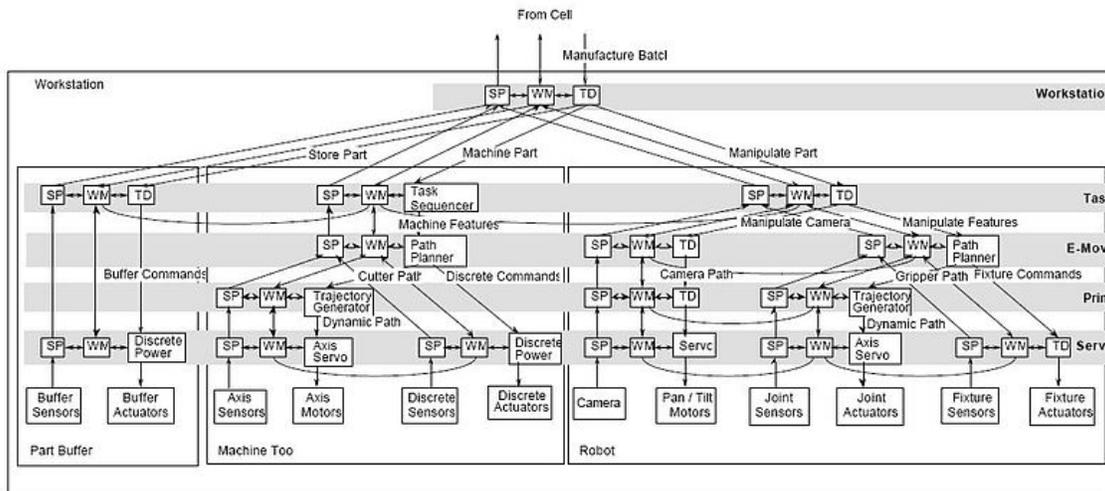
The advantage of laboratory testing is that it subjects replicate packages to identical sets of test sequences: a relatively small number of samples often can suffice. Field hazards, by their nature, are highly variable: thus repeated shipments do not receive the same types or magnitudes of drops, vibrations, kicks, impacts, abrasion, etc. Because of this uncontrolled variability, more replicate sample shipments are often necessary.

Larger scale test markets are used to give additional assurance of performance and acceptability for a new or revised packaged-product. Feedback is carefully obtained and evaluated. Feedback on package performance continues when full production and distribution have been achieved.

## Chapter 9

# Real-Time Control System

**Real-time Control System (RCS)** is a Reference Model Architecture, suitable for many software-intensive, real-time control problem domains. RCS is a reference model architecture that defines the types of functions that are required in a real-time intelligent control system, and how these functions are related to each other.



Example of a RCS-3 application of a machining workstation containing a machine tool, part buffer, and robot with vision system. RCS-3 produces a layered graph of processing nodes, each of which contains a Task Decomposition (TD), World Modeling (WM), and Sensory Processing (SP) module. These modules are richly interconnected to each other by a communications system.

RCS is not a system design, nor is it a specification of how to implement specific systems. RCS prescribes a hierarchical control model based on a set of well-founded

engineering principles to organize system complexity. All the control nodes at all levels share a generic node model.

Also RCS provides a comprehensive methodology for designing, engineering, integrating, and testing control systems. Architects iteratively partition system tasks and information into finer, finite subsets that are controllable and efficient. RCS focuses on intelligent control that adapts to uncertain and unstructured operating environments. The key concerns are sensing, perception, knowledge, costs, learning, planning, and execution.

## **Overview**

A reference model architecture is a canonical form, not a system design specification. The RCS reference model architecture combines real-time motion planning and control with high level task planning, problem solving, world modeling, recursive state estimation, tactile and visual image processing, and acoustic signature analysis. In fact, the evolution of the RCS concept has been driven by an effort to include the best properties and capabilities of most, if not all, the intelligent control systems currently known in the literature, from subsumption to SOAR, from blackboards to object-oriented programming.

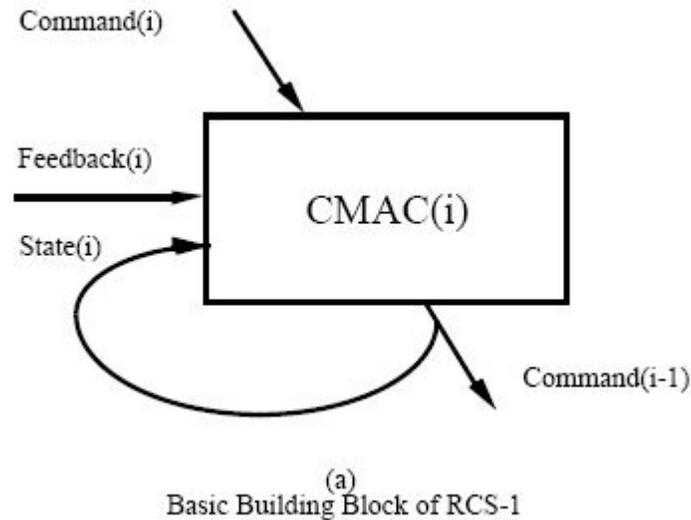
RCS (Real-time Control System) is developed into an intelligent agent architecture designed to enable any level of intelligent behavior, up to and including human levels of performance. RCS was inspired 30 years ago by a theoretical model of the cerebellum, the portion of the brain responsible for fine motor coordination and control of conscious motions. It was originally designed for sensory-interactive goal-directed control of laboratory manipulators. Over three decades, it has evolved into a real-time control architecture for intelligent machine tools, factory automation systems, and intelligent autonomous vehicles.

RCS applies to many problem domains including Manufacturing examples and Vehicle systems examples. Systems based on the RCS architecture have been designed and implemented to varying degrees for a wide variety of applications that include loading and unloading of parts and tools in machine tools, controlling machining workstations, performing robotic deburring and chamfering, and controlling space station telerobots, multiple autonomous undersea vehicles, unmanned land vehicles, coal mining automation systems, postal service mail handling systems, and submarine operational automation systems.

## **History**

RCS has evolved through a variety of versions over a number of years as understanding of the complexity and sophistication of intelligent behavior has increased. The first implementation was designed for sensory-interactive robotics by Barbera in the mid 1970's.

## RCS-1



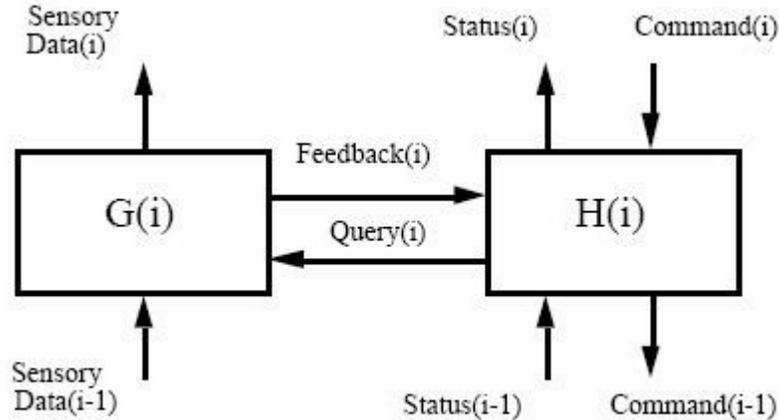
Basics of the RCS-1 control paradigm.

In RCS-1, the emphasis was on combining commands with sensory feedback so as to compute the proper response to every combination of goals and states. The application was to control a robot arm with a structured light vision system in visual pursuit tasks. RCS-1 was heavily influenced by biological models such as the Marr-Albus model, and the Cerebellar Model Arithmetic Computer (CMAC), of the cerebellum.

CMAC becomes a state machine when some of its outputs are fed directly back to the input, so RCS-1 was implemented as a set of state-machines arranged in a hierarchy of control levels. At each level, the input command effectively selects a behavior that is driven by feedback in stimulus-response fashion. CMAC thus became the reference model building block of RCS-1, as shown in the figure.

A hierarchy of these building blocks was used to implement a hierarchy of behaviors such as observed by Tinbergen and others. RCS-1 is similar in many respects to Brooks' subsumption architecture, except that RCS selects behaviors before the fact through goals expressed in commands, rather than after the fact through subsumption.

## RCS-2



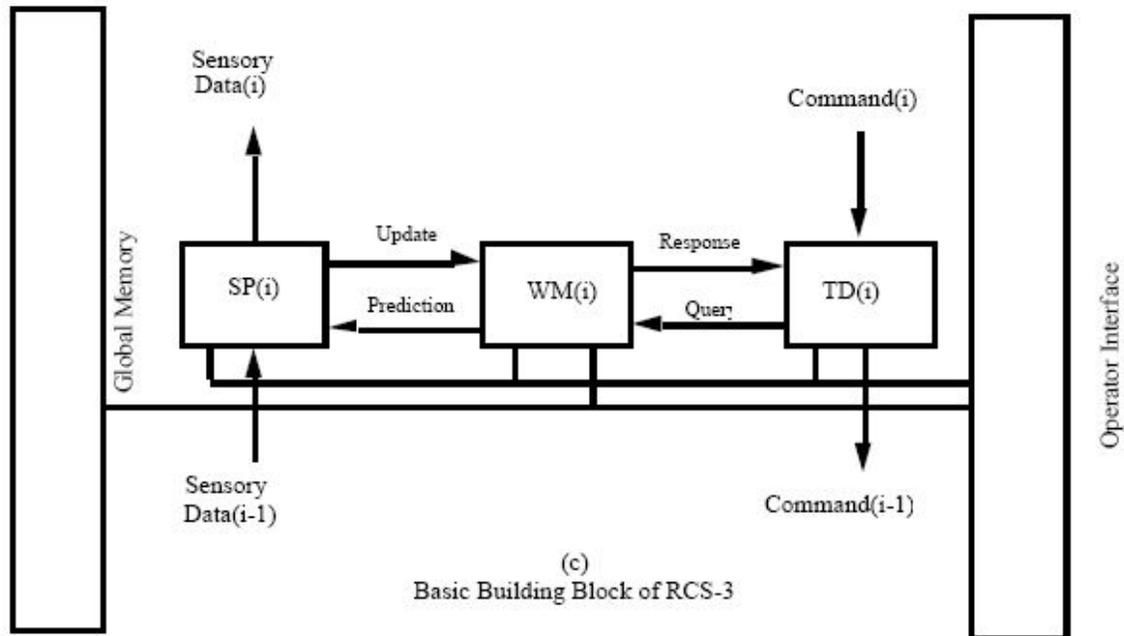
RCS-2 control paradigm.

The next generation, RCS-2, was developed by Barbera, Fitzgerald, Kent, and others for manufacturing control in the NIST Automated Manufacturing Research Facility (AMRF) during the early 1980's. The basic building block of RCS-2 is shown in the figure.

The H function remained a finite state machine state-table executor. The new feature of RCS-2 was the inclusion of the G function consisting of a number of sensory processing algorithms including structured light and blob analysis algorithms. RCS-2 was used to define an eight level hierarchy consisting of Servo, Coordinate Transform, E-Move, Task, Workstation, Cell, Shop, and Facility levels of control.

Only the first six levels were actually built. Two of the AMRF workstations fully implemented five levels of RCS-2. The control system for the Army Field Material Handling Robot (FMR) was also implemented in RCS-2, as was the Army TMAP semi-autonomous land vehicle project.

## RCS-3

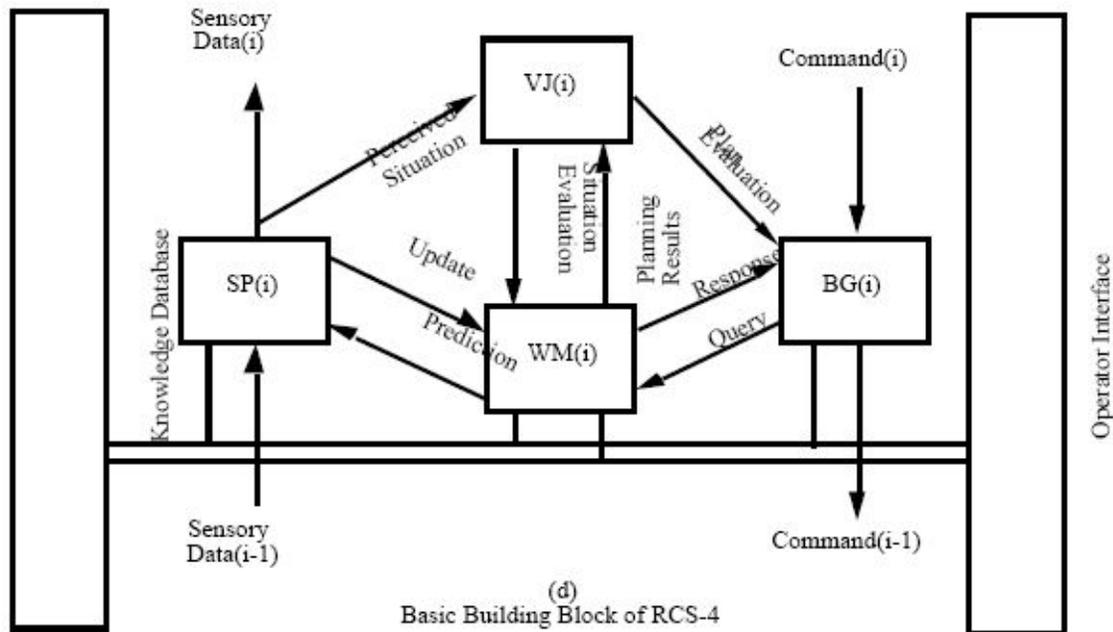


RCS-3 control paradigm.

RCS-3 was designed for the NBS/DARPA Multiple Autonomous Undersea Vehicle (MAUV) project and was adapted for the NASA/NBS Standard Reference Model Telerobot Control System Architecture (NASREM) developed for the space station Flight Telerobotic Servicer. The basic building block of RCS-3 is shown in the figure.

The principal new features introduced in RCS-3 are the World Model and the operator interface. The inclusion of the World Model provides the basis for task planning and for model-based sensory processing. This led to refinement of the task decomposition (TD) modules so that each has a job assigner, and planner and executor for each of the subsystems assigned a job. This corresponds roughly to Saridis' three level control hierarchy.

## RCS-4



RCS-4 control paradigm.

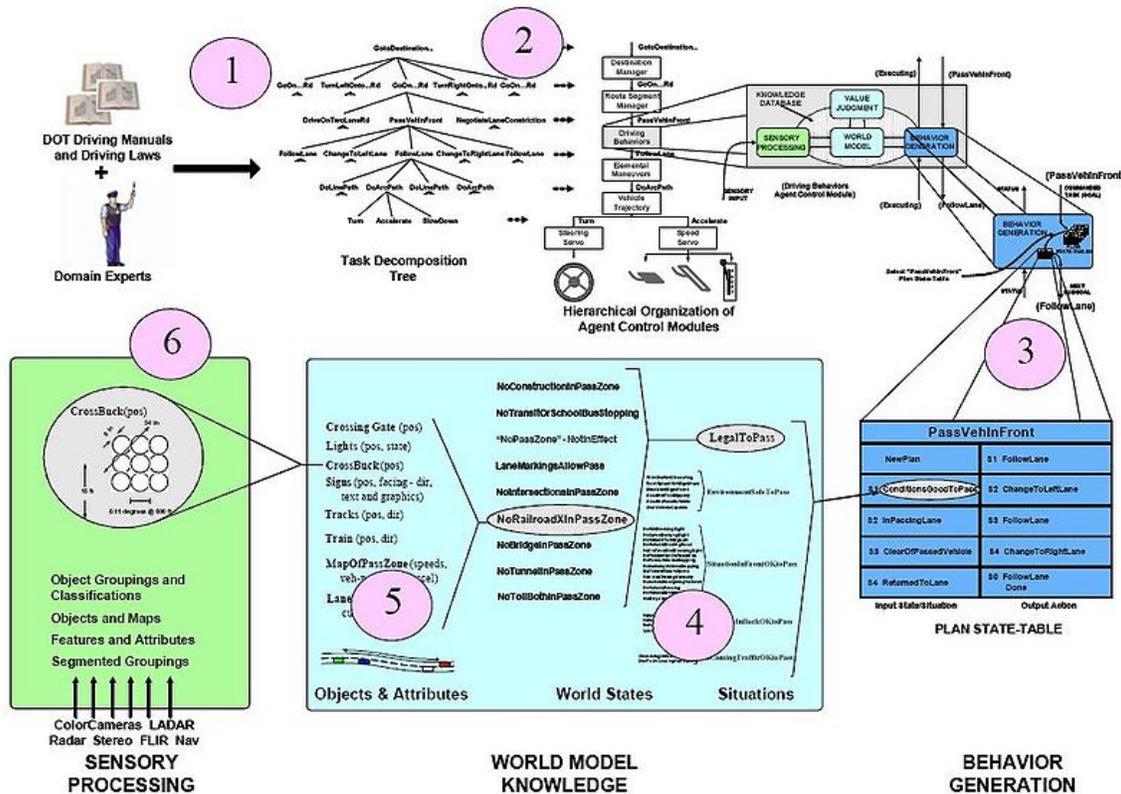
RCS-4 is developed since the 1990s by the NIST Robot Systems Division. The basic building block is shown in the figure). The principal new feature in RCS-4 is the explicit representation of the Value Judgment (VJ) system. VJ modules provide to the RCS-4 control system the type of functions provided to the biological brain by the limbic system. The VJ modules contain processes that compute cost, benefit, and risk of planned actions, and that place value on objects, materials, territory, situations, events, and outcomes. Value state-variables define what goals are important and what objects or regions should be attended to, attacked, defended, assisted, or otherwise acted upon. Value judgments, or evaluation functions, are an essential part of any form of planning or learning. The application of value judgments to intelligent control systems has been addressed by George Pugh. The structure and function of VJ modules are developed more completely developed in Albus (1991).

RCS-4 also uses the term behavior generation (BG) in place of the RCS-3 term task 5 decomposition (TD). The purpose of this change is to emphasize the degree of autonomous decision making. RCS-4 is designed to address highly autonomous applications in unstructured environments where high bandwidth communications are impossible, such as unmanned vehicles operating on the battlefield, deep undersea, or on distant planets. These applications require autonomous value judgments and sophisticated real-time perceptual capabilities. RCS-3 will continue to be used for less demanding applications, such as manufacturing, construction, or telerobotics for near-space, or shallow undersea operations, where environments are more structured and communication bandwidth to a human interface is less restricted. In these applications,

value judgments are often represented implicitly in task planning processes, or in human operator input.

## RCS Methodology

In the figure, an example of the RCS methodology for designing a control system for autonomous onroad driving under everyday traffic conditions is summarized in six steps.



The six steps of the RCS methodology for knowledge acquisition and representation.

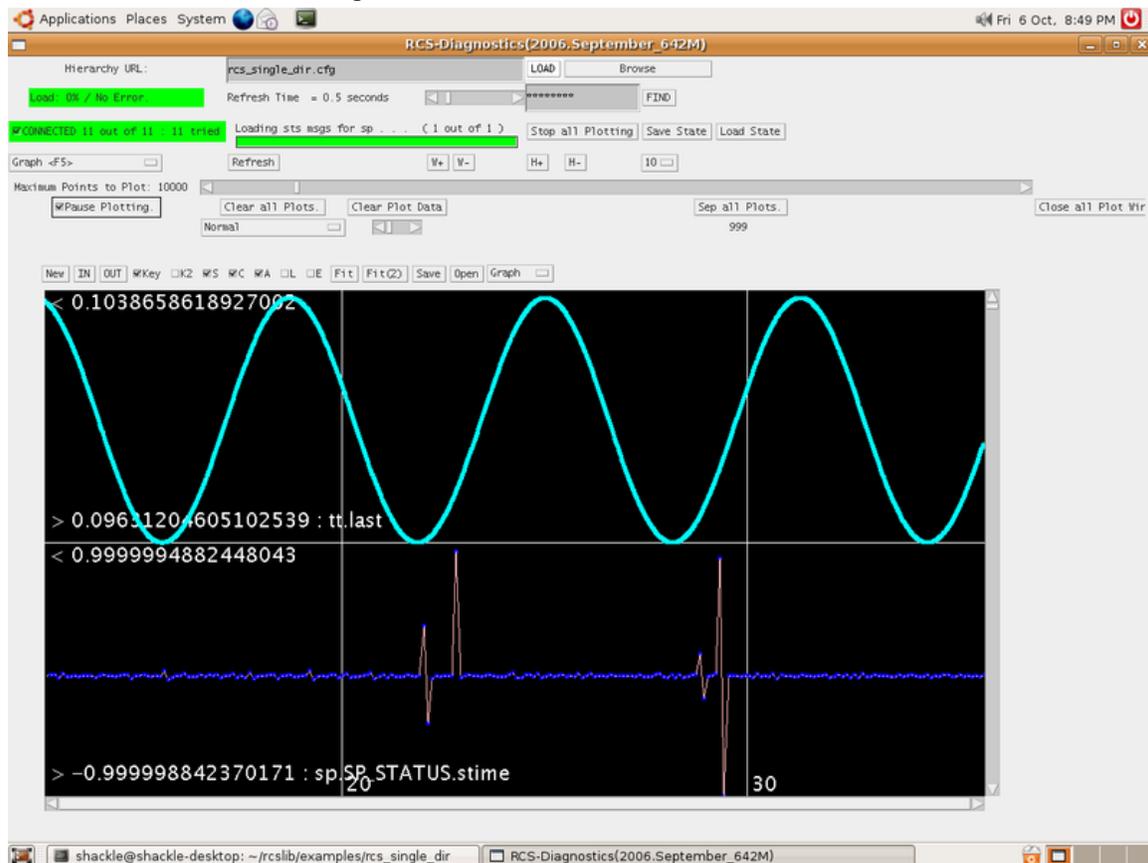
- Step 1 consists of an intensive analysis of domain knowledge from training manuals and subject matter experts. Scenarios are developed and analyzed for each task and subtask. The result of this step is a structuring of procedural knowledge into a task decomposition tree with simpler and simpler tasks at each echelon. At each echelon, a vocabulary of commands (action verbs with goal states, parameters, and constraints) is defined to evoke task behavior at each echelon.
- Step 2 defines a hierarchical structure of organizational units that will execute the commands defined in step 1. For each unit, its duties and responsibilities in response to each command are specified. This is analogous to establishing a work breakdown structure for a development project, or defining an organizational chart for a business or military operation.

- Step 3 specifies the processing that is triggered within each unit upon receipt of an input command. For each input command, a state-graph (or statetable or extended finite state automaton) is defined that provides a plan (or procedure for making a plan) for accomplishing the commanded task. The input command selects (or causes to be generated) an appropriate state-table, the execution of which generates a series of output commands to units at the next lower echelon. The library of state-tables contains a set of statesensitive procedural rules that identify all the task branching conditions and specify the corresponding state transition and output command parameters.

The result of step 3 is that each organizational unit has for each input command a state-table of ordered production rules, each suitable for execution by an extended finite state automaton (FSA). The sequence of output subcommands required to accomplish the input command is generated by situations (i.e., branching conditions) that cause the FSA to transition from one output subcommand to the next.

- In step 4, each of the situations that are defined in step 3 are analyzed to reveal their dependencies on world and task states. This step identifies the detailed relationships between entities, events, and states of the world that cause a particular situation to be true.
- In step 5, we identify and name all of the objects and entities together with their particular features and attributes that are relevant to detecting the above world states and situations.
- In step 6, we use the context of the particular task activities to establish the distances and, therefore, the resolutions at which the relevant objects and entities must be measured and recognized by the sensory processing component. This establishes a set of requirements and/or specifications for the sensor system to support each subtask activity.

## Real-time Control System Software



### Real-Time Control Systems Software.

Based on the RCS Reference Model Architecture the NIST has developed a Real-time Control System Software Library. This is an archive of free C++, Java and Ada code, scripts, tools, makefiles, and documentation developed to aid programmers of software to be used in real-time control systems, especially those using the Reference Model Architecture for Intelligent Systems Design.

### Applications

- The ISAM Framework is an RCS application to the Manufacturing Domain.
- The 4D-RCS Reference Model Architecture is the RCS application to the Vehicle Domain, and
- The NASA/NBS Standard Reference Model for Telerobot Control Systems Architecture (NASREM) is an application to the Space Domain.