Abstract. Manufacturing experiments with full automation for manufacturing of goods, developed, promoted and attempted in the 1980s, have failed for economic and technical reasons. It is now widely accepted that humans are vital to efficient and effective operation of manufacturing processes. Historically, human resources in most manufacturing environments have been mismanaged, and while there has been a virtual proliferation of enabling technologies to support manufacturing systems, little attention has been paid to integrating humans into such systems. Now that humans are being reintroduced in contemporary manufacturing systems, it is necessary to pay serious attention to this most vital of all resources. One of the most critical and pressing human resource management needs is the training of workers, at all levels (line workers, managers, engineers, etc.) in skills they need to make a manufacturing organization competitive. In spite of this pressing need relatively little has been done to develop generic and fundamental methods for training manufacturing workers. This paper reviews training literature, identifies research deficiencies, and proposes a framework for training workers in contemporary manufacturing environments.

1. Introduction

The 1980s witnessed many scientific and technical conferences promoting themes such as ‘Factory of the Future’ or ‘Lights-out Factories’ (Bullinger and Warnecke 1985). By the late 1980s, it was generally accepted that in the future the demand for manufactured goods will be met by a small workforce operating a highly modern organization employing productive and advanced technologies (O’Brien 1991). The argument for increased automation has continued in the 1990s. The emphasis on improved industrial productivity at reduced cost has proved another incentive for limiting influence in the design, development, and implementation of manufacturing systems (Orpana and Lukka 1993). The argument for enhanced industrial productivity is based on the following (Mital and Anand 1992):

(1) the need to enhance the standard of living through the creation of national wealth;
(2) the loss of global competitiveness, and prestige, due to the inability to produce high quality products;
(3) fear of intellectual stagnation;
(4) the loss of creative edge;
(5) the need to respond to market demands quickly, and
(6) the need to prepare for market and technological changes that are occurring more frequently than ever.

It has been reasoned by Mital (1997) that in order to benefit from automation, one does not have to have
complete or total automation. Rather, automation should be used to increase the efficiency and effectiveness of a manufacturing enterprise through the integration and exploitation of available technology. As such, it not only involves integration of CIM technologies (CAD, CAM, CAPP, CAQ, etc.), but also requires changes in management thinking and organizational structure.

The thinking of the 1980s management that ‘human influence in CIM can be completely eliminated’ needs to be examined by asking and answering questions such as ‘Can automation be implemented to an extent that there is very limited or no role for humans to play in modern manufacturing?’ (In other words, ‘Is total automation feasible?’) and ‘Can an effective integration of modern manufacturing technologies and information be achieved without humans?’ It is believed by many that humans have great difficulty in providing the required quality, uniformity, reliability, repeatability, and documentation needed in modern manufacturing. Therefore, the manual alternative in manufacturing is not a feasible option (Sata 1986). According to these individuals, all manufacturing activities, such as metal cutting, materials handling, assembly, inspection, and transportation, which are routinely handled by people, must be performed by computer-controlled machines. The reality is that fully automated factories based on hard automation are not viable for technical and economic reasons except in a few special and isolated cases (Yamashita 1987). Hard automation does not lend itself to situations where a product is to be changed frequently because of user needs, costs or engineering improvements (Hartley 1984). Furthermore, there is the need to provide flexibility as well as capability. Automated equipment, such as robots, provide the flexibility but not the capability. For robots to be capable, they must have the necessary intelligence (Brady et al. 1984) and be able to sense the working situation to see, touch, feel pressure, and sense their own movement; acquire knowledge and judgement to carry out the task properly and act according to the knowledge of the skilled worker (for example, accept parts that may not have exact tolerance, or are not properly oriented); perform tasks reliably to impart the necessary 3-D motions to the product; and communicate with the operator by voice, written sentences, and other appropriate forms of communication (Yamashita 1987). Currently, humans must either work with robots or supervise them and must intervene when problems develop (for example, when the robot drops a part).

Economic viability is also necessary if complete automation is to become feasible. It is very likely that automation, while technically feasible may not be economically desirable. For instance, consider the case of assembly. Nevins and Whitney (1989) state that manual assembly is rapidly disappearing as an option for the reasons stated above. The issue of assembly economics has been examined by Mital et al. (1988), Mital and Mahajan (1989), Boothroyd (1990), Mital (1991, 1992), and Hammer (1992) by comparing human and robot performances. The findings cast considerable doubt on the belief that automated assembly methods will always be cost-effective and lead to increases in productivity. In fact, several case studies from these works indicate that manual assembly is frequently economically more attractive. The economic advantages of one method over the other are functions of factors such as performance times, wage and interest rates, and equipment reliability. In general, the economic disincentives of automated equipment (or option) are primarily due to low reliability, high interest rates, and declining low wages. The ability of humans to learn on the job also works against the automated option. Should these factors change and move in the other direction (for example, with declining interest rates), the automated option could become economically attractive.

The preceding arguments, thus, do not support the philosophy that automation should be used to minimize human interventions because such a move may not have any economic viability. However, if it is determined that human interventions will be economically beneficial, automation should be used to help the workers do their job more efficiently. This would ensure that the manufacturing enterprise is indeed producing the best product possible; a product the market needs and a product that is easy to manufacture quickly, reliably, and economically.

From a cybernetics viewpoint it also appears that complete automation will be a suboptimal solution for manufacturing organizations, at least for the foreseeable future, when compared with solutions that involve humans, machines, and computers in an effective partnership (hybrid systems). The importance of people as components for control and innovation in manufacturing systems is recognized worldwide (Brodner 1985, 1987; Kohler 1988; Kearney 1989; Hockley 1990; Gill 1990; Corbett et al. 1991; Grant et al. 1991; Senich et al. 1991; Nonaka 1991; Hammer 1992; Kidd 1992; Wobbe 1992).

The cybernetics case has been studied by Mital et al. (1994 b) and is summarized as follows; the Law of Requisite Variety states that for any system to remain under control, the controller of that system must be able to absorb the entire range of inputs that may affect the system (i.e. the system or the control process must be at least as complex in its behavior as the system it is trying to control). Given that a manufacturing organi-
zation is an open system, that is affected by its physical, commercial, legal and social environment as well as its own environment, the control subsystem must be able to remain in a stable state. Quite apart from the nature of such inputs (most of which exist in human-compatible form, but many of which could be made computer-compatible), there is the content of this input. Within the organization, the decisions to be made vary in importance, and hence the type of information required for decision-making also varies. The information content varies from very low level of detail (for example, ‘The tool has engaged the workpiece’) to very high level of detail (for example, ‘The recent government legislation carries the following implications’). It is difficult to see how any automated system could deal with high level information of the latter sort, and make the necessary deductions and other inferences without an enormous investment in background knowledge stores. Furthermore, the unexpected nature of some of the inputs (‘Behold, a hurricane has blown the roof in’) will require human-like intelligent control procedures (unlikely to be available in the foreseeable future) to be generated from automated systems.

Secondly, there are the system improvement, system monitoring, and maintenance roles to be performed within manufacturing units. Again, these roles require human-type intelligence, and frequently great manipulative skills for their performance. It is difficult to see how such roles could be performed automatically. It should be evident, therefore, that people will be necessary in manufacturing plants for a long time to come and we must manage this important resource very carefully.

1.1. Management of human resources

Given the importance of personnel to manufacturing, it is indeed unfortunate to find that many companies have failed to properly cultivate this important resource. In fact, the failure of many companies in transition to modern competitive manufacturing organizations is primarily due to their mismanagement of human resources (Etllie 1988, Majchrzak 1988). For example, instead of making the entire manufacturing operation efficient by utilizing people and other resources effectively, many companies have achieved short-term productivity gains by laying off workers. This has been done time and again without any regard for worker welfare or consideration of long-term consequences on the local, regional or national economy. Specifically, many organizations have failed to upgrade worker skills to levels compatible with advanced manufacturing technologies (Butera and Thurman 1984, Gerwin and Taroneau 1982, Shaiken 1984, King and Majchrzak 1996). The workers, thus, have been left with fewer career options and limited economic opportunities. It has been shown that variables such as comprehensive training are essential to human resource management practices, particularly in advanced manufacturing environments (Walton and Susman 1987, Commission on the Skills of the American Workforce 1990, Hitt et al. 1991, Perry 1991, Snell and Dean 1991). Still, relatively few American industry workers receive training (if workers do receive training, the training budget is one of the first items to be cut when austerity measures are effective).

A survey of auto workers at a General Motors assembly plant revealed that less than 20% of production workers received technical training, although nearly 83% received some form of training. A survey of contract labor in the US petro-chemical industry by the John Gray Institute (1991) revealed that less than 33% of workers received company training upon entering the industry. Furthermore, 20% of this same labor force reported receiving no on-going training throughout their employment.

It is also known that the amount of training is a function of professional position, with managers receiving far more training than line workers (Carnevale 1991), professional associations/status union labor receiving significantly greater training than non-union labor (John Gray Institute 1991), and direct-hires receiving double the level of on-going training as contract labor (John Gray Institute 1991). It is important to note that Japan, an economic giant second only to the United States, spends considerable time and effort in in-depth training of its workers in a variety of skills (Muramatsu et al. 1987). Such a philosophy is rarely seen in industry in the United States, exceptions are plants using Japanese management techniques. Also of considerable importance is the fact that workers, in the present atmosphere of downsizing, need to be trained in a variety of skills to improve their chances of regaining meaningful employment. The need for such training has been reported in a study of workers at Toyota (Muramatsu et al. 1987).

A number of investigators have shown that worker skill levels are a direct determinant of levels of quality performance (Flynn et al. 1995, Hackman and Wegman 1995). It is also reasonable to suggest that investments in human resources should keep pace with the changing technology particularly if the workers are to take responsibility for quality, productivity, and customers (Majchrzak and Wang 1996). American industry training programs provide inadequate training for success in contemporary manufacturing, and also
they are generally not linked to product designs (determining the manufacturing technologies and skills necessary to produce a quality product). Without such linkage, it is not possible to optimize worker and, consequently, organizational productivity and product quality. Such a linkage will also assist in evaluating needs for updating and modernizing worker skills.

1.2. Human resource management options

Optimal utilization of human resources requires that workers will possess the skills required to use the technology effectively. As discussed above, American workers are not getting adequate training to develop the necessary skills. Moreover, many workers do not even have the skills needed to make an effective use of available technology, particularly computer-based technology. According to the report of the Commission on the Skills of the American Workforce (1990), there is ‘considerable evidence that the current skill level of the industrial workforce leaves the United States less able to derive competitive advantage from new technologies than our competitors’. According to Adler (1991), there is a general trend towards higher skill requirements among manufacturing workers due to the speed of the automated equipment. The rationale for acquiring specialized maintenance skills is equally persuasive (Bushnell 1983). At the very least, there is a perceived need for an increase in basic skills in mathematics, and verbal and written communication among workers (Jacobs 1994). These general findings are in agreement with surveys conducted by the United States Department of Labor (1993 a, b), and Johnston and Packer (1987). According to the United States Department of Labor survey (1993 a), indications are that future workers in manufacturing will need exceptional performance in the following five competencies.

(1) Managing resources.
(2) Interpersonal skills for team problem-solving.
(3) Information science, including identification, integration, assimilation, and storage and retrieval of information from different sources; preparation, maintenance and interpretation of quantitative and qualitative records; the conversion of information from one form to another and the communication of information in oral and written forms.
(4) Systems, including understanding the interconnections between systems, identifying anomalies in system performance, integrating multiple displays of data and linking symbols with real phenomena.

(5) Technology, including competence in selecting and using appropriate technology for a job, visualizing operations, and monitoring, maintaining and trouble-shooting of complex equipment.

Training of workers to acquire such skills is therefore critical if the American manufacturing organizations are to remain globally competitive. Recognizing this fact, a recent workshop sponsored by the National Science Foundation recommended that training issues in advanced manufacturing (that is investigating and establishing skills needed for future technology, developing techniques for assessing training needs, developing procedures for evaluating cross-training effectiveness, and developing interactive training systems) have an immediate and special role to play in preparing the American workforce for global competition beyond the year 2000 (Mital 1995, 1996).

1.3. Objective and scope of this work

The objectives of this paper are to: (1) review published training literature, (2) identify research deficiencies in industrial worker training area, and (3) propose a generic framework for training industrial workers. The discussion is limited to and is in the context of product manufacturing. The emphasis is on developing a training process framework that would allow workers in manufacturing organizations to acquire skills needed to harness the latest technology.

2. Training—perspective and significance

Industrial psychology literature defines training from trainee and trainer perspectives. From a trainee perspective, training is ‘... the systematic acquisition of skills, rules, concepts, or attitudes that result in improved performance in another environment ...’ and whose effectiveness ‘... stems from a learning atmosphere systematically designed to produce changes in the working environment (Goldstein 1986).’ From a trainer’s perspective, including the organization providing the training, training is ‘... a planned effort by an organization to facilitate the learning of job-related behavior on the part of its employees ...’; the term ‘behavior’ includes knowledge and skills acquired by the employee through practice (Wexley 1984).’ Training as an activity was formally recognized as early as the Industrial Revolution. The spurt of industrial activity, however, did nothing to support workforce training, partly due to the fact that machines were considered far
more efficient than the workers at the time, and partly due to the social legislation that existed in the 18th and 19th centuries in England (Downs 1983). Even towards the end of the late 19th century, industries considered training workers a waste of resources. Frederick Taylor (1911) changed attitudes towards worker training with his scientific management methods; he advocated the selection of the best workers for different tasks, followed by extensive training for such tasks. The two World Wars promoted systematic training and selection of personnel for the wars. Subsequently, the United Kingdom promulgated the Industrial Training Acts of 1964 and 1973. Training was, thus, formally recognized as an important activity (Latham 1988). In the United States, Federal legislation such as the Area Redevelopment Act of 1961, the Manpower Development and Training Act of 1962, the Vocational Education Act of 1963, and the Economic Opportunity Act of 1964 recognized the importance of training the workforce for improving the economic choices of the workers (Walsh 1967). Title VII of the 1964 US Civil Rights Act resulted in consideration of training and training benefits as employment decisions. According to Latham (1988) and Mealica and Duffy (1985), employers in the United States have, by and large, pursued a training philosophy (organization identifies the deficiencies in workers and trains them to improve performance), rather than a selection philosophy (organization identifies individuals with strong potential and prepares them for positions in which they are expected to advance). The pursuit of a ‘training philosophy’, as opposed to a ‘selection philosophy’, and the emphasis towards training as a tool to facilitate employee learning is reflected in McGehee and Thayer’s (1961) definition of training. According to McGehee and Thayer, ‘... training in industry is the formal procedures which a company uses to facilitate employees’ learning so that their resultant behavior contributes to the attainment of the company’s goals and objectives.’ In the event training is used as an employee selection tool, the United States case law requires that performance during training correlates significantly with job performance (Latham 1988). Training programs are now considered vital instructional systems that meet specific learning and behavior needs of the workforce.

2.1. Why training?

There are some basic questions, such as ‘Why training?’ and ‘Does training have any performance benefits?’, that one needs to address. Training the workforce has two important economic advantages: it provides workers’ job options and choices, and potential for higher earnings, and it leads to an overall improvement in an organization’s performance and, consequently, its productivity. Nearly half of a worker’s lifetime earnings are affected by training in school and on the job. Learning occupational skills in school has a considerable influence on a person’s earnings. For instance, according to the US Department of Education, in 1985 college graduates were earning 38% more than high school graduates (Carnevale and Goldstein 1990). The earning potential for college graduates is considerably greater in technology-intensive industries such as manufacturing. In general, high school graduates in high-technology industries earn more than twice as much as a high school drop-out; college graduates earn more than twice that of a high school graduate; and workers with post-graduate education earn more than 30% that of a college graduate (Carnevale and Goldstein 1990). Learning workplace skills on the job has also been shown to positively affect earning rates (nearly 25% increase in earnings in some cases) of workers (Carnevale and Goldstein 1990). For a worker, training and learning on the job also have consequences beyond the current job. According to the studies done by Lillard and Tan (1986), the positive effect of workplace training lasts longer (almost 13 years, compared to training in school lasting only 8 years) and results in increased earnings at new jobs when training is done in prior jobs.

Worker training has also been shown to improve the productivity and the quality of goods produced. A 1991 study of formal training programs in 180 manufacturing firms in the United States, conducted by the United States Department of Labor, indicated that industries that introduced a formal training program after 1983 experienced at least a 17% increase in productivity in 3 years than industries that did not introduce a training program. This increase was nearly 20% for production workers. Another survey of 157 small (500 or fewer employees) manufacturing industries in Michigan found that the reject rate of finished products had significantly dropped after the introduction of formal worker training (nearly a 7% reduction in scrap by increasing formal training from 15 hours to 30 hours) (US Department of Labor 1993 b). In a 1992 Massachusetts Institute of Technology study in 62 automobile plants, representing 24 producers in 16 countries (multi-skilled employees in plants with flexible production operations), employee training in flexible production systems compared to mass production systems, reduced scrap and improved the quality of products.

There is now a general consensus among industries, many Federal government agencies, researchers in academia, and industrial practitioners that for a manufacturing entity to be competitive in the global
market, the development of the human resources base in manufacturing is critical (Report of the President's Commission on Industrial Competitiveness 1985, National Academy of Engineering 1988, National Research Council 1990). In fact, many of these reports highlight the fact that, among countries with large manufacturing bases, the United States no longer dominates in the creation of new and advanced technology, and that many countries now have the scientific and technological infrastructure to create new technology. What then must make a positive difference to US industrial competitiveness, these reports conclude, is the existence and the continued development of a skilled human resources base. The training of workers to acquire skills necessary to use the latest technology effectively is thus a dire need.

3. Summary of training research

In order to develop a complete understanding of worker training, it is essential to review theories dealing with learning, factors affecting learning, and the methods of learning/training that have been described in the published literature. It should be noted that, without exception, materials related to these aspects of training are found in behavioural, social, and psychological literature. The review of this literature is pertinent if the lessons learned elsewhere are to be applied successfully in manufacturing settings.

3.1. Training needs assessment

The systems approach to training includes a 'needs assessment phase'. Needs assessment is a complete analysis of the tasks, behaviors and the environment in which training is to take place. The objectives of the training program, the criteria and measures for evaluation of the training program, and the design of the training program are dependent upon a sound assessment of the needs. Training analysts have traditionally used organizational analysis, task analysis and person analysis as the steps towards obtaining the needs profile for a training situation (McGehee and Thayer 1961). Organizational analysis refers to an examination of the system-wide components of the organization that may affect a training program's factors beyond those ordinarily considered in task and person analysis (Goldstein 1986, 1991). Included in organizational analysis are such factors as the examination of organizational goals, organizational resources, climate for training, and internal and external environ-

mental constraints. When the goals of an organization are incompatible with the goals of the training program, trainees are left with knowledge, skills, and abilities (KSA) that are not usable on the job. Training programs, therefore, must focus on teaching techniques and methods that are consistent with organizational practices (Sonnenfeld and Peiperl 1988, Schuler and Jackson 1987, Carnevale and Goldstein 1990, Carnevale and Schulz 1990, Rosow and Zager 1988). While such analyses are organization-specific, the literature provides some general guidelines (Goldstein 1986):

(1) specific goals for the organization need to be clearly defined and translated into specific goals for the training programs;
(2) organizations should not expect training programs to deliver unspecified and unidentified organizational goals;
(3) training programs should consider the trainee as an individual with social needs.

The organizational climate for training is determined with a view to resolving any potential conflicts among member groups in the organization (Rouiller and Goldstein 1991). Some possible member groups include government sponsors of the training program, employers, training departments, and worker unions.

Perhaps the most important factor affecting organizational analyses is the identification of the external factors that influence training design. These may include social (for example, use of social learning theory for cross-cultural training (Black and Mendenhall 1990), legal, economic, and political factors. In the context of our discussion, rapid advances in manufacturing technology is one crucial external factor that affects training needs of the organization, and also has a direct bearing on the economics of decision making. The literature on training falls short of suggesting methods to perform organizational analyses when technological changes affecting organizational training requirements are expected.

An analysis of the human and physical resources available is another important factor to be considered during organizational analysis. Table 1 presents a sample resource analysis inventory (McGehee and Thayer 1961).

The next step in needs assessment is task analysis which results in a statement of work activities performed on the job and the conditions under which the job is performed. A task description, followed by a detailed specification of the tasks, and a scaling of tasks on various dimensions, such as criticality and frequency of occurrence, make up the steps in task analysis.
Table 1. Sample human resources inventory (McGehee and Thayer 1961).

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<table>
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<tbody>
<tr>
<td>a.</td>
<td>Number of employees in the job classification</td>
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<tr>
<td>b.</td>
<td>Number of employees needed in the job classification</td>
</tr>
<tr>
<td>c.</td>
<td>Age of each employee in the job classification</td>
</tr>
<tr>
<td>d.</td>
<td>Level of skill required by the job of each employee</td>
</tr>
<tr>
<td>e.</td>
<td>Level of knowledge required by the job of each employee</td>
</tr>
<tr>
<td>f.</td>
<td>Attitude of each employee toward job and company</td>
</tr>
<tr>
<td>g.</td>
<td>Level of job performance, quality and quantity, of each employee</td>
</tr>
<tr>
<td>h.</td>
<td>Level of skills and knowledge of each employee for other jobs</td>
</tr>
<tr>
<td>i.</td>
<td>Potential replacements for this job outside company</td>
</tr>
<tr>
<td>j.</td>
<td>Potential replacements for this job within company</td>
</tr>
<tr>
<td>k.</td>
<td>Training time required for potential replacements</td>
</tr>
<tr>
<td>l.</td>
<td>Training time required for a novice</td>
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<tr>
<td>m.</td>
<td>Rate of absenteeism from this job</td>
</tr>
<tr>
<td>n.</td>
<td>Turnover in this job for specified period of time</td>
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<tr>
<td>o.</td>
<td>Job specification for the job</td>
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</table>

Table 2. Essential activities of a job.

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<table>
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<tr>
<th></th>
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<tbody>
<tr>
<td>a.</td>
<td>The worker’s actions.</td>
</tr>
<tr>
<td>b.</td>
<td>The objective or purpose (what gets done as a result of workers actions).</td>
</tr>
<tr>
<td>c.</td>
<td>The machines, tools, equipment, and work aids (MTEWA) used to attain an objective or perform a worker action.</td>
</tr>
<tr>
<td>d.</td>
<td>The materials, products, subject matter, and services (necessary to place the job in its general occupational area and to contribute to an understanding of the basic knowledge required).</td>
</tr>
<tr>
<td>e.</td>
<td>The work performed and worker characteristic ratings including information on worker relationship to data, people, and things, worker functions, work fields (specific methods characteristic of MTEWA), and worker characteristics (physical demands, environmental conditions, temperaments, and aptitudes).</td>
</tr>
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</table>

Table 3. Sample list of task dimensions (Ammerman and Pratzner 1977).

<table>
<thead>
<tr>
<th>Importance of the task</th>
<th>Importance of criticality of task for the job</th>
<th>Importance of consequences of error in task performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time-frequency</td>
<td>Tasks actually performed the previous year</td>
<td>Frequency of task performance on the job</td>
</tr>
<tr>
<td></td>
<td>Most recent time task was performed on the job</td>
<td></td>
</tr>
<tr>
<td>Difficulty of learning task</td>
<td>How difficult is it to learn task?</td>
<td>How difficult is it to learn task on job?</td>
</tr>
<tr>
<td></td>
<td>How much opportunity is given to learn task on job?</td>
<td></td>
</tr>
<tr>
<td>Difficulty of task performance</td>
<td>How difficult is it to perform task?</td>
<td>Why is it difficult to perform task (task complexity, lack of training, monotony, fatigue, etc.)?</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>Where should task be learned?</td>
<td>What level of worker proficiency is expected after training?</td>
</tr>
</tbody>
</table>

The task description, according to The Revised Handbook for Analyzing Jobs (US Department of Labor 1991), is a statement that describes all the essential activities of a job (table 2). A complete specification of the task follows its description. Information for complete specification of a task involved in a job is typically obtained from experts, or by observing the job being performed. A number of rules for task specification have evolved over the years and include directions on the grammar, sentence structure, and the language of the analyst US Department of Labor 1991, Ammerman and Pratzner 1977). Judgments regarding the relevance of task specifications for training program design are then collected from subject matter experts (for example, experienced workers and supervisors). Table 3 presents a sample list of dimensions to include in specific questions about each identified task (Ammerman and Pratzner 1977). Data collected from questionnaires can be analyzed for statistical measures of responses from the different experts. The next key issue in task analysis is the development of KSA (knowledge, skill, and ability) attributes of the individuals undergoing training, defined as follows (Prien 1977).

1. ‘Knowledge (K) is the foundation upon which abilities and skills are built. Knowledge refers to an organized body of information usually of a factual or procedural nature, which, if applied makes adequate job performance possible. It should be noted that the possession of knowledge does not insure that it will be used’.

2. ‘Skill (S) refers to the capability to perform job operations with ease and precision. Most often skills refer to psychomotor type activities. The specification of a skill usually implies a performance standard that is usually required for effective job operations’.

3. ‘Ability (A) usually refers to cognitive capabilities necessary to perform a job function. Most often abilities require the application of some knowledge base’.

Training analysts generally recommend that task information developed from task analyses be supplied to a panel of experts and knowledgeable persons, and they be asked to answer questions such as ‘Describe the characteristics of good and poor workers on name
of task; ‘Think of someone you know who is better than anyone else at name of task.’ What is the reason they do it so well?; ‘What does a person need to know in order to name of task?’; ‘Give concrete examples of effective or ineffective performance and lead a discussion to explain causes or reasons’; ‘If you are going to hire a person to perform name of task, what kind of KSAs would you want the person to have?’; ‘What do you expect persons to learn in training that would make them effective at name of task?’ Future-oriented task analysis (Schneider and Konz 1989) and future-oriented critical incident analysis (Campbell 1988) are two evolving procedures that a job analysts can use for eliciting information from the experts regarding future training expectations for a task. The job analysts would then write KSA statements for jobs keeping in mind issues such as generality versus specificity, redundancy in statements, and triviality of information.

Another approach uses worker traits and interprets jobs in terms of human attributes (attitudes, temperaments, interests, etc.) necessary for success (US Department of Labor 1991). Instructional system development (Ryder et al. 1987), think-aloud verbal protocols and psychometric scaling (Cooke and Schavaneveldt 1988, Green and Gihooly 1990), are evolving methods from artificial intelligence and cognitive psychology fields to elicit information about jobs from experts.

The third and final step in needs assessment is person analysis. It determines the type and content of training needed by an individual. The objective of a person analysis is to enable the training analyst to identify criteria that must be used to better tailor the training program design to the characteristics of the trainee population.

3.2. Training program design

There is recognition that training and instructional programs in organizations are but one part of the complex system that an organization is, and that the efficacy of training can affect other subsystems of the massive system that is the organization. Not only does a systems view of the training function provide a framework for studying the interaction of other components and subsystems involved, it helps in designing appropriate feedback mechanisms for correcting and modifying instruction (Goldstein 1986). Indeed, all research efforts in training and development embody principles of the systems framework.

The use of learning principles as the basis for instructional design is dependent upon the belief that it is possible to design an environment for instruction which can later be transferred to a job setting. However, it is the opinion of many in the training field that learning theory has tended to focus on highly specific laboratory experimentation, and that the principles that have resulted from such experimentation have yielded themselves to very little generalization to field settings (Goldstein 1986). It was observed that some of the core learning principles, such as feedback, practice distribution, and meaningfulness, were inadequate in designing effective training situations (Gagne 1962). Learning theory adds little to explaining complex human behaviour such as problem solving, perceptual motor learning, concept learning, etc. (Baldwin and Ford 1988, Campbell 1988). According to Goldstein, these deficiencies in learning theory have resulted not only in training practitioners ignoring learning principles, but also in the development of instructional theories out of experiences from instructional settings. In fact, most of the current theoretical framework that exists in training literature is based upon these instructional theories.

Theories of instruction attempt to relate specified events comprising instruction, to learning processes and learning outcomes, drawing upon knowledge generated by learning research and theory (Gagne and Dick 1983, Gagne and Glaser 1987, Pintrich et al. 1986). These theories are prescriptive in nature and categorize learning outcomes to organize human performance.

When learning outcomes, or learned capabilities, are matched with different instructional events such as informing the learner of the objective of the instruction, or eliciting the performance from the learner, or assessing performance of the learner, or enhancing retention and transfer of the instruction, different ways of manipulating instructional events for the different categories of learning outcomes result. Table 4 provides an example of some of these instructional events and the conditions of learning implied by these instructional events for the five different types of learning capabilities.

Recent advances in cognitive psychology (Anderson 1985) and cognitive approaches to learning such as automatic processing, mental models and schema, and metacognition (Howell and Cooke 1989) add to the understanding of basic human learning. These are evolving concepts and the usefulness of these concepts in training design remains to be seen.

The principles of training program design include identifying tasks and task components of a job (needs assessment), building these tasks and task components in the training program, and arranging the actual learning of these task components in an optimal
Table 4. Sample instructional events, conditions of learning for the five learned capabilities (Gagne et al. 1979).

<table>
<thead>
<tr>
<th>Instructional event</th>
<th>Intellectual skill</th>
<th>Cognitive strategy</th>
<th>Information</th>
<th>Attitude</th>
<th>Motor skill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informing learner of objective</td>
<td>Provide description and example of the performance to be expected</td>
<td>Clarify the general nature of the solution expected</td>
<td>Indicate the kind of verbal question to be answered</td>
<td>Provide example of the kind of action choice aimed for</td>
<td>Provide a demonstration of the performance to be expected</td>
</tr>
<tr>
<td>Eliciting the performance</td>
<td>Ask learner to apply rule or concept to new examples</td>
<td>Ask for problem solution</td>
<td>Ask for information in paraphrase, or in learner’s own words</td>
<td>Ask learner to indicate choices of action in real or simulated situations</td>
<td>Ask for execution of the performance</td>
</tr>
<tr>
<td>Enhancing retention and transfer</td>
<td>Provide spaced reviews including a variety of examples</td>
<td>Provide occasions for a variety of novel problem solutions</td>
<td>Provide verbal links to additional complexes of information</td>
<td>Provide additional varied situations for selected choice of action</td>
<td>Learner continues skill practice</td>
</tr>
</tbody>
</table>

3.3. Factors affecting training

Apart from the different types of instructional and training media, training design requires consideration of the training environment and the trainee behavior. The factors that affect a trainee’s behavior before training include trainee readiness and trainee motivation (Noe 1986). Trainee readiness involves both maturational and experimental factors in the learner background (Goldstein 1986). Information about trainee background (what the trainees know before beginning training) is therefore important for training design.

The motivation of a trainee to undergo training is another important precondition to learning. Motivation has been observed to involve behaviour that is active, purposive, and goal-directed (Bourne and Ekstrand 1973). Even though most theoretical and empirical research on motivation has been done in relation to performance on the job, industrial psychology has two theories to offer about motivation. The first theory seeks to explain how behavior is energized, directed, sustained and stopped. The second theory, the theory of content, seeks to explain what things motivate people (Steers and Porter 1983). There are also theories that aid in the establishment of motivational levels in training and learning settings:

1. the reinforcement theory—the response of a person to stimuli reinforces or rewards the person, which positively orients trainees towards performance (Pedalino and Gamboa 1974, Yukl and Latham 1975) (timing of reinforcement, partial reinforcement, and punishment, are also important factors);
2. the instrumentality theory (Vroom 1964)—cognitive expectancies concerning outcomes that are likely to occur as a result of the participant’s behavior;
3. the need theory (Atkinson and Feather 1966)—behavioral tendency to strive for success;
4. the theory of hierarchy of needs (Maslow 1954);
5. the two-factor theory (Herzberg et al. 1959)—postulates the existence of extrinsic (pay, job security, etc.,) and intrinsic (recognition, responsibility, etc.) factors;
6. the goal-setting theory (Latham and Locke 1979, Locke et al. 1981).

The extent of original learning occurring during training is known to influence the amount of transfer of training that will occur during performance of the job (Goldstein 1986). This implies that design of the learning environment should ensure substantial learning for its effect to be transferred over to actual job performance. The size of the training unit (whole versus part learning) is one of the important variables that has been shown to affect task performance (Holding 1965). The difficulty of the total task has been suggested to be the sum of the difficulties of the
sub-tasks involved in performing the total task. One of the principles of training design suggests that when a task has high organization, whole methods are more efficient than part methods for increases in task complexity. When a task has low organization, part methods are more efficient than whole methods for increases in task complexity (Naylor 1962). Also, for tasks that can easily be separated, combining them at a later time does not pose any difficulty for the learner (Holding 1965). In such a case, proper analysis of the job is important for correct sequencing of component learning, and for ensuring that the learner has the proper capabilities to perform the components (Briggs 1968). The principle of mass (no rest) versus distributed (with rest) practice is also important in enhancing transfer from the learning environment to the actual job. Rest intervals during practice sessions (distributed practice) have been shown to be more effective in training than mass practice for enhancement of motor skills (Lorge 1930, DeCecco 1968). It is generally thought that massed learning conditions only hamper performance but not learning (Holding 1965, Reynolds and Bilodeau 1952).

Overlearning has implications for skill acquisition and transfer of training. Overlearning is important for thorough learning of the task (McGehee and Thayer 1961) and to maintain performance during emergency and stress conditions (Fitts 1965). Knowledge of results or ‘feedback,’ even though questionable in tracking and trouble-shooting tasks (Gagne 1962), improves performance due to motivational and informational functions involved in feedback (Holding 1965, Thorndike 1927, Komaki et al. 1980). The concept of retention of previously learned materials has been studied mainly in laboratory settings (Johnson 1981). The few studies that have been performed in military settings (Hagman and Rose 1983) have shown that retention of learning is influenced by the degree of original learning, the meaningfulness of the material presented to the trainee, the amount of interference (from previously learned materials and from activities that occur during learning of the original material that affect recall), and the motives and perception of activities associated with tasks.

3.4. Training methods

Training literature is replete with a variety of instructional methods, such as classroom lecturing, programmed instruction, computer aided instruction, machine simulators, behavior modification techniques, simulations involving business games, role playing, and behavioral role-modeling used. Reviewers (Campbell 1988, Tannenbaum and Yukl 1992) have, however, concluded that most research studies on training methods have been demonstration-type studies involving comparison of one training method with another or to a no-learning control condition. These studies demonstrate that a method ‘works’ or is ‘superior’ to another method, but add little practical value as they do not show why a certain method enhances learning or how a certain method can be used more effectively for training (Tannenbaum and Yukl 1992). In the following paragraphs, some of the more commonly used methods of training are briefly reviewed.

Simulations and games seem to be popular methods of training in the military and for training managers. To simulate is to replicate essential characteristics of the real world in order to facilitate learning, and transfer of such learning. Simulations vary in size and scope depending on the complexity of issues being simulated and the participant size.

The most important, and perhaps controversial, issue involving the use of simulation is simulation fidelity (Hays and Singer 1989). Many simulators, such as those used for flight simulation, carry a great deal of physical fidelity (representation of actual flying characteristics), but lack psychological fidelity, the ability of the simulator to reproduce, during training, behavioral processes essential for job performance. Most simulations use partial task simulation due to either the prohibitive cost, the dangers involved in simulating entire tasks, or the non-importance of certain factors in contributing to the learning of a task (Goldstein 1986). For example, the inclusion of motion in flight simulation, in addition to possibly being a non-contributing factor to learning, costs an additional $250,000. In addition to issues involving simulation fidelity, simulations utilized in team training environments present unresolved research issues such as individual versus team feedback affecting team performance (see Swezey and Salas 1992, for other issues in team training); identification and quantification of parameters describing team behavior and team communication; and coordination and decision making (Denson 1981). Research on original learning efficiency, transfer of learning to the new task, and retention of learning, all important measures in evaluating transfer of training and all vital to the integrity of simulation results, is plagued by design problems due to lack of a control group (Goldstein 1986). There is also very little information on long-term retention of skills obtained through simulation (Williges et al. 1972). Efforts to design better simulators which improve learning during training are currently underway.
Techniques such as role-playing also provide trainees an opportunity to experience and explore solutions to a variety of on-the-job problems. Role-playing is used primarily for interpersonal problems and attitude change and development of human-relations skills (Bass and Vaughan 1966). This method succeeds only when the participants actually willingly adopt the roles and react as if they were really in the work environment (Campbell et al. 1970). There are different forms of role-playing such as trainees playing reverse roles (Speroff 1954), multiple role-playing among trainees (Maier and Zerfoss 1952), and self-confrontation (King 1966).

Behavioral role-modeling, an approach based on social-learning theory (Bandura 1969, 1977), is an approach for the acquisition of novel responses and modification of human behavior through observation, modeling and reinforcement. Some of the key elements of the behavior role-modeling approach for training include:

1. providing the trainee with numerous, vivid, detailed displays (on film, videotape or live) of a manager-actor (the model) performing the specific behaviors and skills for the trainee to learn;
2. giving the trainee considerable guidance in and opportunity and encouragement for behaviorally rehearsing or practicing the behaviors he/she has seen during role playing;
3. providing him/her with positive feedback, approval or reward as his/her role playing enactments increasingly approximate the behavior of the model (Goldstein and Sorcher 1974).

In addition to the techniques described here, there are other training techniques for managerial and interpersonal skills: achievement motivation training (McClelland and Winter 1969), leader match training (Fielder 1964, 1967, Fielder et al. 1971), and training the raters (Latham et al. 1975).

One of the most widely used methods of training a worker is on-the-job training. However, there seems to have been very little research done on the utility of this method. Most of the training researchers seem to use this method as a control procedure for research investigating other training techniques. The best available information for the on-the-job training method is based only on intuition (Goldstein 1986). This is all the more striking, as on-the-job training is often the only instruction that manufacturing workers may receive for certain types of jobs. Even this instruction may be limited to the worker simply watching an experienced worker performing a task. With proper design of the on-the-job training protocol, there could be certain advantages to this training method over others. Transferring the training becomes less difficult as the worker is being trained in exactly the same physical and social environment in which he is expected to perform after training. Besides, well designed on-the-job training provides workers with an opportunity to practice the required behavior, and could result in the collection of more job-relevant evaluation criteria. However, on-the-job training can be easily abused by using simple instructions and poor training design. On-site and on-the-job training seems to be the least researched and the most poorly designed method of training at the present time.

The lecture method is often inexpensive compared to the other methods of training; there is a tendency among researchers to use the lecture method for control purposes, and to proclaim the superiority of other methods. It is popular in educational and school settings, but it is insensitive to individual differences, and provides limited feedback to the trainee. This technique, however, may be used when knowledge gain is the ultimate goal of training. The method may also be used to impart information of general awareness nature. There is little empirical evidence in the training literature on the efficacy of the lecture method.

The latest method that has generated excitement among training practitioners is the use of computers as tools for instruction, commonly referred to as computer-assisted instruction (CAI). There are a number of computer-assisted training techniques in vogue, among which the most important are the drill-and-practice method (Suppes and Jerman 1970, Suppes and Morningstar 1969, McCann 1975), and the tutorial form of instruction (Collins and Adams 1977). The major advantages of CAI are the individualization of instruction, provisions for good reinforcement of learning, and good data-collection provisions. The major disadvantages are the cost and affordability of CAI systems, and the issue of whether a machine-oriented learning environment is enough stimulus for learner satisfaction, motivation, and further development.

In comparing the pros and cons (cost and proximity to real working atmosphere) associated with various training methods, it appears that on-the-job training has the best potential, provided that the shortcomings generally associated with it (that is, lack of proper instructions) are overcome. The most desirable attributes of the method are its low cost and the ability to replicate the working environment.
3.5. Evaluation of training

Evaluation is defined as the systematic collection of descriptive and judgmental information required to make effective training decisions related to the selection, adoption, value, and modification of various instructional activities. Some of the difficulties with evaluating training programs include difficulty in establishing relevant evaluation criteria, lack of personnel trained in the evaluation methodology, difficulties in showing statistical differences between alternatives, and the fear of negative consequences of a poor evaluation (Goldstein 1986).

Developing effective evaluation criteria is the first step in evaluation. The most important requirement in establishing evaluation criteria is the relevance of the criteria in evaluating success in performing the task. If performance during training is used as a measure of success on the job, the evaluation should attempt to establish the relationship between performances during training and on the job. A similarity between the training evaluation criteria and job performance evaluation criteria is suggested by Thorndike (1949). It should be noted that evaluation criteria could be deficient in a number of ways. One deficiency could be that an important KSA attribute is identified but left out of the criterion constructs. It is also possible that KSAs identified during the needs assessment phase are required for performance of a job, but not included in training. Also, the evaluation criteria used should reflect the fact that trainees will not be able to perform as well as an experienced worker, at least initially, and the performance will improve with training over a period of time.

It is also possible that extraneous elements such as opportunity bias (individuals having differing opportunities for success at job, unrelated to skills developed through training), group-characteristic bias (characteristics in the group setting not permitting trainees to demonstrate skills gained from training), knowledge of training performance (individuals performing well in training being similarly evaluated in the job setting) may contaminate criteria for evaluation. It should be noted that many factors may affect the reliability of evaluation criteria. These factors may include: the size of the sample, variation in the ability among the participants, ambiguity of instructions, variation in conditions during measurement periods, and assistance provided by instruments. Under such circumstances, a measure of reliability for the evaluation criteria should be added (Nagle 1953). Also, whenever, possible, multiple and independent evaluation criteria should be used to provide some reliability. At least four levels of criteria (reaction, learning, behavior and results) should be included (Kirkpatrick 1959). Reaction denotes what trainees think of the training program. It can be measured by a questionnaire designed on the basis of information obtained during needs assessment. Learning measures should include components that measure learning during training (for example, written tests and learning curves). Good training performance may not result in good job performance if there are difficulties in transfer setting design. Measures that are used during training can typically be also used for measuring job performance. Results, including such measures as costs, turnover, absenteeism, grievances, and morale, can be used to relate results of the training program to organizational goals and objectives (Kirkpatrick 1959).

There are other measures, such as trainers’ attitudes, the trainees’ expectations from the training programs, learning and performance, that can be used to evaluate training programs. Learning criteria measured early in training, and behavior criteria measured after training and transfer to the job, should reflect the effects of the time dimension upon learning as time of data collection adds to the variation in criteria used in evaluating training.

Evaluation criteria could also be classified into criterion- and norm-referenced measures, and objective and subjective measures. Criterion-referenced measures provide an achievement standard for individuals as compared with specific behavioral objectives; norm-referenced measures, on the other hand, compare the capabilities of an individual with those of other trainees in the program. Measures that require judgment, and opinion, are subjective (such as rating scales).

The most important questions to be answered in evaluating the efficacy of training programs are:

1. has a real change occurred?
2. is the change attributable to the instructional program?
3. is the change likely to occur again with a new sample?

A pre-training and post-training test will help determine if the trainees’ performance improved significantly after training. The most important consideration in this testing is the timing of the post-test. It has been suggested that two post-training tests should be given so that comparisons can be made between the pre-training test and first post-training test, the pre-training test and the second post-training test, and the first and second post-training tests (Goldstein 1986). Measures associated with the objectives of training should be used in the tests.
A number of possible sources of error have been pointed out in the literature, suggesting possible considerations of these as control variables in the experimental design. Threats to validity could come from:

1. history (e.g. time lag in administration of testing);
2. maturation, referring to the biological or psychological effects that systematically vary with time (such as fatigue and interest in the program);
3. testing (such as influence of pre-test on the scores of the post-test);
4. instrumentation (any changes in testing instruments between pre- and post-tests);
5. errors due to statistical regression;
6. differential selection of participants;
7. experimental mortality (differential loss of participants from control or treatment groups);
8. interactions;
9. diffusion or imitation of treatments within an organization;
10. compensatory equalization of treatments (benefits that control subjects get which wipe out measured differences);
11. compensatory rivalry between respondents receiving less desirable treatments;
12. demoralization of respondents in control group (Cook and Campbell 1976, 1979).

Threats to generalization of the study to other groups or training situations could come from:

1. increased sensitivity of participants after pre-test;
2. interaction of selection and experimental treatment;
3. awareness of participation, or the 'I'm-a-guinea-pig effect';
4. carry over effects of other treatments (Campbell and Stanley 1963).

The different types of experimental designs used in training include:

1. pre-experimental designs involving either a one-group post-test only design, or a one-group pre-test/post-test design;
2. pre-test/post-test control-group designs;
3. quasi-experimental or time-series designs (similar to (1) except that a series of measurements are taken before and after the training).

4. General review findings

Based on the review of published literature, a number of observations were made. Some of these have been pointed out earlier. The following are the main observations resulting from this review.

Very little training-related work exists in engineering. Most research literature on training is concentrated in the behavioral sciences. Engineering training literature, whatever little there is, generally deals with the development of mathematical models for a flexible workforce (not reviewed in this paper) or surveys of human resource management practices in industries. The overall conclusion of surveys is that training the workforce is indeed essential. There are, however, no systematic investigations of training methods in the manufacturing context that have been reported in engineering literature.

Training research in the behavioral sciences has resulted in useful insights into considerations that should be taken into consideration when designing training experiments or training programs. Many of the approaches to training that have been discussed in the behavioral literature, such as the systems approach, and specific techniques and methods in training, including task analysis and job analysis, have been in existence and in active use in industrial engineering settings for job and work design for a long time. Application of these techniques in training research in manufacturing organizations, therefore, should not require developing new techniques and approaches.

No on-site training studies in manufacturing organizations were identified in the published literature. The bulk of training research in the behavioral sciences has dealt with non-manufacturing occupations, such as music, police work, training in the military, and languages. As mentioned earlier, these studies provide insights into training methods, factors affecting training and influencing training outcomes, training performance measures, and human behavior. However, they provide very little insight into training practices, needs, methods, and evaluation criteria, that one would find useful in developing training programs for workers in a manufacturing environment. Such insights are vital in order to develop effective training programs and strategies for preparing the American manufacturing workers for global competition.

Besides the above deficiencies, the current deficiencies in the behavioral training research on training humans apply as well. The latest available review on training humans concludes that researchers are only now beginning to '... consider trainees as active participants in the system who interact with the
environment before training, during training, and after training...'. Further, there is a '. . . paradigm shift from research designed to show that a particular type of training ‘works’, to research designed to determine why, when and for whom a particular type of training is effective (Tannenbaum and Yukl 1992).’ Also, the conclusion of Tannenbaum and Yukl that training researchers need to consider the purpose of the training and the type of learning involved in training, is equally valid for any future training research in manufacturing. These reviewers also suggest that cognitive concepts and high technology training methods are becoming increasingly popular in training settings. In addition, these reviewers conclude that the distinction between on-the-job training and off-site training is becoming blurred due to the development of on-line training technologies.

5. A proposed framework for training manufacturing workers

In this section, we present a framework for training workers in a manufacturing environment. In the literature review, we identified two main reasons for training: to provide the worker with more job options and choices, and to improve the productivity of the company. A manufacturing organization is driven by the products it develops and markets. The productivity of the organization is improved by developing processes that aid in manufacturing the product with the required quality, short lead times, and low unit cost. Some specific reasons for training manufacturing workers include:

(1) Lack of adequate instructions: most work instructions or process plans require an understanding of the process. It is difficult for a novice to be involved in the production of parts because of a lack of understanding of the terminology and operations of the manufacturing processes and systems. Training increases the domain knowledge that the operator possesses and therefore improves the processing operation. This results in lower scrap rates, lower production cost, shorter cycle times, and better quality of the product.

(2) Improvement of efficiency: training may also be required for the operator to develop a thorough understanding of the process such that instructions, written or otherwise, are not required for continued performance of the tasks. This will improve the efficiency of the operation, thus reducing time and cost. The learning process will also result in reduced scrap rates.

(3) Inadequate man-machine interfaces: many training issues arise because of inadequate design of the user interfaces on machines. Operators will have to be trained to understand and adequately operate the equipment. Such training will also result in better products, lower lead times, and lower cost.

Overall, the need for training in manufacturing environments is driven by the need for the manufacturing personnel to develop an understanding of the products, processes, and systems that they are required to manufacture/operate. Because the nature of processes and systems is dictated by the products, the first step in developing a training program has to concentrate on product design. Figure 1 outlines the proposed framework for training workers in manufacturing environments. It is based on the premise that for a manufacturing entity to compete effectively in a global market, it must manufacture quality products that users want or need. These products should be usable and reliable, and able to be produced quickly and economically. The very first requirement is to determine and consider users’ needs and wants. The product design must consider these along with the function the product is supposed to perform. Figure 2 presents a structured approach to implementing a major part of the framework (up to skill gap identification) and specifies the major activities, and the information flows required to accomplish them.

A longer-term approach to developing training programs should be based on a technological forecast and strategic plan that outlines what markets the company intends to penetrate and therefore what new products are expected to be developed. The product concepts as well as expected advances in product development related technologies will provide a long-term vision of the types of technologies that the manufacturing personnel will deal with during production. As shown in figure 2, the identification of short- and long-term strategic needs should be done by the company’s upper management based on information about the economic environment and competitor positions. The constraint on this activity is that the strategic needs should focus only on the company’s core competencies, i.e. the special knowledge and skills that it possesses that makes it a successful competitor in the marketplace. The output of this activity would be the strategic goals that the company would be required to achieve in the short and long-term.
Once it has been ensured that the product has been designed to meet the specifications and needs of the market, efforts need to be directed to the assessment of technologies available to manufacture it. The technology considered should include not only what is available in-house but what is used by the competition as well. For a short-term training effort, the focus on processes required to manufacture a particular product may be appropriate. However, a long-term manufacturing technology forecast should also be developed to identify the knowledge and skills the personnel will be required to have in the future. Knowing what technology is available in-house and what should be procured from outside to remain competitive will lead to determining investment needs. Selection of new equipment should also be based on the quality of the user interfaces. As shown in figure 2, the development of a technology forecast should be performed by the management based on surveys of experts, and other techniques for obtaining information on expected advances in manufacturing technology. The forecast should be directed by the strategic goals of the company, i.e. it should be focused on topics and areas that directly contribute to the company's near- and long-term growth objectives. Another constraint on the forecast development is the technology currently used by the company. A forecast of advances and evolutions in manufacturing technology should address how it will affect the current manufacturing capabilities of the company. Specific focus should be on whether the current equipment would continue to be useful, or could be upgraded to adapt to the new product and process requirements. The output of this activity is the manufacturing process technology forecast.

The availability of capital will determine equipment and automation capabilities, which in turn will influence the method(s) of manufacture. The methods of manufacture in this context include the choice of materials, and consequently manufacturing pro-
cesses, method of assembly and quality requirements. The extent of automation must be based on economic justification (Mital 1992) as well as the capabilities of the humans and the equipment. The capabilities of humans and machines are essential for allocating functions (Mital et al. 1994a, b) and for the final determination of the equipment needed. The extent of automation as well as the particular equipment selected will have a major impact on the complexity of instructions given to the humans to operate the machines. The time and cost of production as dictated by the level of automation and the type of equipment will have to be used to evaluate alternate product designs. Thus, after the method(s) of manufacture have been determined for a particular product design option, the design should be reexamed to identify opportunities for redesign that could directly impact the production time and cost, now based on an understanding of the available equipment capabilities.

The allocation of functions also provides a basis for determining what skills the workers will need. A comparison between the available and needed skills will identify skill deficiencies that will have to be made up through training. In the design and development of the training program, it would be worthwhile to consider immediate, short-term, and long-term skill requirements. As shown in figure 2, these skill requirements will be a function of the technology forecast. Based on this forecast, the company should identify potential users, i.e. personnel in various functional units that will be affected by the predicted product and process changes. This activity should be done by lower level management and related engineering personnel. The output of this activity would be the list of affected functional units and the corresponding personnel that would need to be trained. Using interview, surveys and other data collection instruments, the available skills inventory of the affected personnel needs to be determined. By understanding the technology forecast, the required skill sets can be identified. The assessment of the gaps between the available skills inventory (where they are now) and the required skill sets (where they need to be) will result in the skill gaps that would need to be filled by appropriate training.
As the review in Section 3 indicates, the design and development of the training module will need to consider at the very least, the following questions:

1. should the workers be trained in several skills or only a particular skill?
2. should the focus be on building up on available skills (retraining) or is the technology chosen such that it would amount to fresh training (for fresh training, the residual effect of older skills will need to be considered)?
3. what training method should be used (simulator, lecture, on-the-job, etc.)?
4. what should be the performance measures training should enhance and how are they related to workers’ performance on the actual job?
5. what should be the criteria for evaluating worker proficiency during and after training?

It should be noted that the training framework proposed in figure 1 and briefly discussed above is solely based on the review of published training literature and corresponding deficiencies. There are many issues that are still unresolved. For example, is it better to train workers in several skills (cross-training) or a specific skill (longitudinal training)? Clearly, cross-training enriches the individual but may result in penalizing efficiency, whereas longitudinal training will reverse those effects. What should be the balance to achieve enrichment as well as efficiency? Such issues need to be addressed in future research. The fact that such issues are yet to be resolved, however, should not restrict us from developing a generic training process framework. Such efforts, at the very least, will focus attention on issues of immediate concern that future research will need to address.

6. Summary

In this paper we have established the need for training manufacturing workers in skills the rapidly changing technology dictates they have. Upgrading worker skills is necessary not only for competing successfully in the global market but also for properly managing our human resources. We have provided a brief review of the training literature, which primarily exists in the behavioral sciences area, and established that there are certain deficiencies (for example, a serious lack of onsite industrial studies) that future training research needs to address. Finally, we have provided a framework for training manufacturing workers that takes into account users, product design considerations, manufacturing technologies, technological changes, and available worker skills.

References


ETTLIE, J. E., 1988, Taking Charge of Manufacturing (San Francisco: Jossey-Bass).


HARTLEY, J., 1984, Robots at Work (Bedford: IFS).


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King, P. H., 1966, A summary of research in training for advisory roles in other cultures by the behavioural sciences laboratory (Wright-Patterson Air Force Base, OH: Aerospace Medical Research Laboratories).


McCann, P. H., 1975, Training Mathematics Skills with Games (San Diego: Navy Personnel Research and Development Centre).


Mealiea, L. W., and Duffy, J., 1985, Contemporary training and development practices in Canadian firms. Annual Meeting of the Atlantic School of Business, Halifax, Canada.


Mital, A., 1996, Identification and ranking of research needs in preparing the American workforce for global competition beyond the year 2000: the role of ergonomics in designing for manufacturability and humans in general in advanced manufacturing technology. Final report of two workshops submitted to the National Science Foundation, Cincinnati, OH.


