Worker mobility and training in advanced manufacturing

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Received 1 June 2002; received in revised form 13 September 2002; accepted 22 May 2003

Abstract

Worker training is a priority for manufacturing organizations, and State and Federal policymakers in the United States. There is a need among US manufacturing industries for a training process plan, including information on what to train the worker in given the changes in product, process, and system-level technologies, and how best to deliver such training at minimal cost. Also, from the viewpoint of the manufacturing worker, possession of transferable skills is commonly expected to provide the worker flexibility and mobility. The objectives of this paper are to examine the issues involved in generating such a training plan, and suggest a framework for generating such a plan. A case study illustrating application of elements of the training framework is also presented.

Relevance to industry

Manufacturing industry can use the framework presented in this paper for development of effective training plans (both in terms of cost and technical effectiveness) so that workers are ahead of constant technological changes in manufacturing.

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Keywords: Worker skills; Advanced manufacturing technology; Worker training; Workforce mobility

1. Introduction

“…If we are obliged to lay men off for want of sufficient work at any season we purpose to so plan our year’s work that the layoff shall be in the harvest time, July, August, and September, not in Winter. We hope in such case to induce our men to respond to the calls of the farmers for harvest hands, and not to idle and dissipate their savings. We shall make it our business to get in touch with the farmers and to induce our employees to answer calls for harvest help.”

The above quotation is from an interview New York Times conducted with Henry Ford in January 1914. The issue addressed in the interview, namely, finding alternative work for workers who are laid off due to want of sufficient work, remains important and urgent even today. According to the Bureau of Labor Statistics’ recent data on workers who had 3 or more years of tenure on a job they had lost or left between January 1995 and December 1997 because of plant or company
closings or moves, insufficient work, or the abolishment of their positions or shifts, nearly 28% of the 3578 thousand displaced workers were manufacturing workers (both durable and non-durable goods manufacturing). Among the different durable goods manufacturing industries, nearly 33% of the 121,000 displaced workers in the machinery tool manufacturing industry were either unemployed or not in the labor force in February 1998. Nearly 36% of the 95,000 displaced workers in the transportation equipment manufacturing industry were either unemployed or not in the labor force in February 1998. These numbers were nearly 40% (of the 86,000 displaced workers), 56.9% (of the 109,000 displaced workers), 20% (of the 81,000 displaced workers) 40% (of the 39,000 displaced workers) in the food and kindred products manufacturing industry, the apparel and other finished textile product manufacturing industry, the printing and publishing manufacturing industry, and the rubber and other miscellaneous plastics products manufacturing industry, respectively. Table 1 provides recent Bureau of Labor Statistics estimates on displaced workers classified by occupation of lost job and employment status of the worker in February 1998.

As can be seen from the table, nearly 21% of all displaced workers were either precision production, craft and repair workers, or were machine operators, fabricators and laborers. In addition, a large proportion of these workers also were unemployed or could not participate in the labor force. Table 2 is a summary of data on the full-time earnings of manufacturing workers who were reemployed (after losing their previous jobs between January 1995 and December 1997 because of plant closings or moves, insufficient work, or the abolishment of their positions or shifts) in February 1998. It is evident from Table 2 that among all US industries, not only were the highest percentage of displaced workers from the manufacturing industry, but also, that manufacturing workers were the ones whose immediate second jobs paid them the least (including the number that only made more than 20% above previous earnings, if above) compared to workers from all other industries who were reemployed.

Compounding the problem is the fact that the data presented do not indicate the nature of the second job for manufacturing workers who found employment—it does not indicate if they found employment in manufacturing (which means they perhaps will get to use all the skills that they built in their previous job), or in some other industry (which will impose an additional burden on the new employer to train the person in the industry practices, and an additional intangible burden on the worker to have to let go of the previous skills and learn new skills).

In summary, while many developments, chiefly technological, have taken place since 1914 in US manufacturing, manufacturing industries, to this day, continue to lay off workers in large numbers. Active provision of alternative work for such workers is the theme of this paper. An active

Table 1
Displaced workers by occupation of lost job and employment status in February 1998 (Data refer to persons who had 3 or more years of tenure on a job they had lost or left between January 1995 and December 1997 because of plant closings or moves, insufficient work, or the abolishment of their positions or shifts)

<table>
<thead>
<tr>
<th>Occupation of lost job</th>
<th>Total (in thousands)</th>
<th>Total (%)</th>
<th>Employed (%)</th>
<th>Unemployed (%)</th>
<th>Not in the labor force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>3578</td>
<td>100.0</td>
<td>75.9</td>
<td>10.0</td>
<td>14.1</td>
</tr>
<tr>
<td>Precision production, craft and repair</td>
<td>391</td>
<td>100.0</td>
<td>88.3</td>
<td>5.3</td>
<td>6.5</td>
</tr>
<tr>
<td>Machine operators, fabricators, and laborers</td>
<td>343</td>
<td>100.0</td>
<td>55.9</td>
<td>21.0</td>
<td>23.0</td>
</tr>
</tbody>
</table>
provision of alternative work, rather than a passive or a reactive provision, imposes upon such a provision, several goals and characteristics, among which the two most important are: (a) in the long run, there should be little or no worker layoffs; (b) in the short run (before the effects of implementing the long-term provisions are realized), workers who are laid off should be able to find work, and work that pays them, at the very least, comparable to what their previous work paid.

The long-term goal (a) above is achievable only through designing human-centered manufacturing systems that use and develop further the special and unique skills humans bring into the manufacturing domain. Designing human-centered manufacturing systems needs a careful examination of the thinking of the 1980s that human influence in manufacturing could be completely eliminated through complete automation of all manufacturing activities. The reality is fully automated factories based on hard automation are not viable especially in situations where a product is to be changed frequently because of user needs, costs, or engineering improvements. Hard automation of all manufacturing activities is also an economically undesirable option at the present time. In addition to technical and economic issues, humans are also considered to be important cybernetic components for control and innovation in manufacturing systems, a fact that further points to the desirability of human-centered manufacturing systems.

Issues involved in designing human-centered manufacturing systems is discussed in Mital (1997) and Mital et al. (1999). This paper presents a framework to address the short-term goal (b) presented above. Specifically, the objective is to present a framework to generate a knowledge base that will equip the worker (the scope is restricted to line workers in US discrete product manufacturing) with mobility through the provision of skills and training. It is desirable for such a knowledge base to have the following two characteristics:

(a) be applicable for all discrete product manufacturing industry groups such as automobile manufacturers, aircraft manufacturers, etc.;
(b) contain worker training plans (including the training contents (skills), and training delivery protocols) that are optimal (most generic and least expensive for manufacturing industries).

This paper is organized as follows: Section 2 presents the integrated framework for development of the knowledge base, and outlines the impediments to implementing the framework. A case study in application of elements of the framework is presented in Section 3. Conclusions and future research directions for work with the framework are provided in Section 4.

2. An integrated framework for worker mobility enhancement

An extensive review of important training issues such as training needs assessment and training evaluation can be found in Pennathur et al. (1999). The review presented in Pennathur et al. (1999) indicates the following:

(a) 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, deals with the development of mathematical models for a flexible workforce 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 reported in the engineering literature.

(b) Training research in the behavioral sciences has resulted in useful insights into considerations that should be taken into account 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.

(c) Very few 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, while results from these studies provide insights into training methods, factors affecting training and influencing training outcomes, training performance measures, and human behavior, 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 hardcore 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 researchers 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 online training technologies.

2.1. The framework: objectives, characteristics, and bases

The overall objective of the framework presented in Fig. 1 is to provide a research setting by identifying the variables and issues involved in generating a training process plan that will optimize two important considerations: (a) the training costs to industries, and (b) the mobility of the worker. To achieve this overall objective, the framework must have the following characteristics: it must consider all US discrete product manufacturing industries, and not be exclusive to one or a few industries—being inclusive of all industries will, expectedly, result not only in reducing the cost to a specific industry (the more the number of different types of discrete product manufacturing industries included in the framework, the smaller the share for any one industry), but will also, expectedly, result in maximizing potential worker mobility (if all types of discrete product manufacturing industries are included, it will result in a broader set of training plans representative of the entire discrete product manufacturing industry). In addition, the content of the knowledge and training process plans generated as a result of using the framework has to, to the extent possible (which is actually a research issue in generating the plan), approach general and broad industrial applicability, rather than specific applicability. These characteristics are particularly important as conventional wisdom indicates that firms are willing to pay only for any training for any specific skills they need—in general, it is known that the share of a firm's
training cost for any “generic” training a worker receives is small.

The framework proposed in Fig. 1 is based upon the following constructs: (a) that all discrete product manufacturing is composed of some form of material processing, some form of assembly, some form of inspection, and some form of maintenance and repair, and further, that these activities are common to any and all discrete product manufacturing, a fact that can be exploited in generating training plans that achieve the overall objective of maximizing worker mobility while at the same time reducing the training costs for the entire discrete product manufacturing industry; (b) that the fundamental manufacturing activities are becoming, and will in the future become, information intensive due to advances in information technology—any training plan that does not consider this fact will be deficient.

The question that the framework in Fig. 1 poses is: What is the least costing (to the industry as a whole) training plan (including the skills, and the training methods and delivery protocols) that will maximize the mobility of a trainee (mobility will be maximum if, as a result of the training, the trainee is able to work effectively in each discrete product manufacturing industry; posed in other words, what is the least costing training plan that will transfer effectively to the most number of industries?).

2.2. Elements of the framework

As depicted in Fig. 1, the framework can be conceptualized to consist of the following broad elements, all necessary for any research and implementation activities to be carried out with the framework: (a) representative discrete product manufacturing industries; (b) manufacturing activities and associated technologies; (c) methods for generation of skills and training protocols; (e) measures for evaluating goals (both micro-goals and macro-goals—a micro-goal could be to evaluate the better training protocol, among different training protocols, for imparting a certain skill; the macro-goal is to maximize worker mobility as determined by the efficacy of the transfer of the final training plan to different discrete product industries.

Research issues and variables that are part of the framework are discussed at three different levels in the following sections: tier 1, consisting of discussions at the “activity” or the “manufacturing function” level; tier 2, consisting of discussions at the level of a specific company; and tier 3, consisting of discussions at the level of the US discrete product manufacturing as a whole. It should be borne in mind that the division of the discussion into tiers does not imply that, research, when the framework is implemented, will necessarily proceed serially, tier by tier.

2.2.1. Tier 1: function level

Discrete product manufacturing industries, as the name implies, deploy technology and manufacture products. The output is not continuous as in the case of thermal power plants or nuclear power plants; rather, it is a discrete product. Technology is classified into three types in our framework: product technology, process technology, and system technology. Product technology refers to the technology content in the product—for instance, the type of engine in an automobile, or the type of sensors used in a remote control unit, etc. The technology content in the product is an important consideration in our framework as it directly influences human performance (and hence the skills needed and the training protocols) of certain manufacturing activities such as product troubleshooting or diagnosis. Process technology, in our framework, refers to the technology content in the process employed to manufacture the product—for instance, the use of a special laser cutting technique for a complex three-dimensional surface in an automotive component, or micro-drilling of a precision component. Obviously, depending upon whether the particular processing function has been allocated to the human or whether it is automatically done by the machine, process technology will also influence performance of the human. System technology, in our framework, refers to technologies that are employed for the system-level coordination of manufacturing—for instance, a company may employ “Just-In-Time” techniques and associated technologies for
its production management. System technology imposes performance demands on the human as well—team-based work is a good example of this demand. Also, as the arrows in the framework in the technology block in Fig. 1 indicate, product technology (depending on the product design) could decide the process and the system-level technologies used. In addition, the dotted lines enclosing the technology block models the fact that technology is always in a state of flux and is constantly changing.

The main manufacturing activities that line workers engage in can be broadly classified into the following: (a) materials processing using manufacturing processes; (b) assembly; (c) inspection; and (d) maintenance and troubleshooting. There are other pre- and post-manufacturing activities such as packaging and shipping which are not considered in the framework, but, which can equally be made a part of the framework in future work. These four manufacturing activities, namely, materials processing, assembly, inspection, and maintenance and troubleshooting are necessary activities in any discrete product manufacture. As mentioned earlier, and as indicated in Fig. 1, the block labeled “technology” including product, process and system technologies, affects the block labeled “activity” including material processing, assembly, inspection, and maintenance activities. For example, the technology content in the product determines product maintenance activities; an electronic printed circuit board manufacturer may decide to use a specific type of surface mount technology in its assembly of circuit boards; and, a company could decide to use computer-aided maintenance management software (a system technology in our context) for its predictive maintenance activities.

The goal in tier 1 is to address the skills needed, and the training protocols for imparting these skills at the task level, for materials processing, assembly, inspection, and maintenance, troubleshooting and diagnosis activities. The following sections present a systematic method to generate the knowledge base (consisting of the skills needed, and the training protocols based on how skills are acquired) at the activity level.

There have been many attempts in the training literature to study skill acquisition. The Knowledge, Skills, Abilities classification according to Prien (1977) reviewed in Pennathur et al. (1999) is one such classification. Rumelhart and Norman (1978) identify three types of learning processes—accretion, restructuring, and tuning. According to Rumelhart and Norman, accretion is the acquisition of facts in declarative memory, restructuring is the acquisition of procedures in procedural memory, and tuning is the modification of existing procedures to enhance reliability and efficiency of performance. Anderson (1982) postulated a three-stage model for skill acquisition—a cognitive stage, an associative stage, and an autonomous stage. In the cognitive stage of performance, the learner attempts to comprehend the task and how it should be performed. Work in this stage is based on instructions or modeling and demonstration of how a task is to be performed. Declarative knowledge about a certain domain consisting of any facts, information, background knowledge, and instruction about a skill acquired during the cognitive stage, is converted into procedural knowledge or production rules in the associative stage of performance. According to Anderson, at the autonomous stage of performance, skilled performance is automatic requiring very little effort on the part of the learner. These constructs are as a result of research in experimental and behavioral psychology.

According to Rasmussen (1986), in systems that use advanced information technology, and in systems that require human decisions in supervisory control environments, models from the various branches of psychology and the traditional human factors field provide little help in modeling due to their “kinship to classical experimental psychology and its behavioristic claim for the exclusive use of objective data representing overt activity.” Rasmussen (1986) proposes a conceptual reference frame (commonly known as the SRK framework) for modeling skill acquisition for engineering systems. The overall framework presented in this dissertation uses Rasmussen’s reference frame for generating skills needed for the different manufacturing activities taking into account the technology content of the product,
and the process and system technologies for each activities.

According to Rasmussen, there are three typical levels of performance: a skill-based level, a rule-based level, and a knowledge-based level. Rasmussen refers to sensorimotor performance during acts or activities that take place without conscious control or attention but as smooth, automated, and highly integrated patterns of behavior, as skill-based performance. He considers human activities as a sequence of such skilled activities, and further postulates that the flexibility of skilled performance is due to the ability to compose from a large store of automated subroutines the set of routines specifically suited for a task or activity. At the level of rule-based or “goal-oriented” performance, there is conscious control of the sequence of activities leading to performance, through stored rules or procedures that may have been derived empirically from previous performance, or other instruction. The goal, according to Rasmussen is found implicitly in the situation releasing the stored rules. It is important to note that rule-based performance kicks in when work is in familiar situations. During performance in unfamiliar situations (unfamiliar being defined a task or work environment for which no know-how or rules are previously stored or available in skill), performance, according to Rasmussen, moves to the higher level of performance—the knowledge- or model-based level. The performance is goal controlled with an explicitly stated goal based on an analysis of the environment and the overall aims of the person.

The implication of Rasmussen’s SRK framework for training activities is that training helps develop the automated sensorimotor patterns that are essential for skilled performance. Further, the automated sensorimotor patterns continue to develop even while performance is driven by higher-level activities based on rules and knowledge implying that performance proceeds from the lower to higher levels of resources—in a skilled operator, the rules and knowledge (which are higher level resources) deteriorate with development of the automated sensorimotor patterns that aid skilled performance.

Central to the SRK framework is the division of information as perceived by a human into three classes: signals, signs, and symbols. This classification of information in our framework is important as the central theme in the framework is the need for the human operator to cope with the manufacturing technology, and is becoming information based. According to Rasmussen, human operators perceive continuous, quantitative signals for performance at the skill-based levels. Signals represent direct, continuous, physical, time-space, sensory data without any meaning attached to them. Performance at the skill-based level may be triggered by cues from the higher levels of control. Signs are responsible for performance at the rule-based level, and can only be used to select or modify the rules controlling skilled performance. Signs cannot be used for functional reasoning, for generation of new rules, or for prediction of human response to unfamiliar situations. Symbols refer to concepts related to functional properties of a system, and can be used for functional reasoning and related computation. In essence, symbols represent the internal conceptual representation of reasoning and planning.

Closely related to the classification of information perceived by the human is Rasmussen’s classification of human–machine interaction (for the information perceived) into four categories: direct manipulation of objects, indirect manipulation of objects, remote manipulation of objects, and remote process control. According to Rasmussen, most manual tasks such as assembly involve direct manipulation where a direct manipulation of the physical environment takes place. Also, in direct manipulation, objects are perceived in terms of their functional implications, and control of the movement of the necessary limbs to perform the function is based on sensing and perception of cues as signs. In indirect manipulation, training is said to have been successful when there is perception that the mechanical tools that are used to manipulate or transform objects are extensions of the human body. In indirect manipulation, attention and intention are both focused on the task at the interface between the tool and the environment, not the tool operation itself. When the actual location of the task and the actual location of the human controlling or performing the task are separate, there is said to be remote.
manipulation of the task. There is an intermediate information channel in this case which may be considered as an extension of the senses. Human attention and control will be devoted to the remote interface. Skilled performance takes place in the task itself, and not in the remote manipulation interface. Remote process control is when coded symbolic information and indicators about a process that is changing and is invisible is inserted into the space–time loop. Interface manipulation and recognition of the coded symbols and their associated meaning take up most of the sensorimotor capacity of the human in this case. Design of the interface becomes a critical issue in this case.

To summarize, from a worker training perspective, the goal of the framework presented in this work can be defined as identification of optimal training protocols for the tasks that have to be performed using certain advanced manufacturing technologies. The three key elements are technology, tasks, and training. Each of the sections that follow briefly discuss each of these three elements for materials processing activities, assembly, inspection, and maintenance and troubleshooting.

2.2.1.1. Materials processing. With significant automation of most manufacturing processing activities, processing of materials is perhaps the activity requiring least manual psychomotor skills. While a normative task model for the material processing activity is difficult owing to the specificity of the different manufacturing processes, it is generally acknowledged that processing technology has advanced to such an extent that all that the operator has to do is to program the machine to process the material. Skilled workers are considered adept at reading drawings and transform the contents of the drawings into motions of a machine. Shop floor programming methods based on a skilled worker’s manufacturing knowledge, planning capabilities, and situational knowledge about the states of machines and tools in order to produce correct and optimal programs, are becoming commonplace. Identification of information, preparation of information, conversion of information, and employment of computer technology to perform the processing activity, can be considered the key tasks involved in material processing.

The tasks can be made more specific depending on the technology employed, and the processing activity. Table 3 provides an example of specific tasks involved in jobs performed by a numeric drill operator. Material processing activity is mostly rule and knowledge based for most operators, but for skilled performance should be analogic and based on the sensory experience of operators—design of the programming interfaces is critical for skilled performance of material processing activities.

Table 3
Broad tasks involved in numeric drill operation (based on US Department of Labor, 1993)

<table>
<thead>
<tr>
<th>Task category</th>
<th>Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification of information</td>
<td>Take part from CNC machine and put it on a workbench and rest it on a nest or master. Ensure proper setup using a master. Check part dimensions using several gauges. Load machine and cycle. Check the next part worked on that machine to ensure that the adjustments are correct. Consult blueprint to determine work to be performed.</td>
</tr>
<tr>
<td>Information preparation</td>
<td>Transfer information (tools and programs needed to perform the job) to the control (a computer) from paper. Use five consecutive pieces to measure machine specifications and make a Statistical Process Control Chart.</td>
</tr>
<tr>
<td>Convert information</td>
<td>Read equipment gauges and make adjustments as necessary to the work process. Accurately read statistical samples and display information on a SPC chart. Work with other drill operators to try to eliminate scrap.</td>
</tr>
</tbody>
</table>
2.2.1.2. Assembly. Industrial assembly can be defined as “the aggregation of all processes by which various parts and subassemblies are built together to form a complete, geometrically designed assembly or product (such as machine or an electronic circuit) either by an individual, batch or a continuous process,” with efficiency, productivity and cost-effectiveness as goals (Nof et al., 1997). Assembly technologies are of a wide variety ranging from manual, mechanized, and automated assembly lines to robotic and other forms of flexible assembly technologies. The assembly technology used is also a function of product complexity and the type of industry (for example, assembly technologies such as surface mount technologies are common in electronic industries, whereas technologies such as riveting are common in industries requiring mechanical assemblies). Assembly tasks, in general, are broadly classified into part handling tasks, part mating tasks, and part joining tasks. Part handling tasks include setup activities such as part retrieval, kitting, and fixturing. Part mating involves alignment of two or more parts (peg in a hole, hole on peg, multiple peg in hole, and stacking). After parts are mated, they are joined or fastened by one of the many available fastening methods such as fastening by screws or bolts, retainers, press fits, welding, adhesives, riveting, surface mount technology, etc. Assembly operations requiring human input, are in general, considered skill-based operations requiring psychomotor manual skills. The goal of the training program should be to equip the worker with skill for each of the subtasks that are necessitated by the particular technology in current or future use for that subtask.

2.2.1.3. Inspection. The goal of industrial inspection systems is to test and decide the “quality” of parts or processes based on certain quality criteria. A number of tasks or functions are involved in the testing and decision-making process that is inspection. Drury and Prabhu (1994), for example, define the following five fundamental inspection functions: (a) setup, which ensures that the inspection system is functional and calibrated; (b) presentation, which ensures that the item to be inspected is presented to the inspection system; (c) search, which ensures detection and location of all possible faults in the item under inspection; (d) judgment and decision, which ensure that all identified faults are measured and correctly judged; and (e) action or response, which ensures that an action corresponding to the judgment and decision is taken to rectify the fault. All inspection activity is composed of at least these fundamental task elements. The process and system technologies used to accomplish these different tasks can be varied depending upon whether the task is performed by a human or by an automated device, and depending upon the industry. Also, performance can be skill based (requiring manual skills), or be rule or knowledge based depending on the inspection task and the technology used.

2.2.1.4. Maintenance and troubleshooting. The key element in maintenance and troubleshooting tasks can be said to be fault diagnosis and repair. Based on the available literature in the area of fault-finding strategies (Rasmussen, 1984; Patrick and Haines, 1988; Wognum, 1990; Swezey et al., 1991; Schaaftal, 1993; Munley and Patrick, 1997), the important tasks involved in troubleshooting (as determined for an expert technician and hence a normative model) can be classified into: (a) symptom identification; (b) symptom interpretation; (c) fault determination; (d) fault ordering; (e) repair determination; (f) analysis of repair strategy consequences; (g) repair listing; and (h) evaluation of solution. These tasks proceed sequentially in any maintenance and troubleshooting activity. In the industrial domain, there are a variety of technologies that need to be maintained, in addition to the product technology, and the machines employed in the actual production. For example, some common mechanical equipment include plain bearings, rolling bearings, flexible couplings for power transmission, chains for power transmission, overhead and gantry cranes, chain hoists, v-belt drives, mechanical variable-speed drives, and gear drives and speed reducers. Some common electrical equipment include electric motors, control components such as operating coils in a magnetic motor controller, industrial batteries, and illuminating devices in use in the industry. In addition, there are service equipment
such as air-conditioning equipment, ventilating fans and exhaust systems, dust collecting equipment, centrifugal pumps, reciprocating air compressors, valves, piping, scaffolds, etc. The maintenance of lubricating systems and devices, and the calibration and maintenance of mechanical instruments for measuring process variables, and electrical instruments for measuring, servicing, and testing other equipment assume importance.

2.2.2. Tier 2: company level

At the level of a single company, the issue seems to be one of managing worker flexibility in performing different jobs. Research at this level is driven by the need to balance out training policies (including the breadth versus depth of skill) with determination of low-cost staffing plans and policy decisions to deal with employees with varying productivity levels. Brusco and Johns (1996), for example, propose a preemptive integer-goal programming model to determine the number of employees in each skill category to satisfy demand for labor and minimize staffing cost; the secondary objective of their model is to minimize the number of transfers among different skill categories. They examine six cross-training policies through the goal-programming model—no cross-training, a policy that allows workers in each skill category to be cross-trained in one other category at 50% productivity level (a low depth, low breadth policy), a policy that allows 100% productivity in the second skill category for which they are cross-trained (a high depth, low breadth policy), a policy that allows for each worker to be cross-trained at 50% productivity in two secondary skill categories (a low depth, medium breadth policy), a fifth policy which is low depth and high breadth (each worker is allowed to have 50% productivity in all secondary skill categories), and a sixth policy with high depth and breadth (each worker is assumed to be 100% productive in all skill categories). Their simulation results show that the breadth of cross-training is more important than the depth of cross-training as measured by the labor savings that result from such staffing policies. Felan et al. (1993) examine this issue through simulation from the perspective of a job shop, and compare the benefits resulting from additional workforce staffing with the development of a multi-skilled workforce. The two cost criteria they use are the number of worker transfers between machines or departments (this is a cost as it results in a loss in capacity during the transfer), and utilization (the percentage of time the operator is running the machine). The authors conclude that labor flexibility is a more conservative approach to increase process flexibility than additional labor staffing. Their simulation results show that increasing staffing levels results in a reduction in inventory levels, lead time, and due date performance in a job shop, but results in a higher cost than the cost incurred by simply cross-training the workers. Park (1991) reaches similar conclusions from his simulation study. Toyota Motor Company uses a system of forced job rotation, where each worker rotates through and performs every job in the workshop. Toyota follows three steps in the job rotation plan—the rotation of the managers and supervisors (so they serve as models of the multi-functioned worker), the rotation of the workers within each shop and rotation of the worker several times a day in a line. There is no published information, however, on the costs and the time it takes for such training plans to materialize in Toyota. Job rotation by brute force may not be an optimal approach, considering the skills to be transferred, the individual characteristics of the workers, and the training budget available for the company.

To summarize, the most important research issue at this level is to determine a management policy that will reduce the training-related costs for a company while at the same time accounting for the demands for labor.

2.2.3. Tier 3: all discrete product manufacturing

The research issue that the framework attempts to address is: what is the least costing training plan that maximizes worker mobility? Worker mobility will be maximum if the training plan enables the worker to work in any discrete product manufacturing industry, and perform any manufacturing activity. The research issue can also be rephrased into the following question: what is the least costing training plan that will effectively transfer to as many industries as possible? Two such
extreme plans that increase mobility in different ways are presented in Figs. 2 and 3. The training plan depicted in Fig. 2 can be considered a longitudinal training model (longitudinal in terms of the manufacturing functions). A worker, for example, could be trained in assembly activities and assembly activities alone, but for all discrete product manufacturing industries (a list of the possible discrete product manufacturing industries is easy to generate—one can follow the Standard Industrial Classification for manufacturing industries as generated by the Bureau of Labor Statistics. The other option is to use a list generated by manufacturing organizations such as the Society of Manufacturing Engineers, which consists of broad categories such as automotive manufacturing industries, machine tool manufacturing industries, heavy equipment manufacturing industries, aircraft and aerospace manufacturing industries, electronics manufacturing industries, and consumer goods and process industries.

There is an increase in mobility for the worker, as the worker from being an assembly worker for a certain company (with the product, process and system technologies that go with the company), now becomes an assembly worker for any discrete product manufacturing company (which will entail a training plan that reconciles all the differences in technology and operations between different industries). The same can be true for all manufacturing activities—an electrical maintenance technician for a specific company could be trained to perform electrical maintenance in all industries. The training plan depicted in Fig. 3 can be considered a cross-training model. From performing a specific type of a specific manufacturing activity for a specific company (e.g., electrical maintenance for a company), the worker could be cross-trained to be able to perform all types of a single class of manufacturing activity (e.g., cross-training in electrical, mechanical, hydraulic, and software maintenance would make a previously electrical maintenance worker a generic
maintenance technician). Again, from being a generic worker for a specific manufacturing activity, the worker could be cross-trained in all manufacturing activities to be a generic line worker for the entire company or a specific industry group or all US discrete product manufacturing industries.

In both Figs. 2 and 3, there is a gradual increase in the area of the blocks representing the skills from bottom-up. This increase in area (representing an increase in the number of skills) could be used as a macro-measure of the increase in worker mobility. Traditional training effectiveness measures can be used to measure the micro-level improvements that result from training plans that are a part of the framework.

Given the requirement that any training plan generated from the framework should have broad applicability to different industries, and given that there are differences in product, process, and system-level technologies among companies in the same industry group, and among different industries (making the domain knowledge for training varied), the modeling precepts that follow have to be kept in view when the training plan (the content, method of delivery, etc.) is prepared and implemented, and outcomes measured. These precepts are founded upon theory in transfer-of-training research. The goal in our framework is to ensure a positive transfer of the training plan across different industries. Fig. 1 depicts this issue. The training plan is generated as a result of input from different discrete product manufacturing industries; the plan is then expected to result in a trained worker who can work in any of the

![Diagram](image-url)

Fig. 3. The cross-training model depicting a possible variant that can result from the basic framework.
industries (which participated when the plan was generated). Based on the effectiveness of the transfer of the training content to different industries, the training plan can then be modified to maximize transfer (indicated by the feedback arrow in Fig. 1). There are two classical theories on transfer of training that provide insight into how to ensure and maximize transfer in a plan: the identical elements theory proposed by Thorndike and Woodworth (1901), and the transfer-through-principles proposed by Judd (1908). According to the identical elements theory, transfer occurs when there are identical elements in both the original and the transfer situations. In the case of our framework, this will mean the presence of identical elements among all industries. The framework presented in this work, is in fact, based on exploiting the fact that similar manufacturing functions are present in different discrete product manufacturing industries, and further, that manufacturing technology is information based in all discrete product manufacturing industries. There is a strong likelihood, hence, that based on the identical elements theory, it is possible to develop a training plan that will be applicable to all industries, and hence make the worker truly mobile. The transfer-through-principles theory suggests that the trainee need not necessarily be aware of similar elements in a situation for transfer of training content to occur, as long as relevant underlying training principles are employed. The similarity or identical elements can either be in the stimuli that trainees encounter during training or during actual job performance, or it can be in the response that trainees need to provide during training or during actual job performance. According to Bruce (1933), based on stimulus–response analysis, transfer of training can be affected in the following four different ways: (a) a high positive transfer will occur if new stimuli are similar to the original ones, and the responses in the two situations remain identical; (b) a slightly positive transfer will occur if new stimuli are different from the original ones, but the responses remain constant; (c) negligible transfer will occur if the stimuli are identical, and the responses are similar but not identical; (d) negative transfer will occur if the responses are dissimilar even though the stimuli are identical. In general, the Bruce–Wylie laws (Bruce, 1933) state that the amount of transfer depends on the degree of similarity between situations, and the direction of transfer depends on the similarity of the two responses. The Osgood’s (1949) theoretical model of training transfer describes the variances in the amount of transfer with gradients in similarity between the training and operational settings (which in our case can be extended to one training setting and more than one operational setting to which the contents of the one training setting have to transfer). According to Osgood, based on a three-dimensional surface (stimulus similarity on one axis, response similarity on one axis, and the amount and direction of transfer on the third axis), transfer is a function of stimulus and response similarity. With identical stimuli, the effect of variation in required responses moves from maximum transfer at identical responses, through zero to negative transfer as antagonistic responses are reached. The Osgood’s transfer surface model has been shown to be inadequate in predicting negative transfer and in predicting transfer involving complex task performance. Miller (1954) hypothesized a point of diminishing returns for transfer, where the value of transfer gains are outweighed by the costs of training. Literature on information processing theory has identified four factors that influence transfer in information processing-based tasks: (a) relationships between cues for retrieval of information, and the encoded information; (b) retrieval of information during the initial study phase; (c) organizational strategies and schema for task performance; and (d) automation of performance with consistent stimulus training. The general conclusion of cognitive theories of transfer of training is that physical similarity and fidelity (of equipment, etc.) is less important than the essential cuing relationships between the information attributes of the stimuli, and the responses. The field of equipment fidelity research (Demaree et al., 1965; Caro, 1970; Altman, 1970; Wheaton and Mirabella, 1972; Wheaton et al., 1976; Holman, 1979; Rose et al., 1985; Klein, 1982; Adams, 1979) also provides useful insights that can be used in our framework for evaluating the effectiveness of the overall
training plan, especially as related to training delivery methods.

2.3. Impediments in implementing the framework

Even though the framework presented in the paper is ambitious, there are a number of technical, economic, cultural, and other barriers that could possibly affect implementation of the framework. These are briefly discussed in the following paragraphs.

To realize the benefits of the framework, it is necessary that during the research stage, there be participation from as many discrete product manufacturing industries as possible. Participation from only a few industries (owing to the industries’ need to protect technology their technology), will minimize the impact of the training plan, its transfer, and the ability to increase worker mobility.

Even though it may be possible to generate the training content that would increase worker mobility, tailoring the plan to individual workers may dilute the effectiveness of the plan at the implementation stage, due to individual differences in learning.

A number of studies in labor economics have shown that, in real life, it is difficult to precisely measure the amount of informal training that occurs during on-the-job training. This limits the researchers’ understanding of the on-the-job human capital investments.

Even within a single firm, there are a number of factors that may impede any training related research and implementation—in general, it has been established from National Longitudinal Surveys conducted by the Bureau of Labor Statistics, and Surveys of Employer-Provided Training conducted by the Bureau of Labor Statistics and the Organization for Economic Cooperation that the number of hours of training tended to be higher at firms that are larger, non-union, and have higher number of benefits and workplace practices, and smaller numbers of part-time workers. It has also been found that variables such as education that have an affect on formal training also affect informal training in a similar fashion. It is the general conclusion from these studies that employers who show signs of promoting a long-term relationship with the employees tend to train and to train more intensively. Firms with many fringe benefits and innovative workplace practices are more likely to provide formal training and to spend more on training.

Within a firm, what has been termed the politics of production including issues such as during and distribution of working hours, remuneration, social regulation of team work, motivation and supervision of employees, and staff management, to mention a few, have been found to be the most influential in shaping future factories through human skills and training. A pay-for-skill remuneration system, requiring a complete change in the organizational culture of firms has been shown to increase flexibility, improve productivity, and increase average wage levels (Brodner, 1985).

For a worker used to the organizational culture of a certain firm, or even a certain industry group, mobility resulting from the training plan generated from the framework need not necessarily translate into effective performance in a different firm belonging to the same industry group, or even a different industry due to the differences in organizational culture between two firms or two industry groups.

Age of the worker, the extent of tenure with a certain employer, familial considerations, geographical considerations, etc., are other factors that affect mobility, but, do not directly influence the generation of a training plan using the framework.

3. A case study in electromechanical fault finding

This section presents results from a case study conducted as part of validating elements of the conceptual framework presented in the earlier section. The goal of the case study was to investigate the effect of two different training strategies on fault-finding performance for troubleshooting faults in a product with electromechanical components.

This case study was performed at the Cincinnati and New Jersey plants of a local manufacturer of parking control systems. The company, founded in 1896, employs 70 workers locally, and has plants
in New Jersey, California, Canada, and Japan, in addition to the plant at Cincinnati. Figs. 4 and 5 depict a typical parking system that makes use of the products made by the company.

The parking system consists of the following typical subunits:

(a) **Electronic ticket printer (ETP) series ticket dispenser**: This dispenser (Fig. 6) prints the machine number, rate, sequence number, and the year, month, date, and time of entry of the vehicle into the parking facility. This device is field programmable, and has multiple input/output capability for lot full, gate control, low ticket, and counting situations. The display on the ticket dispenser is two-line by 20-character backlit LCD. Voice announcement for easier operation, and manual, semi-automatic, and automatic ticket issuance are options that come as add-ons.

(b) **Barrier gates**: The barrier gate (Fig. 7) uses vehicle detector harness loops, which consists of five turns of Teflon wire wrapped in vinyl plastic tape. In addition, it has other safety features such as auto stop and back out (with timed automatic gate closing).

(c) **Fee computer**: The fee computer (Fig. 8) is connected to the barrier gate through the vehicle detector loops and an interface box. The fee computer manufactured by the company is 100% field programmable, including 10 different rate structures, and customized receipt headers. It has provisions for payment by cash, prepaid cards, discount tickets (for special events), and credit cards (optional). The entire fee is computed with one keystroke operation, and can print transactions on revenue, and other statistical and diagnostic reports through the built-in differential counters (for example, an indication that the parking lot is full).

(d) **Ticket reader/validator**: The ticket reader/validator (Fig. 9) provides for automatic reading/writing of ticket data with facility to print the validation data on the ticket. In addition, it encodes the payment time on a ticket.

(e) **Fee indicators**: The fee indicator (Fig. 10) is a large, easy-to-read, five-digit, LED display that can be used to indicate fee, change due, and current time.
3.1. Materials and methods

The overall goal of the case study was to determine if the company’s workforce was equipped to deal with technology change in the company, and how best to provide such equipment to the workforce. This case study would also serve as a demonstration of the link between technology, tasks, and training, and how to create knowledge for a portion of the theoretical framework presented in Section 2 of this paper. Discussions with the company engineers and executives revealed that the technology content of the manufacturing processes employed by the company in making the parking system subunits was very limited—manufacturing processes included simple sheet metal processing operations and some degree of assembly operations. The technology content of the product made by the company, and its associated systems, however, were expected to change significantly. Accordingly, the goals were to forecast technology changes in parking systems (considered as the
product as a whole), examine and analyze the product troubleshooting task for a specific future technology (technology at the prototype stage), and decide on a training method for the troubleshooting tasks based on common available training methods for such tasks.
3.2. Technology assessment

Based on the product and its subsystems, it was felt that significant technology changes could occur in three broad areas in the technology content of the parking systems: the revenue control subsystem, the count monitoring subsystem, and the access control subsystem. A panel of three senior technical marketing and engineering experts from the company were selected by the company’s Vice President of Manufacturing to participate in the study. The authors served as the moderator for the panel with the help of the Vice President of Manufacturing. It was felt that due to the potential sensitive nature of the information involved, use of any external panel experts should be avoided. None of the three panel experts knew the composition of the panel. This was to avoid the possibility of identifying a specific opinion with a particular expert. Anonymity of the panel experts also ensured that each idea was considered on its merit, regardless of whether the panel expert had a high or a low opinion of the originator of the idea.

The panel experts were expected to interact through answers to questionnaires. The initial round of questions sent to the panel experts was
broad and open-ended, and consisted of the following three questions: (1) what specific trends and technology changes do you foresee happening in the revenue control subsystem for parking gate systems? (2) what specific trends and technology changes do you foresee happening in the count monitoring subsystem for parking gate systems? (3) what specific trends and technology changes do you foresee happening in the access control subsystem for parking gate systems? A summary of the responses provided by the three panel experts to the three questions in the initial round is provided in Table 4.

It is clear from the summary responses of the experts that the experts were in agreement with one another about the broad technology changes they anticipated in parking system design.

Based on the technology assessment and the fact that ticket dispensing mechanisms are an important component of any future parking system, and based on extended discussions with the Vice President of Manufacturing at the company, it was decided that the study would further focus on the ticket dispenser and the ticket dispensing mechanisms. Ticket dispensing mechanisms have evolved from being a completely mechanical system, to being an ETP system with a single ticket feed system, to now being a system with dual ticket feeds and a Read, Write, Print, Vault system using electronic sensors in addition to belts and motors for ticket guidance and issuance.

3.3. Training experiment

As already briefly mentioned, the goal of the experiment was to compare the effectiveness of commonly available training strategies for troubleshooting and fault-finding tasks. Literature on training for troubleshooting and fault-finding (Anderson, 1982, 1985; Swezey et al., 1991) suggests that, in general, two different strategies can be used for such training: a strategy of teaching task-specific procedures (also known in the training literature as procedural knowledge) as opposed to one emphasizing general theory and principles (also known in the training literature as declarative knowledge). In particular, at least four different components of training content are considered important: theoretical knowledge of the functional interrelationships among equipment elements and the causal aspects of their operation; structural knowledge of the component parts of equipment; procedural knowledge of the specific steps involved in operating and/or maintaining the equipment.

Participants in this study consisted of four volunteer workers in the company (two males and two females). All participants were involved in maintenance or troubleshooting of one kind or another in the company. The ages of participants ranged from 40 to 52 years with the mean age 43 years. None of the participants had any prior detailed knowledge of the ticket dispenser products used in this research, and the mechanisms involved therein.

The product used in the experiment was ticket dispensers. With the help of the designers and quality control personnel involved in designing and manufacturing these ticket dispensers, a list of 10 important faults that could occur in the product, with the symptoms for such faults was generated. The list of faults, their symptoms (as would be seen by the individual trying to troubleshoot the fault), and the actions needed to generate these faults in the ticket dispenser are provided in Table 5.

The goal was to simulate the 10 faults in the prototype ticket dispenser unit and determine which instructional strategy worked better for troubleshooting each of the fault. The task for the worker after instruction was to identify each fault from the symptom simulated in the prototype.

Two workers participated in the “theoretical instruction group”, and two in the “procedural instruction group”. The training was delivered in a classroom lecture style. Both groups were shown the prototype and the different units such as the sensors, the motors, etc., inside the ticket dispenser as and when the instructions were carried out.

The material used for the theoretical instruction group consisted of handouts describing the theoretical knowledge of the functional interrelationships among equipment elements in the ticket dispenser, the causal aspects of their operation,
Table 4
Summary of technology assessment for parking systems

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Expert</th>
<th>Summary of response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue control</td>
<td>1</td>
<td>The goal of parking facility operators and owners is to increase profitability by: (a) reducing equipment costs; (b) reducing labor costs; (c) improving audit controls and reducing thefts; (d) offering easier and more flexible systems to users which will increase volume, market share, etc. The major trends are: (a) move toward automated (non-attended) equipment and systems; (b) the acceptance of various types of payment mediums for parking. The currently available technologies that allow industries to move this way are: (a) the ability to read/write tracks 1, 2, and 3 on magnetic strip readers; (b) the ability to locate, identify, and print license plate numbers of vehicles entering a facility to the tickets issued at the entrance (license plate recognition); (c) the ability to accept credit card, coins, bank notes, debit card, etc., for payment without the need of having a person present. The changes seen in the industry are: (a) the use of credit cards and coins for payment of parking fees at the exit lane equipment; (b) the integration of license plate recognition and inventory systems into long-term parking facilities. The future technology that may impact the parking industry: (a) the ability to communicate through radio frequency, proximity reader technology, or satellite communications to a central vehicle computer registered to the owner of the vehicle. This technology would allow us to identify and locate the registered owner of the vehicle, and debit the amount for parking directly from their account automatically.</td>
</tr>
<tr>
<td>Access control</td>
<td>2</td>
<td>Revenue products will all become PC (embedded PC) based to provide new levels of product flexibility and adaptability. New methods of payment will be used. RFID and smart card technologies will be incorporated to provide payment (debit) from AVI tags and by both disposable and intelligent smart cards. These will be accepted in in-vehicle parking meters, pay/display and pay by space systems, fee computers and automatic pay stations. All these needs may exist in one city, hospital or university. Different types of smart card formats and no agreement on an electronic purse format currently are slowing implementation.</td>
</tr>
<tr>
<td>Access control</td>
<td>3</td>
<td>The trends are grouped into the following four areas: (a) popularity of machine-readable systems such as punch-hole, bar code, and magnetic stripe can effectively reduce loss of revenue through theft or “shrinkage.” Cashiers are for the most part relieved of the decision-making process in the revenue transaction; (b) fully automatic pay on foot stations with the addition of multiple note dispensers for change, credit card payment options, and extensive reporting have helped the unit gain acceptance with parking consultants and end-users. This trend will only gain in popularity, as a cost-effective, labor saving revenue control system; (c) credit card in/credit card out payment system, where customers will be able to “dip” a credit card at the entrance and exit, and have a speedy option to exit cashiering with the facility management software being capable of invoicing the customer; (d) AVI or hands-free ticketless parking is going to come. Customers will have a device on their car such as a bar-code decal or a transponder that will identify them in a unique fashion to the facility management software. Customers will simply drive through the entrance and exit lanes and the system will “see” them and record time in/time out with some variables with respect to rate structures for different types of parkers such as early bird, daily, weekend, etc. Extensive accounts receivable reporting will enable invoicing of customer, debit card functions or more traditional pay.</td>
</tr>
<tr>
<td>Access control</td>
<td>2</td>
<td>RFID technology (AVI and proximity) are already used for contract parkers and toll roads. These will also soon be used for revenue in large facilities (such as airports) which will share the system being used on toll roads and bridges. The EZ pass system used in New York and New Jersey for bridge and tunnel tolls will be accepted at the Port Authority of New York and New Jersey Airports in the near future. Also, the state of New Jersey is considering using an intelligent smart card for the state photo drivers license (photo ID) which will contain personal history and credit card information. A portion could also be used as a debit card to pay for tolls. One could also recharge the amount on the card for the purpose.</td>
</tr>
</tbody>
</table>
| Access control   | 3      | AVI can provide contract parking as well as cash control. In each case, the patron will either pay up front or have a credit card “on file” with the main office through the facility management software. In this fashion the customer can either pay for the specified amount of time with cash, check or credit card. The more convenient way would be for the customer to have his credit card on file and to “hit” the card at a specified dollar level so that the customer does not have to go to main office to transact payment. Display readers (ability to show a short message) allow many different features for use...
and structural knowledge of the component parts of the ticket dispensers. In addition, a schematic of the ticket dispenser was also distributed to the group. The instruction lasted nearly 1 1/2 h. In addition, the two participants were allowed time for questions and clarifications they had about the training material.

The material used for the procedural instruction group consisted of a step-by-step troubleshooting and action checklist (presented in Table 6) prepared to troubleshoot the specific faults that were simulated in the experiment. In addition, the two participants in this group received the schematic used for explaining the location and the functioning of the different units in the ticket dispenser.

The experiment used a completely randomized design (10 faults × two subjects × two instructional strategies). The time taken by each subject to troubleshoot the fault and identify the fault or faulty component was monitored and used as a measure of performance after receiving instruction and training in a particular manner.

3.4. Results

The results of the experiment are shown in Table 7. A t-test performed for each of the faults indicated that there was no significant difference ($p \geq 0.1$) between the two instructional strategies on fault-finding performance. Since this field experiment had only a very small sample, the results are no surprise. Based on the sample that was available for this experiment, it was concluded that the instructional strategy did not have a significant effect on performance. Although sample sizes in this experiment were small, the case study demonstrates the effectiveness of the process for determining training requirements and developing suitable training protocols to satisfy those requirements.

4. Conclusions

A theoretical research framework is intended to conceptualize definitions, constructs, and research
variables involved in a problem, and suggest possible hypotheses for research. Research using the framework presented in this paper will be iterative in nature—development of a training plan (including the instructional contents in the plan, and the best method to deliver such instruction), followed by a determination of how effectively the plan transfers to as many industries as possible, followed by a refinement of the training plan to increase the effectiveness of transfer to any one industry or extend the transfer base by including more industries.

There are a number of issues in this iterative process that need to be addressed. Foremost among these are:

(a) cataloguing the specific product, process, and system technologies in current use, and that are anticipated in future (any technology in the prototype stage, for example), in the discrete product manufacturing industries that are participants in any work involving the framework;
(b) based on input from each industrial participant, and based on the framework elements for skill development, developing generic skill sets containing the instructions (the meta-knowledge, the rules, and skills needed to operate technology);
(c) experimentation (including all the traditional training variables from industrial psychology) with the developed skill set including determination of good training methods for imparting the generated common (to all industries) skill set;
(d) development of a measurement system for determining the effectiveness of the transfer to each industry participant, and thereby, the

Table 5
A list of faults, their symptoms, and actions needed to generate the faults in the ticket dispenser used in the research

<table>
<thead>
<tr>
<th>Fault no.</th>
<th>Fault Description</th>
<th>Symptom</th>
<th>Preparation needed to simulate fault</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bad sensor #11</td>
<td>“TAKE TICKET” message displayed and TICKET DISPENSER BEEPS. No ticket in the throat</td>
<td>Disconnect sensor #11 from PCB</td>
</tr>
<tr>
<td>2</td>
<td>Bad sensor #01</td>
<td>Cannot load tickets</td>
<td>Disconnect sensor #01 from PCB</td>
</tr>
<tr>
<td>3</td>
<td>Vaulted ticket tray is full. Press RESET button</td>
<td>“LANE CLOSED” message displayed</td>
<td>Retract 45 tickets prior to test</td>
</tr>
<tr>
<td>4</td>
<td>Print/magnetic head not secure</td>
<td>Ticket(s) cannot be read by fee computer/validator</td>
<td>Lift print/magnetic head section</td>
</tr>
<tr>
<td>5</td>
<td>Bad motor #3</td>
<td>Ticket does not advance when TICKET ISSUE button is pressed</td>
<td>Disconnect motor #3 from PCB</td>
</tr>
<tr>
<td>6</td>
<td>Bad solenoid (ticket guide)</td>
<td>Ticket jams when retracted (vaulted)</td>
<td>Disconnect solenoid</td>
</tr>
<tr>
<td>7</td>
<td>Bad sensor #13</td>
<td>“TICKET JAM” message displayed and vaults the ticket continuously</td>
<td>Disconnect sensor #13 from PCB</td>
</tr>
<tr>
<td>8</td>
<td>Magnetic encoding type set to “GPP” instead of “APS”</td>
<td>Ticket(s) cannot be read by fee computer/validator</td>
<td>Change MAG TYPE (ticket type = GPP)</td>
</tr>
<tr>
<td>9</td>
<td>Bad relay module</td>
<td>Gate vend fails</td>
<td>Disable relay for gate open</td>
</tr>
<tr>
<td>10</td>
<td>BAD TICKET ISSUE BUTTON</td>
<td>Will not issue ticket(s)</td>
<td>Disable ticket issue button</td>
</tr>
</tbody>
</table>
mobility that the training plan can provide a trainee;
(e) once a measure for mobility is established, one of the specific hypothesis that can be tested is:

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ticket jam</td>
<td>Inspect transport guide for physical obstruction—remove obstruction</td>
</tr>
<tr>
<td></td>
<td>Use diagnostic mode (SENSORS) and test applicable sensors (before and after the jam)—replace sensor</td>
</tr>
<tr>
<td></td>
<td>Use diagnostic mode (MOTORS) and test applicable motors (before and after jam)—replace or repair motor (motor circuit)</td>
</tr>
<tr>
<td></td>
<td>Inspect ticket and confirm dimensions, weight, transparency, moisture retention—replace ticket stock or light bulb</td>
</tr>
<tr>
<td>Ticket cannot be read at fee computer/validator</td>
<td>Inspect magnetic stripe for encoded data (use magnetic view spray)</td>
</tr>
<tr>
<td></td>
<td>If data exists, then:</td>
</tr>
<tr>
<td></td>
<td>Use diagnostic mode (TICKET) and insert ticket in READER mode to inspect encoded information—for APS Entry ticket data, check rate code, lot number, date and time, back out ticket; For CTP7 or GPP ticket data, change MAG TYPE in SET UP</td>
</tr>
<tr>
<td></td>
<td>If data does not exist, and information is printed on ticket:</td>
</tr>
<tr>
<td></td>
<td>Confirm magnetic head is seated properly, and correct position of magnetic head</td>
</tr>
<tr>
<td></td>
<td>Confirm Print/Mag head section is seated properly, and correct position of Print/Mag head section</td>
</tr>
<tr>
<td></td>
<td>Check Print/Mag head section circuit</td>
</tr>
<tr>
<td>“LANE CLOSED” message displayed</td>
<td>Check parameter setting</td>
</tr>
<tr>
<td></td>
<td>Use remote control (PROGRAM) and change setting if required</td>
</tr>
<tr>
<td></td>
<td>Check HOST COMPUTER status (if applicable) and change status if required</td>
</tr>
<tr>
<td></td>
<td>Check vault tickets counter: use remote control (PROGRAM)—if count is 50, press RESET switch by ticket tray</td>
</tr>
<tr>
<td>Gate does not Vend</td>
<td>Check parameter setting</td>
</tr>
<tr>
<td></td>
<td>Use remote control (PROGRAM) and change setting if required</td>
</tr>
<tr>
<td></td>
<td>Use diagnostic mode (RELAYS) and confirm OUTPUT</td>
</tr>
<tr>
<td></td>
<td>If there is no output, replace applicable relay</td>
</tr>
<tr>
<td></td>
<td>Check gate operation and repair gate as required</td>
</tr>
<tr>
<td></td>
<td>Check ticket dispenser to gate wiring and correct wiring as required</td>
</tr>
<tr>
<td>Cannot issue ticket (push button)</td>
<td>Check display for idle screen</td>
</tr>
<tr>
<td></td>
<td>If “LANE CLOSED” see “LANE CLOSED” symptom checklist</td>
</tr>
<tr>
<td></td>
<td>If “TICKET JAM” see “TICKET JAM” symptom checklist</td>
</tr>
<tr>
<td></td>
<td>If “OUT OF TICKETS” replace tickets</td>
</tr>
<tr>
<td></td>
<td>Check PUSH BUTTON operation and replace push button if needed</td>
</tr>
<tr>
<td>Ticket does not feed in dual ticket feeder or Read, Write, Print, Vault unit</td>
<td>Locate section where failure occurs</td>
</tr>
<tr>
<td></td>
<td>Use diagnostic mode (SENSORS) and test applicable sensors (before and after feed failure), and replace appropriate sensor, if needed</td>
</tr>
<tr>
<td></td>
<td>Use diagnostic mode (MOTORS) and test applicable motors (before and after feed failure), and replace or repair motor (motor circuit).</td>
</tr>
</tbody>
</table>

does the longitudinal training model (Fig. 2) presented as part of the framework result in greater mobility, or does the cross-training model (Fig. 3) result in greater mobility?
an important contribution of research with the framework will be integration of manufacturing engineering and cognitive engineering precepts—for instance, development of an effective training plan will provide deeper insight into how humans learn; this insight can ultimately be used in designing technology that will facilitate human operation, and not require any training for its use; the eventual goal will be the design and operation of human-centered manufacturing systems, that use the skills that humans inherently bring into an activity;

research using the framework can also contribute significantly to knowledge in the labor economics field, specifically, the concept of human capital (where training the human is considered an investment) and the enhancement of human capital;

another important offshoot of the results from this framework will be the integration of the skills and training knowledge base in the curriculum of schools and other training providers—training is a big budget activity in the USA, and the availability of an effective training plan that minimizes cost will result in a better utilization of available resources; and

the framework, in itself, is subject to revision and change—with the emergence of newer forms of work such as telecommuting to work, remote manipulation, etc., any framework for imparting skills and training should be flexible as well.

Acknowledgements

The authors thank the Center for International Manufacturing at UTEP for supporting part of this work.

References


