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Publication of this paper sponsored by Railway Systems Section.

Computer-Assisted Technical Training for Railcar Maintenance Supervision

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ABSTRACT

In order to upgrade its training program for line supervisors (foremen), the Car Maintenance Department of the New York City Transit Authority hired a consultant in 1981 to (a) conduct a comprehensive needs analysis, (b) develop training materials for those areas identified by the analysis, and (c) develop an implementation plan. The project designed, developed, and implemented a comprehensive curriculum of 15 technical background courses for line supervisors. All courses are conducted by using an individualized, self-paced, mastery-based training methodology. In addition to the courses, a complete training management system has been designed and implemented. This system permits the management of the individualized instruction program, with complete tracking and testing of each trainee, together with appropriate permanent record keeping. Reception has been extremely positive both as to the value of the content of the courses and to the computer-based delivery methodology. Most trainees comment that they enjoy the interaction with the computer and they feel comfortable with the individualized, mastery-based methodology.

The Car Maintenance Department (CMD) is one of the four departments comprising the New York City Transit Authority's rapid transit group. It functions in coordination with the other three departments (Maintenance of Way, Transportation, and Stations) to provide rail rapid transit service to the people of metropolitan New York. Its mission as a member of the rapid transit team is to plan, manage, and maintain an effective and efficient CMD in order to continually make available to the Transportation Department the required quantity of safe, reliable, clean, and suitable revenue and nonrevenue cars within available resources.

In real terms the CMD is charged with the maintenance of 6,147 revenue cars, of which it must provide an average of 4,937 each day to make up the trains that serve the riding public. The allocation of resources and all CMD activities are conditioned by the requirement to meet daily service. When resources are limited, as they currently are, such resources are, and of necessity must be, allocated primarily to day-to-day activities that contribute directly to meeting daily service. This defines the basic, overriding constraint on all CMD operations (training included).

Although the pressure of daily service is real and the shortage of financial and other resources within the CMD during the past several years has been acute, the Department has nevertheless striven to implement such long-range programs as it could to provide the operational support to day-to-day maintenance activities. Chief among these are the car overhaul programs, which entail scheduled car overhaul and special retrofit projects to increase the reliability and enhancement of the fleet. Scheduled maintenance activities, which had to be virtually suspended following the New York City fiscal crisis during the mid-1970s, are now being reestablished. Furthermore, the investment in training represented by the program to be described in this paper constitutes another long-term effort to rebuild the base of the CMD operational structure.

In a survey of its training needs, CMD management had concluded that an appropriate point at which to focus initial training upgrade efforts was line supervision. This group represented a target population of manageable size, whose role in overall CMD operations was regarded as especially important.

A request for proposal (RFP) was sent out in October 1980 to a list of selected, qualified consultants to carry out the following tasks:

1. Conduct a comprehensive needs analysis,
2. Develop materials to train line supervisors in the areas of need identified in the front-end analysis, and
3. Develop an implementation plan for carrying out the training program.

After an extensive selection process, a contract was awarded in January 1981 to Control Data Corporation, Professional Services Division. Work started in early 1981 and was completed in August 1983.

BACKGROUND

The needs analysis phase was completed during the first 5 months of project activity. It included a comprehensive study of the line supervisor's work environment, organizational roles, job tasks, technical background, and technical requirements of the job.

The needs analysis also dealt with the line supervisor's supervisory role and associated skills. Recommendations were made concerning training in this area as well as in the technical domain. However, in this paper only the implementation of the technical training program is discussed.

In this section and in the following two sections the findings of the needs analysis are summarized, and the specific training problems the final program was to address are described. General background information relative to the job requirements and assignment patterns of the line supervisor is given in this section.

The CMD operates 2 main repair shops for heavy car repair and overhaul, 11 inspection barns for scheduled car inspections and running repair, and 2 trouble barns for light running repairs. Altogether, CMD operations are dispersed over 15 sites, plus 1 more site that acts as headquarters for administration and management. The revenue rolling stock fleet consists of more than 6,000 cars, a number that represents about two-thirds of the U.S. fleet of heavy rail transit vehicles. The fleet runs about a quarter-billion car miles in the course of carrying about 1 billion passengers per year. To accomplish this "daily miracle", the CMD employs more than 6,400 employees, which include about 700 line supervisors.

The line supervisors divide their time between work on the floor with the hourly workers and various administrative tasks. The line supervisor's primary job responsibility is the direct supervision of hourly workers. Two out of three line supervisors are in assignments that involve direct supervision; the remaining work is in administrative support, training, material control, or quality control roles that, for the most part, do not involve supervision. However, because line supervisors change assignments relatively often, essentially all of them perform substantial supervisory functions during their time in title.

The technical component to the line supervisor's job is marked by great diversity. Unlike the hourly worker, who remains, except in rare cases, in a single specialized technical title, the line supervisor works in one title that can involve him in supervision of all of the hourly technical specialties and in other areas as well. Coming as he does from one of the hourly specialties, the line supervisor's technical background is typically not as broad as the range of his possible assignments.

On the other hand, the type of technical knowledge required by line supervisors in their role as first-line managers is not the same as that required for hourly workers. The hourly worker must possess detailed working knowledge of a restricted class of equipment. This knowledge is used to support the manual skills involved in repair and maintenance of the equipment, together with some fault isolation and troubleshooting activity.

In contrast, the line supervisor must possess a more general functional-relational knowledge of a broader range of equipment. This knowledge is used to support interpretive and diagnostic skills that are applied to the management of technical situations. As the first-line manager of technical situations, the line supervisor's prime responsibility is the administration of technical resources to see that the appropriate resources--be they hourly worker skills, materials, tools and gauges, technical documentation, or technical expertise--are made available and properly applied to the jobs in his area.

Analysis of line supervisors' backgrounds compared with their actual work assignments revealed that 29 percent of them are in assignments within their former hourly title area, 62 percent of them are in a technical area outside their former area, and 9 percent of them are in nontechnical assignments. Further examination of these data led to the conclusion that approximately 50 percent of line supervisors were assigned to areas for which they had not fully adequate backgrounds, based on their technical experience as hourly workers. Although the majority of current line supervisors have gained reasonable command of their assignment areas through on-the-job experience, this method of acquiring knowledge and skills is inefficient, slow, and costly in terms of mistakes and low performance during the learning period. Furthermore, this problem can be compounded if line supervisors tend to change assignments frequently. Analysis revealed that this was in fact the case.

The assignments held by the line supervisors were analyzed to determine the average length of an assignment. Based on the sample, the average assignment length was found to be 20 months. In a total population of about 700 line supervisors, an average assignment length of 20 months implies that an average of 35 individuals change assignments each month within the CMD, not including initial assignment of newly made line supervisors. This represents significant movement from assignment to assignment, especially in view of the differing technical requirements of the various assignments.

Thus these two factors--the match of current assignment to technical background, and the rate and pattern of assignment change--are critical for the design of a training program for line supervisors. They bear on the questions of how much training demand there is, when in a line supervisor's time in title such training should be delivered, and what form the delivery should take.

TECHNICAL TRAINING NEEDS

The line supervisor needs a technical background in order to do his job. As a manager of technical resources and situations, it is important that the line supervisor have command of a certain level of technical knowledge.

A task analysis was conducted to ascertain the detailed nature of the line supervisor's role. This analysis revealed that his skills and knowledge need in the technical domain is primarily in two general categories: information management and resource management.

As an information manager, the line supervisor must be able to specify work and resources for a job by using information from hourly workers, standard operating procedures (SOPs), standard inspection procedures (SIPs), or other sources; he must be able to interpret information in technical documentation sources such as manuals, flow diagrams, car equipment information system computer reports, or manual trouble reports; he must be able to communicate technical information to hourly workers, to higher supervision, and to technical experts who might be called in; he must be able to identify technical information relevant to a given situation; and he must be able to assemble and report information on area production, materials use, and labor hours expended.

In addition, as a resource manager the line supervisor must use technical background to perform the evaluative and diagnostic functions necessary to make a correct resource-allocation decision: he must be able to evaluate a job and specify the work to be done, he must be able to evaluate finished work for quality of workmanship, and he must be able to diagnose equipment and direct hourly workers to the system, subsystem, or component involved. All of these capabilities serve to permit him to make decisions on the management of technical resources: What is the problem for which resources may be required? Who, what, how much, and how many of the resources at hand will be needed for a job? What are the time and scheduling constraints? When is a job to be considered done, to what standards? The technical training need that emerged from the task analysis could be briefly stated as follows: to give the line supervisor the capability to handle and direct the flow of technical information and resources, permitting him to make cost-effective inspection, repair, and overhaul decisions.

As it is evidenced by the description of the line supervisor's role just given, the most prominent specific skill called for in the resource manager function is that of car equipment troubleshooting.

TRAINING DELIVERY

When line supervisors change assignments, as they often do, they move among areas with different technical background requirements. Given the prevailing pattern of job change, it would not have been practical to give technical training to the newly made line supervisor in every area of potential assignment. Instead, technical background training should take place immediately before, or shortly after, the line supervisor takes up an assignment, and it should be specific to that assignment. In this way the training is targeted to just those who need it, when they need it.

To make this scheme effective, the technical courses must be kept at the general background level--the level appropriate to a line supervisor--and they must be kept relatively short. With line supervisors changing assignments on the average of every 20 months, devoting more than 1 week to preparation for a new assignment would impose large burdens on the training system, and would imply an unacceptably large amount of time off the job to take training for this population as a whole. It was therefore recommended that courses be of 3 to 4 days maximum duration.

To bring line supervisors in when they need training, and to give to them just the training they need, has implications for how the training is delivered; namely, the training system would have to be significantly more individualized than it was. Constraining the timing of training until lecture-style classes of 20 to 30 trainees could be accumulated, as is the usual practice, would render the scheme previously described inoperable.

More individualization imposes a need for different kinds of training materials than were in use. With movement away from pure lecture delivery, materials would have to be systematically organized to permit trainee use in a mode independent of the presence, or absence, of an instructor. The role of the instructor would also change. As a manager and facilitator of learning instead of straight lecturer, most instructors will find their work more effective, especially if supported by well-organized training materials.

If higher levels of individualization appear to impose increased demands on the training program (and indeed they do in the area of training administration), there are benefits that more than compensate. The principal benefit is dramatically increased trainee involvement in his own training, with corresponding increases in learning retention. Another benefit is the possibility to assess trainee learning and remediate it on an individualized basis, a step that substantially improves overall learning. Also compensating for the increased administrative complexity of more individualized training is the fact that training only those who need training, giving the trainee only the training he needs, and assessing and remediating his mastery of the training cuts down significantly on the waste and inefficiency inherent in lecture-type training where some out of each class do not need the training, others are not prepared for it, and still others do not absorb it. The increase in training efficiency is significant and evident when individualization is introduced. For this reason, the move from lecture-based training to individualized delivery was the key recommendation of the needs analysis.

TRAINING PROGRAM STRUCTURE

To actually implement the recommendation of the needs analysis that the training be individualized, special program design constraints had to be taken into account. The solution to the program design problems posed by individualization was a comprehensive computer-based training system in which learning objectives, supporting materials in various media, assessment instruments, learning activities, and all associated records are carefully coordinated and maintained for each individual trainee and for all groups of trainees.

The system provides a strong measure of control to the CMD in managing the training of a diverse trainee population in a broad range of technical areas. It permits the training administrators to accurately and continuously assess both the progress of trainees and the effectiveness of the training program.

The training solution proposed and built to deliver the capabilities just described was based on the PLATO learning management (PLM) system. This computer-based system was specifically developed to handle training applications where multiple users, wide content range, and diverse materials make administration of the learning process a complex task. The key features of the individualized learning management system are as follows.

1. Individualized instruction is self-paced and accommodates trainees with varied backgrounds and entry skills.
2. An assessment system with individualized learning prescriptions and remedial branching is a built-in part of the system.
3. Training is managed and delivered in a variety of instructional media, with each one chosen for maximum effectiveness.
4. Each trainee can be routed through a sequence of courses that has been specifically tailored to his particular needs.
5. Mastery of objectives is assured through automatic monitoring of test results and generation of instructional prescriptions that direct the trainee to specific learning resources for remediation.

6. The system is modular in structure, which permits ease of modification and update.

7. Management of training is supported through automatic record keeping and collection of data for use in evaluating the training materials.

8. Flexibility in course and module selection, together with criterion options, allows for extension of the materials to other maintenance workers.

9. Access to the system is virtually round-the-clock and available at remote sites, thus permitting scheduling flexibility.

10. Efficiencies derived from application of this approach can reduce training times by as much as 30 to 60 percent. At the same time, the mastery-based structure maintains performance at high levels.

The training program was designed around a flexible hierarchical structure. The levels in this structure were curriculum, course, module, and instructional unit. These structural elements, their mutual relationships and interconnections, the logical routings between them, and associated text and data storage allocations were preprogrammed into the PLM software utility that was used as the basis for creation of the training program.

The PLM structure, starting with the lowest level--the instructional unit--and proceeding to the highest level--the curriculum--is as follows (the description of PLM capabilities given here represents a partial summary of principal features intended only to give a general idea of how the CMD training needs were met).

1. Instructional unit: An instructional unit (IU) consists of an instructional objective, test questions for assessing trainee mastery of the objective, and references to learning resources that teach the objective. The criterion for mastery of an IU is set as a percentage correct out of the total number of questions presented to the trainee as a test of IU mastery. A question pool is provided so that repeat testing on an objective can be carried out without duplication of test questions.

2. Module: A module is a group of IUs related to a single topic or concept. Tests are delivered to the trainee at the module level. A module test consists of sets of questions covering each of the IUs in the module. The criterion for mastery of a module is set as a percentage of IUs mastered out of the total number of IUs in the module.

The module test is delivered initially as a pretest. If the trainee masters all of the IUs in the module on the pretest, no further instruction on the module is required.

Learning resources are prescribed to the trainee at the module level. Based on which IUs are not mastered during the first module test attempt (pretest), specific learning resources are prescribed to the trainee. Completion of the learning activities specified in them usually enables the trainee to master the IUs not mastered on the first test attempt when the module test is taken a second time. A maximum number of allowed module test attempts is set. Trainees must consult with their instructor if module mastery is not achieved within the allowed number of attempts.

3. Course: A course is a group of modules related to a single subject area. The modules in a course can be sequenced so that mastery of some modules is prerequisite to presentation of others. Mastery of a course is accomplished by achieving mastery of a preset number of modules in that course.

4. Curriculum: A curriculum is a set of courses. Generally, the set consists of all the courses comprising a given program of training. Different curricula may be set up for different groups of trainees. In this sense, the CMD training program is in reality many programs, each specialized to meet the needs of particular groups of line supervisors. Mastery of a curriculum is based on mastery of its related courses.

By using this system trainees are automatically routed by PLM through instructional units, modules, courses, and curricula. Tests for mastery of IUs and modules are delivered directly on the PLATO screen (they can also be printed out and administered by paper and pencil). All records of trainee performance are stored by the system and organized for display either per trainee or per predefined group of trainees. Instructors provide access to learning resources, are themselves learning resources, and function generally as managers of the training activities.

Through the use of the PLM system a desirable level of individualization of instruction can be achieved without creating unmanageable administrative burdens. In fact, training administration is more systematic, and, as a consequence, so is the training.

The PLM system also permits substantial efficiencies. With material systematically structured in modules, the content of which can be pretested, trainees already possessing sufficient knowledge of the subject matter can test out of these topics, receive targeted learning resource prescriptions for what they do not know, concentrate on this material, and thereby complete training in a shorter time with less use of training center resources.

The PLM structure has substantial flexibility: IUs can be readily grouped, regrouped, and assigned to various modules; modules can be similarly clustered in numerous ways to make up different courses; and finally, courses can be assembled to form a variety of curricula. With the basic building blocks (IUs, modules, and courses) resident in computer storage, these operations are accomplished quickly. This flexibility is used in the CMD training program to construct training curricula that are customized to specific subgroups within the target population, and even, if the situation warrants, to individual trainees.

LEARNING RESOURCES

Although all of the testing and trainee activities are managed directly by the PLM, the learning resources can take a variety of forms. For the proposed program, the bulk of the learning resources are in print form or PLATO computer-assisted instruction (CAI) activities. Two major reasons led to the selection of PLATO as the primary delivery medium for the nonprint material.

1. The PLATO delivery technology is already available, as it is the basis of the PLM system that will provide the learning management for the program.

2. PLATO is an effective medium in which to deliver equipment troubleshooting material. Its interactive capabilities will permit this material to be taught with maximum effectiveness. Because troubleshooting comprises a key part of many of the technical courses, PLATO was the medium of choice for most of the nonprint delivery.

The PLATO CAI courses focus largely on car equipment troubleshooting. In these learning activities a trainee applies the newly acquired general technical knowledge to actual troubleshooting situations simulated on the computer. The trainee is presented with an equipment problem and must, through correct diagnostic methods, deduce the underlying cause. The situations are custom designed to include those problems that are most frequently encountered and most critical on the job.

The print materials used in the program fall into two categories: existing CMD technical documentation and specially created training manuals. Color-coded training manuals have been prepared in each of the principal technical areas to be covered. Each manual presents general equipment function and theory of operation. A special section on contract variations is included that describes how the particular equipment changes for one car contract to the next. Each manual also contains a section on troubleshooting and a glossary of terms. All manuals were developed following the XYZYX guidelines, which represent the new CMD standards for the preparation of technical documents.

A third type of learning resource, the equipment mock-up, plays an important role in the training design. Through this medium the line supervisor gains direct experience with the main systems and assemblies. The mock-ups are actual, working versions of car equipment that are installed on racks to permit full viewing of the mechanism.

An actual subway car, which is parked in the training center automobile parking lot, is also available as a learning resource. This railcar can be used to develop hands-on experience with typical car equipment.

The fifteen technical background courses that constitute the line supervisor training program as developed to date are given in Table 1.

TABLE 1 Technical Background Courses

No.	Course	Description
1	Electric up	Nomenclature, function, and maintenance
2	Electric up	Troubleshooting methods
3	Electric down	Nomenclature, function, and maintenance
4	Electric down	Troubleshooting methods
5	Electronics	Nomenclature, function, and maintenance
6	Electronics	Troubleshooting methods
7	Doors	Nomenclature, function, and maintenance
8	Doors	Troubleshooting methods
9	Brakes	Nomenclature, function, and maintenance
10	Brakes	Troubleshooting methods
11	Climate control	Nomenclature, function, and maintenance
12	Climate control	Troubleshooting methods
13	Trucks	Nomenclature, function, and maintenance
14	Car body	Nomenclature, function, and maintenance
15	Road car inspection	Repair and movement of stalled and disabled trains

PROGRAM IMPLEMENTATION

To administer and coordinate the project, a steering committee was formed with representatives from the Office of the Vice President for Rapid Transit, Management Development, Car Maintenance, and the line supervisors' union. In addition, subcommittees were established to handle day-to-day activities such as technical information gathering and dissemination of project-related information. A special subcommittee was set up to introduce and advertise this new training program to assure a favorable climate, especially among field personnel.

The program of 15 courses, delivered with the methodology previously outlined, has been fully implemented. Currently, instruction is delivered at two learning center sites. The learning centers are now equipped with a total of 25 computer terminals housed in carrels. Space for an instructor is also provided. Most instruction is now being given during the regular 8:00 a.m. to 4:00 p.m. weekday shift. However, the program has been available during other shifts, and eventually round-the-clock availability is envisioned.

Instructors receive 2 to 3 days special training in the use of the PLM system. They function as a source of expertise on content questions as well as serving as the administrators of the learning system.

The PLM system automatically collects and stores data on each trainee. If a trainee should for any reason have to interrupt his work in a given course, PLM keeps track of where the trainee stopped and brings him back to this point when he resumes. Individual trainee records are avialable on-line as are cumulative statistics on each course.

A questionnaire is attached to the end of each curriculum to get student feedback. It is presented on-line under PLM management, and the statistics likewise are gathered and displayed.

Also available on-line is a note-sending and reply utility that permits a trainee (or other person using the material) to write a comment or question. The note is automatically tagged as to the place in the instructional material at which it was written and filed for use by course instructors and for design and evaluation purposes.

These features of the computer-managed instruction system play a central role not only in program administration but in program evaluation as well. Use of this system has given the CMD the means to monitor program implementation at every level of detail, from individual trainee responses to a particular test question to global statistics on performance of groups of trainees in a given subject area.

RESULTS TO DATE

Two courses (doors--nomenclatures, function, and maintenance, and doors--troubleshooting) have been operational for several months. Reception has been positive both as to the value of the content of the courses and the computer-based delivery methodology.

Only a few cases have been encountered where a trainee was frustrated when using the PLATO terminal. Most trainees commented that they enjoyed the interaction with the computer and were comfortable with the individualized, mastery-based methodology. Indeed, the familiarity with computers gained by the trainee in the course of instruction represents by itself a hidden benefit to both the individual and to the Transit Authority.

With the completion of the current project, the CMD is looking toward several system enhancements. Perhaps most important will be the eventual extension of the system to permit access at the field job site. This is being accomplished by locating terminals in the various barns and shops. Concommitant with this change will come reliance on delivery through microcomputers using flexible disks instead of through terminals linked to a mainframe computer as is now the case.

A second step for the CMD will be the establishment of an in-house courseware development capability. Such a step is now made possible by the newly available programmerless courseware authoring systems. These will permit the CMD to carry forward plans for expansion of computer-based training to other target populations, especially hourly workers.

Finally, the computer-based training system has opened up new options for the use of related advanced instructional technology. For example, under current consideration is a random access slide and audio unit that is attachable to the existing terminals. Such a device offers the benefits of full color, high-detail slides for complex graphics, together with the enhanced communication achievable through the use of an audio portion.

OTHER APPLICATIONS

The instructional methodology described in the previous sections has general applicability. Indeed, individualized, self-paced, mastery-based instruction has been used in a variety of contexts. These include elementary and secondary schools, colleges, commercial and industrial training, and military training. Studies have indicated that, when correctly implemented, the method usually has substantial advantages over more conventional techniques.

Two instructional applications of computers are described in this paper. One is the computer management of instruction (CMI). Some form of CMI is almost mandatory if individualized instruction in a variety of learning media is to be delivered effectively to a large, heterogeneous target population. Fortunately, with the explosive increase in the use of computers for instruction, many vendors now offer CMI software systems to run on a wide range of hardware.

The second instructional application of computers addressed here is CAI. Once a commitment to individualization and CMI is made, the capability to deliver CAI is also present because the same computer hardware can be used for both applications. Because maximum hardware use is generally a desirable goal, it usually makes sense to develop CAI as one of the learning resources to be managed under the CMI system. Here again the widespread use of computers in training has lead the marketplace to provide many options for those wishing to use CAI material (courseware).

First, software vendors are offering an ever-widening selection of off-the-shelf courseware on subjects ranging from basic English and mathematics to electronics, mechanisms, and computer technology. More will be on the way as major publishers enter the market. Some of the off-the-shelf material has direct application to training situations.

The second option for acquiring CAI software is to develop it, or have it developed, as a custom program. This is often desirable for training applications because they typically involve detailed information on equipment, procedures, and other organization-specific content. A number of vendors provide CAI software development services, and most custom courseware currently comes from this source. But the trend today is toward the creation of in-house courseware development capabilities.

This trend has been accelerated in the past 4 years by the development of programmerless CAI authoring systems. As the name implies, these systems permit the creation of courseware without the need to actually write a computer program. The availability of authoring systems permits organizations that may lack access to programming experts the capability to develop CAI materials. Currently, it is clear that most courseware will be created with authoring systems rather than through direct programming. The combination of authoring systems and in-house capabilities will serve to dramatically decrease the cost of custom CAI courseware in the years to come.

Publication of this paper sponsored by Railway Systems Section.