a firm basis for selecting navigational hardware and determining training requirements. Until now, ship controllability and maneuvering margins have been based on experience, intuition, and rules of thumb. CAORF plans to develop indexes of controllability for safely navigating ships in confined areas. The ultimate goal is to model human performance with sufficient accuracy to predict how a ship design will perform in a specific waterway for a range of pilot and helmsman capability.

CAORF studies of bridge design will focus on layouts of equipment, the nature and amount of information to be presented, types of displays and controls, and the relations of such equipment to the functions of the watch.

The long-range aim in analysis of harbors and restricted waterways is to produce design information for port and harbor designers and data on which safe and productive procedures for waterway operations can be based. All aspects of the effects of local environment on ships' pilots will be considered, from manmade navigation aids to how pilots use the cues available in land features.

A primary objective of training and licensing research is to determine how simulators can and should be used in training watch officers. The plan is to suggest what level of simulators will suffice for any area of training in which costs and benefits can be justified and to contribute to the specification of such simulators.

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Locomotive Engineer Training: State of the Art

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A training program developed by the Santa Fe Railway to train individuals for the position of locomotive engineer on today's railroads is described. The program uses the traditional method of the fireman-engineer relationship in conjunction with classroom instruction and locomotive and train simulation. Its ultimate objective is to produce people who have the best possible qualifications to operate locomotives and handle trains safely and efficiently. The Santa Fe Railway feels that standardization of instruction is the key to reaching this goal and that centralized training and the use of simulation have proved to be the best way to achieve standardization.

The history of railroading in North America has been exciting, romantic, violent, pioneering, and important. Over the past 100 years, railroads have criss-crossed the country, opened it to civilization, and served it at war and in peace.

Even 100 years ago, the railroads were a growing dynamic force, always looking for new and better ways to do things. They searched for and came up with efficient new designs in rolling stock and developed highly flexible piggy-back loading, powerful new locomotives, and coal train service to meet modern demands. Throughout this period, however, the training of those responsible for operating the locomotive fleet on the railroads of North America has remained essentially the same.

Traditionally, a fireman-engineer relationship was the basis for engineer training. The system grew out of need, and the relationship and the system seemed logical because no one had developed a better way to train locomotive engineers. Firemen rode with the engineer, performing various duties under the engineer's direction for a four-year incremental period, observing, assisting, occasionally participating, hopefully retaining what they could, and being periodically tested under actual operational conditions. Finally, at the end of the period, firemen were given a final examination that, if passed successfully, qualified them as locomotive engineers.

The problem with this method of training was that the training was only as good as the supervising engineer. Because each engineer taught the job as he understood it, many trainees unknowingly picked up bad habits. This four-year program of learning by osmosis remained virtually unchanged until the present decade.

In the late 1960s, railroads were faced with a predicament. With an ever-increasing influx of business and a growing retirement rate among locomotive engineers, they found themselves facing the problem of getting enough qualified people to operate locomotives in order to move millions of tons of freight to its destination. As a result, various types of training programs were instituted. Each railroad had its own version. Some stayed with the traditional fireman-engineer method whereas others used the same method but added classroom instruction. A few used both methods and incorporated the use of locomotive and train simulation.

In 1968, the Santa Fe Railway initiated the purchase of a locomotive and train simulator from the Link Division of the Singer Company. Sophisticated training and simulation equipment was, by now, an accepted way of life in aviation. But what about the job of a locomotive engineer? Was it possible to teach people the basics of operating a modern locomotive with a long string of loaded cars behind them? Was it possible to train them without making frequent expensive trial runs? The management of the Santa Fe Railway answered yes to these questions at that time, and the answer remains the same today.

The Santa Fe Railway took possession of the locomotive simulator from Link in 1969. A locomotive engineer training program was formulated, and in 1970 the first formal training class was held for the purpose of promotion to locomotive engineer. This paper provides a basic description of the training program as it is today on the Santa Fe Railway.

LOCOMOTIVE ENGINEER TRAINING PROGRAM

The Santa Fe Railway's locomotive engineer training program lasts 25 weeks and is divided into three phases. The first phase is 18 weeks of on-the-job training during which the fireman-engineer training method is used. A supervisor designates specific job assignments and/or locomotive engineers in each trainee's home territory that trainees are required to work with during this period for the purpose of familiarizing themselves with the territory they will be required to work in, the duties of a locomotive engineer, train handling, rules of operation, and operation of the equipment. In addition to the required books and manuals on the craft, trainees are issued a study guide that contains all the questions on which they will be examined during the second phase of the training program. A vast amount of knowledge and practical experience can be gained during this phase of training but, again, the trainee may be exposed to only one method or possibly to several different methods of operation and may be confused or undecided as to the correct method.

The second phase of the training program consists of six weeks of classroom instruction that includes locomotive and train simulation. Each trainee is required to attend classes eight hours a day, five days a week, at the Locomotive Simulator Training Center in Topeka, Kansas. Transportation, lodging, and per diem allowance, in addition to salary, are furnished each trainee to eliminate any financial burden during this period.

The training center consists of one large permanent classroom and three completely self-contained converted passenger-type railway cars that make it possible to move the center to any point on the railroad. The permanent classroom houses the majority of the air-brake, train-handling, and mechanical instruction training aids. For air brake and train handling, complete locomotive remote-control equipment (RCE), freight-car brake equipment, and air-brake demonstrators are used.

There are two locomotive air-brake demonstrators in the classroom: One is equipped with 26-L brake schedule RCE equipment and controls and all the safety devices that are found on locomotives; the other is equipped with 24-RL brake schedule equipment. These locomotive air-brake demonstrators may, if desired, be hooked up to four freight-car air-brake demonstrators, each of which is equipped with AB, ABD, ABDW, and Z1AW control valves. By the use of volume reservoirs, each of which represents 25 car lengths in volume [approximately 377 m (1250 ft)], a total of 1515 m (5000 ft) of brake pipe can be simulated. The freight-car brake modules can be cut in at 25-car intervals to represent a train that has as many as 100 cars. This equipment has been tuned for the proper amount of transmission, application, release, and exhaust timing. RCE air-brake functions can also be demonstrated by use of this equipment.

In addition to the demonstrators, air-brake and mechanical components have been cut away to allow an internal view of the working parts and thus enable a better understanding of the equipment.

The trainee's air-brake knowledge is enhanced by extensive instruction in train handling on all types of terrain—from level to undulating to mountain territory that has as much as 4 percent grade conditions—and with trains that handle as little as 454 t (500 tons) and as much as 12 700 t (14 000 tons) or more.

The mechanical instruction is not designed to make trainees qualified electricians or machinists but to make them familiar with and enable them to understand the many classes of power with which they will be required to work. By using an extensive mechanical slide presentation and visual aids, trainees learn to trouble-shoot mechanical and electrical difficulties on every diesel locomotive currently in operation on the Santa Fe Railway. They also learn to inspect and recognize problems that they cannot correct but that they must report to the proper mechanical personnel. Training in this category results in more efficient use of the equipment and saves many hours of delay in train movement.

Uniform understanding of operating rules throughout the system is of major importance, and centralized training has brought this task into the realm of reality. Operating rules—and especially rules that affect train movement—are given a single interpretation, and practical applications are used to clarify any rule that is in question and thus eliminate any possible misunderstanding.

Two small classrooms are housed in one of the three railway cars: One is used for operating rules, and the other, which is equipped with a 26-L brake schedule air-brake demonstrator and air and mechanical visual aids, is used for air-brake, train-handling, and mechanical classes. Because of class and simulator scheduling, all classrooms may be in use at the same time. Administrative and instructors' offices are housed in a converted business car that also has a small shop and file room. The third railway car houses the nation's first locomotive and train simulator.

The third phase of the training program is the "road trip examination" week—the final week of the 25-week training program. Trainees who have successfully completed and passed all required examinations return to their home territory and, under the scrutiny of a qualified supervisor, operate actual trains to demonstrate their knowledge of the rules of operation and their proficiency with mechanical (diesel electric locomotive) and air-brake equipment and train handling. If trainees prove their skills in these categories, the supervisor designates and qualifies them as locomotive engineers.

Trainees who are not able to prove the skills and knowledge that are required are given a second opportunity to complete the requirements within not less than 30 and not more than 90 days. If the requirements are not completed, the trainee's employment in engine service is terminated. Adherence to definite standards for the qualification and promotion of people to the position of locomotive engineer ensures that these positions are filled by people who are capable of performing the required duties.

LOCOMOTIVE AND TRAIN SIMULATOR

The Santa Fe Railway's locomotive and train simulator comprises five major subsystems, which are described below.

Cab and Instructor's Station

The simulator cab is divided into two basic areas. The trainee's side is an exact duplicate of the interior of an SD-45 General Motors diesel electric locomotive, including throttle, gauges, air brakes, and all functional controls. All positions of the 26-C and SA-26 self-lapping air-brake valves initiate the corresponding response from the air-brake system. The control stand contains interface equipment that activates the gauges and lamps; the response to power and braking commands is implemented through this interface.

The instructor's console is located toward the rear of the cab area in a position from which the instructor is able to observe the trainee. The instructor is able to insert a multitude of training problems into the system,

including locomotive malfunctions and varying train configurations, braking, and signals. Situations that require emergency procedures that could never be practiced during an actual run without risk to life and danger to expensive equipment can be simulated. The trainee is able to gain experience in weeks that would normally take years to obtain on the job.

Data Processing System

A Honeywell H-316 digital computer, with a duplicate backup in case of failure, controls the simulator system. With related interface, it ties together instructor and trainee functions, programmed information, and visual film cues. The output of the computer provides the trainee with factual, real-time, meter, and gauge indications; precise motion cues; and the appropriate sound and visual presentation. Associated with the computer complex are such input-output devices as a teletypewriter that allows the flexibility to vary the criteria of the training plan, configuration control, diagnostic programs, computer readout operations, and performance parameters.

Visual System

The visual system makes it possible for a trainee to get a motion-picture view of what an engineer would see from the window of a locomotive during an actual run. A collimating and ocular lens mounted ahead of the front window provides realistic image depth; that is, viewers must refocus their eyes as they would under actual conditions when looking at objects that vary in distance.

Environmental realism is maintained by this "down-the-track" visual system. Motion pictures produced on the Santa Fe Railway's own lines are projected. The speed of the projector, which is under the control of the computer, responds instantly to speed changes initiated by either the instructor or the trainee. The projector is a completely synchronized, computer-controlled mechanism that is capable of producing a flickerless, variable-speed motion-picture image; it is constructed so as to continuously provide variable-speed control, automatic reverse, manual advance, and automatic or manual rewind.

The system was designed for 16-mm film for maximum economy of operation and replacement. Design refinements that produce high-resolution depth and brilliance in the projected image have been made in the projection and optical system.

A vital requirement in training a locomotive engineer is a realistic and controllable signal system. Signals must appear as they do at dusk or in full daylight. The signal must also enlarge as it does under actual conditions as the train approaches and passes it. Two additional projectors, equipped with (900-W) xenon lamps, are used for the purpose of directing color aspects into block signal stanchions as they are displayed along the right-of-way and emerge in the forward field of view. Each projector casts a concentrated beam of light on the surface of the rear-vision screen with an intensity, definition, and behavior that are similar to the pattern of a laser beam. The light travels through a series of zoom lenses that change the spot diameter and is reflected off moveable mirrors that are controlled by servomotors to change the beam's position on the screen and thus enable it to track the signal stanchion throughout its entire visual progress. Colors are changed by displacement of red, yellow, green, and white filters mechanically introduced into the path of the light beam; the color selection is determined by the instructor or by automatic sequence.

A track-and-ballast simulator, not unlike a treadmill in design, is just below the cab's right window. The movement is synchronized with locomotive speeds up to 8 km/h (5 mph). This is an important visual aid for engineers when they start a train.

Visual cues, like sound cues and motion cues, are important to the total environmental concept generated in the simulator. These cues are part of the conditioning involved in training. For example, in the case of the track-and-ballast simulator, an engineer is able to judge the gradual starting speed of a locomotive against the spacing of the track ties as the locomotive begins to move. Too rapid acceleration of a long train from a dead stop would remove all coupler slack too quickly (equal to considerable track distance) and have damaging whiplash and pull-apart effects. Conversely, improper braking would have a jarring, telescoping effect on the cars. Other simulated environmental cues, such as the clicking of rail joints and cab sway, are equally important in the critical judgments made by the engineer.

Cathode-ray-tube data screens have been incorporated to display any function in the air brake and train dynamics system. One is located at the instructor's console and one on top of the locomotive control stand. The track gradient, expressed as a percentage, is exhibited continuously as the profile progresses from the locomotive to the rear car. The tractive effort of the locomotive, the draft gear stresses at coupler positions throughout the train, the various changes in air-brake pressures throughout the system, and the time-rate-of-change values in force displacements are continuously indicated. Rolling resistances, adhesion factors, and many other forces imperceptible to the engineer are available for continuous observation.

Motion System

A realistic hydraulic motion system provides lateral, longitudinal, and roll motion cues. The system simulates acceleration, deceleration, slack action, track superelevation, bunching, side motion of turnouts, and rough track swaying. The hydraulic-actuated motion system is actually an integral component of the simulator suspension mechanism. Five hydraulic cylinders are situated within the system so that their separate or combined functions will displace the cab as the appropriate dynamics of motion force are induced. The motion can move the cab in three directions: forward and backward by as much as 15 cm (6 in) at 2 g in force, left and right by as much as 7.6 cm (3 in) at 0.5 g in force, and roll by as much as 20.5 cm (8 in) from the center in either direction. Cab vibration is also attuned to the dynamics of the simulated locomotive.

Sound System

To create a realistic environment, related cab sounds are reproduced stereophonically. The vibration and sound of diesel engines, track noise, and passing trains and other expected sounds are present, and air sounds within the cab area are faithfully reproduced in real-time sound and duration through speaker units positioned in the cab and situated so that they will authentically reflect the identity and direction of sound origins.

Subsystems

All subsystems of the simulator are operated and synchronized by the high-speed digital computer that processes the appropriate data to determine simulated locomotive characteristics, track conditions, train loads, and track profile.

Usefulness of the Simulator

The simulator has undergone many modifications, particularly in the visual and computer program systems, in a continuous program of upgrading to make all systems conform to current, real-world track-train dynamics.

A singular advantage of the simulator is that trainees enter it fully aware of the fact that they are in a simulator and that their immediate responsibility is to learn to function as an engineer and nothing else. Their concentration is not inhibited by the fear of error or distracted by extraneous conversation, noise, or activities as it might be in a real locomotive cab. This sense of security enables the trainees to devote full concentration and effort to the task before them—that of operating a locomotive over territory with which they may or may not be familiar.

The capability to repeat particular training sequences and to introduce malfunctions or emergency procedures enables trainees to develop consistent, error-free responses. These emergency situations, which can be repeatedly introduced and experienced, could not otherwise be experienced under normal operation without causing problems for personnel, equipment, and cargo.

CHANGES IN THE SIMULATOR AND TRAINING PROGRAM

The years 1968, 1969, and early 1970 were years of change in the simulator and the training program. Since that time, many improvements have been made. The visual system was improved by use of a better-quality rear-image screen of less thickness and higher resolution than the original. This allows more light to penetrate through and results in greater definition and brilliance of color. This system was also enhanced by improved film quality and processing techniques. The latest change in this area is filming from the engineer's station on an actual locomotive instead of an especially adapted film car. This allows the front portion of the locomotive within camera-lens view to be filmed so that the trainee sees what normally would be seen from an actual locomotive. All filming is produced, photographed, and edited by the Sante Fe Railway. The only outside aid used in this category is 16-mm camera rental and film processing.

The addition of the data screen at the instructor's console and later above the locomotive control stand on the simulator allows the instructor and the trainee to have a complete read-out of the functions of the air-brake system and track-train dynamics on the entire simulated train.

The original computer program has been modified in several areas. The most recent change has been to the air-brake-function program. Since a trainee can see on the data screen the changes that result from various brake applications and releases and can see and feel these same results in the dynamics of the simulator, it was necessary to give a factual real-time read-out display of train interaction.

Signal-spot projection has progressed from a programming headache in the beginning to a relatively simple task. Obviously, because of the many changes in track curve and grade, up to 50 or more program inputs must be made in order for the signal spot to remain projected at its exact location on the screen as the simulated train traverses the track profile.

Methods of instruction and examination used in the six-week classroom phase of the training program have undergone many major changes. Books, manuals, instructional materials, and examinations are updated when necessary to keep current with operating procedure and standards. In a total effort to allow each trainee to obtain the education and knowledge required, instructors are used who have many years of experience and knowledge in the subjects they teach. The table below gives the number of hours applied to each subject of training during the six-week classroom phase of the training program, which incorporates the use of simulation:

Subject	Number of Hours
Orientation	2
Mechanical (diesel electric locomotives)	36
Air brake and train handling rules	54
Rules, Operating Department	58
Locomotive and train simulation	14
Written examinations	36
Final examinations	40
Total	240

CONCLUSIONS

The accomplishments of the training program thus far have been significant. Approximately 2600 qualified locomotive engineers are currently working on the Santa Fe Railway. Of these, approximately 1500 have been trained, qualified, and promoted as a result of the locomotive engineer training program. Ninety-three percent of the people who have entered the training program have been promoted to the position of locomotive engineer. In annual examinations on system operating rules, this new generation of engineers consistently score high. The training and knowledge they have received during the 25-week program on all aspects of the craft have better equipped them to cope with the actual situations they will experience.

We are now able, as never before, to keep abreast of the growing retirement rate and handle the ever-increasing volume of business. Daily car loading, on any railroad in North America, is the ruling yardstick by which business is measured. Service is the commodity by which industry measures a railroad. So it is no surprise that the ultimate objective of a locomotive engineer training program today, as it was at the beginning of this decade—not only on the Santa Fe but on all railroads—is to produce people with the best possible qualifications to operate locomotives and handle trains in a safe, efficient manner. The Santa Fe Railway feels that standardization of instruction is the key to reaching this goal, and centralized training and the use of simulation have proved to be the best way to achieve standardization.

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