each hub center has produced equipment per diem savings that more than offset the increased highway drayage costs. Using a competitive bid process for drayage and ramping services has controlled the cost of providing these services, thereby expanding BN's competitive range.

Finally, the hub centers have helped BN to improve its corporate culture both organizationally and philosophically. Each hub center is very much an individual entrepreneurial joint venture, responsible for its product and profit. Line personnel have a high degree of autonomy in their tasks. Basically, they are asked only to do their best and to produce a product that works and is profitable.

Hub center team members have responded in very positive ways. For example,

- Hub center personnel helped design BN's new floor tie-down system for trailers;
- Hub center personnel invented lift shoe adapters that permit older lift devices to handle wider trailers plus enable all BN lift equipment to safely handle privately owned trailers that do not have lift pads;
- Hub center personnel adapted weight scales from the logging industry to intermodal use, so that each unit is weighed as it is lifted;
- Hub center personnel have absorbed a near doubling of business volume without requiring additional help; and
- Quality personnel are trying to be transferred into the hub centers, not out of them.

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New Concepts in the Control of Train Movement

PETER J. DETMOLD

ABSTRACT

The concepts on which the Advanced Train Control Systems project is founded are described. These are of two kinds; there are the technical concepts on which the systems will be based and the organizational principles that permit the North American railroad industry to initiate a quantum improvement in this specialized technology. Both are described. The Advanced Train Control Systems project is a cooperative endeavor on the part of the railroad industry to control the use of their resources in a more cost-effective manner. The substantial increases in the productivity of labor and capital to be expected from their use will include savings in fuel, maintenance of rolling stock and track, and savings from the better utilization of motive power and cars as well as from the increase in route capacity obtainable at any level of investment in track. The project constitutes a step in the direction of automation.

The concepts described in this paper may be new, but the notion that productivity in industrial countries should follow a long-term rising trend--albeit an intermittent one--is as old as the Industrial Revolution. It is as old as the idea that the progressive advance in science should enable the industrial work load to be accomplished with a decreasing proportion of the time of the work force and increase leisure time and free labor to make new products.

The history of transport in general and of railroads in particular is one of increase in the productive use of labor, material, and resources. The railroads of the United States and Canada have already achieved a high level of efficiency in these areas and this observation extends to the central train control (CTC) signaling that is in general use. On the two major Canadian railways, for example, the productivity of labor in all trades involved in transportation in man-hours per gross ton-mile moved has grown at an average rate in excess of 6 percent per year since 1968. It must be added that increasing lengths of haul and the proportion of traffic made up of large unit trains of bulk freight have contributed to this surprising statistic.

However, some are concerned that many of the sources of technical advance that have served well over many years are nearly fully exploited. By the end of the decade, a technical plateau may well have been reached from which further progress in these areas would be both costly and difficult to achieve.

During the last decade the Track Train Dynamics program of the Association of American Railroads (AAR) has thoroughly explored the means of squeezing the last modicum of reduction in specific resistance to traction through improved metallurgy, track lubrication, and train stability, among other measures. Aerodynamic improvements and the use of the radial truck offer further savings.

Similarly, the High Productivity Integral Train project is encouraging the supply industry to pare down the tare weight of freight cars and, incidentally, to eliminate some of the causes of high cost in locomotive and freight car maintenance. Also, recent advances in the design of motive power have achieved substantial improvements in fuel consumption and an increase in haulage capacity in freight service of around 35 percent compared with the designs of the mid-1970s. And train information systems have started the caboose on its journey into folklore.

But once the benefits from these important developments have been exploited in revenue freight service, further advance must await the development of improved materials, less costly manufacturing techniques, or some major innovation. By 1990 scientific analysis and engineering technique may well have exploited to the full the design of the freight train and its track as currently envisaged.

Progress has not been confined to trains. Hump yards have been automated. Track re-laying has been highly mechanized. Workshop procedures have been streamlined. Computerized information systems abound. And computerized dispatchers' aids already predict the most favorable "meets" (passing places on single-track routes).

Substantial though these fields for improvement may be, it is doubtful whether collectively they would be sufficient for the productivity of railroads to continue to keep pace with the growth in the productivity of labor in all U.S. industry, which has averaged a rate of about 3 percent since 1980. Research and development expenditure in the United States has been rising year by year since 1977, suggesting that further increases in productivity are in store. Should railroads not continue to keep pace with this general progress, inevitably the scale of their operations will decline.

How should it be made certain that the rate of productivity increase in railroading equals and hopefully surpasses North American averages? The best prospects appear to be through the more efficient use of resources, that is, by controlling operations more efficiently so that the maximum possible output is achieved per unit of investment in track, motive power, freight cars, terminals, and workshops and per unit of expenditure on labor, fuel, and other materials.

ADVANCED TRAIN CONTROL SYSTEMS PROJECT

The Advanced Train Control Systems project results from this basic premise that the principal area for technological advance in railroading is likely to come from the improved means of controlling operations. This prospect results from the enormous advance in the state of the art in microelectronic technology that has taken place during the last two decades in the aerospace, defense, and computer industries. All through history, railways have often borrowed the means of major technological advance from other industries. The steam engine, for example, was originally designed for pumping water from mines; the diesel was used in trucks long before its introduction to railroads on a substantial scale. Why not once again convert scientific developments from elsewhere to improve the economics of railroading?

With such thoughts as these in mind, the following seven railroads got together in September 1983 to write the operating requirements for these new systems:

- Algoma Central Railway
- British Columbia Railway Company
- Burlington Northern
- Canadian National Railways
- Canadian Pacific Limited
- Norfolk Southern Corporation
- Seaboard System Railroad

In the summer of 1984 they were joined by the Southern Pacific and the Union Pacific. And the Consolidated Rail Corporation (Conrail) and the Santa Fe are now supporting the project, which will be managed in a joint operation involving the Railway Association of Canada and the AAR and specialized personnel from participating railroads. First the basic concepts around which these systems are being designed will be described and then the organizational principles, which are certainly new to the railroad industry and novel in a number of respects.

The project involves a number of systems, extending from the simple to the complex. Not all the concepts described would necessarily be included in all the systems and few of them would be involved in the most simple. But for the sake of brevity and simplicity, all the concepts will be described together as if they were being applied to the most advanced system that any of the participating railroads might envisage.

THE CONCEPTS

The most fundamental concepts that underlie the most advanced system are as follows:

- All information that is relevant to train movement should be passed to a single point covering some large territorial area.
- The sequence and combination of decisions that use resources safely and in the most economical manner should be computed.
- These decisions should be conveyed in the form of continuously updatable instructions to enginemen and others concerned, track forces, for example. (As far as enginemen are concerned, all information pertinent to their immediate actions would be concentrated in an electronic display in the cab.)
- Instructions must be acknowledged and, to the extent that is possible, enforced if they have been overlooked.

These four operations may be viewed as a closed loop of information, computation, instruction, acknowledgment, and, if necessary, enforcement essential to an automated as distinct from a permissive system. Many of the components of this process (track circuits, for example) are far from new and only a small proportion of the functions called for in the operating requirements are wholly novel. It is in their use in a highly automated system controlled from a single point that the major significance of the project lies.

One possible layout involving control loops is shown in Figure 1, which shows some of the more important functions that will be described in the following paragraphs.

Information

The control of all facets of train movement at a single point requires that all physical characteris-

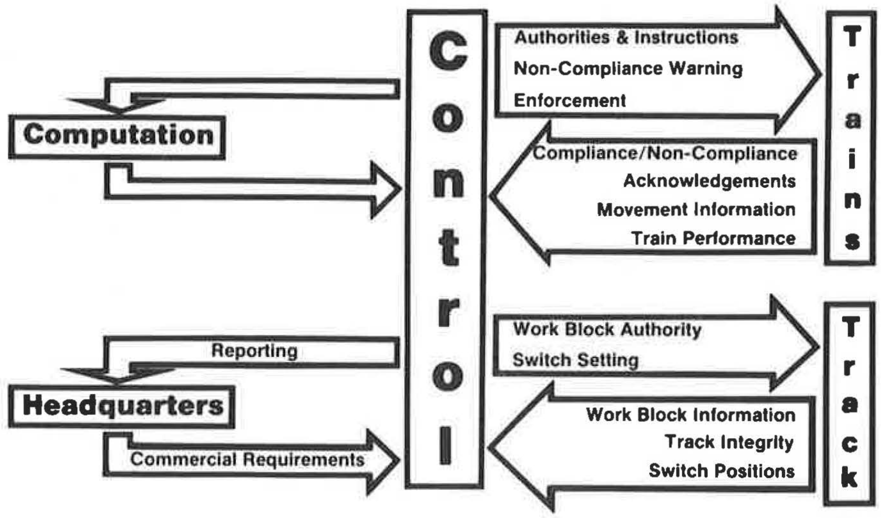

FIGURE 1 Control loops (one possible layout).

tics of the route network be represented in electronic form. The information needed at the control point to achieve these purposes falls into four discrete groups expressed in the following continually updated statements of

- The presence, identity, location, speed, and direction of movement of any train in the system;
- The position of all switches and the integrity of track and its freedom from excessive stresses and from obstructions, such as the presence of maintenance equipment or rock slides;
- Notice of any irregularity or defect on the train itself, such as the indications of defective equipment and monitoring systems for locomotive performance;
- The timetable together with statements of the last acceptable arrival times for the highest-priority traffic on each train.

Determination of the Decision Sequence

A major future task will be to develop the capability to compute the decision sequence with the best prospects for achieving commercial objectives at minimum cost consistent with high safety standards. The results of these computations will be conveyed to the dispatcher in the form of instructions for onward transmission if approved by him.

An essential component of the computing software will be a conflict-resolution module that will project, with continuous updating, the paths of all trains. It will detect such conflicts as might arise both between trains and with track vehicles and inform the dispatcher of them together with recommendations for their resolution. This function will require computation of all changes in speed of each train with regard to gradients, curvature, and speed restrictions, as well as the performance capability--including the braking capability--of the trains themselves at all points on the route. From this will be estimated the speed necessary for each train to maintain at every point on the route in order to reach its destination or next point of conflict in the most cost-effective manner consistent with safe operation and the achievement of commercial goals.

To this end, a movement cost model will simulate, perhaps every few minutes, the cost of the operation over the next several hours, searching for the most cost-effective decision sequence with regard to wage cost, fuel, wear and tear on trains and track, utilization of trains, and sufficient opportunities for track maintenance for the work to be done economically. For example, the energy consumption routines will search for the sequence of power settings on individual trains that meets the required timing with minimum fuel consumption and also for the timetable that achieves the commercial requirements of the traffic in the most energy-efficient manner.

There is no reason why the appropriate power setting should not be indicated to the engineer together with a continuous indication of the desired train speed. With microprocessor-equipped locomotives a further development objective would be to adjust the power automatically. There is, of course, the need to avoid differences in velocity along the train of a sufficient order to lead to run-ins and run-outs of unacceptable severity. The final step therefore would be to also automate train-handling techniques and thus avoid such occurrences.

Fuel savings will be achieved in the following principal ways:

- On single track, meets will be planned to occur at places where the total energy lost both by the unnecessary slowing of the main-line train and the stopping of the siding train would be minimized. They will, for example, be planned to occur at those points such as the summit of a grade where the train stopped would have been running at low speed rather than at the foot of a grade where it would be running at high speed before climbing another.
- The train to be stopped would be paced so as not to enter the siding much before the last moment that would avoid slowing the train taking the main line.
- Trains would not use high power to accelerate to a high speed when this could not be maintained for more than some short distance.
- The timetable (as already implied) would be adjusted to facilitate an energy-efficient movement.
- On double track (including that with bidirectional movement) and on routes with alternate lengths of double and single track, train speed would be adjusted continuously to minimize braking.

These examples will suffice to illustrate the point that there will be extensive demand for movement control software of increasing sophistication and complexity. Whereas the hardware for Advanced Train

Control Systems, once engineered effectively, may be expected to remain unchanged for a number of years, the software will be subject to ongoing development into higher levels of power as railroads advance into the age of automation during the remainder of this century and beyond.

Instruction, Acknowledgment, and Enforcement

The most favorable decision sequence must be transmitted both to train crews and field forces in the form of instructions and to others, such as terminal managers, in the form of information. Before this is done, however, powered switches must be moved to and locked in the correct position and it must be verified that hand switches are correctly set.

In all probability, an electronic display in the cab will convey to the crew the authority to proceed, the desirable speed, and other pertinent information such as the next permanent speed restriction or slow order, work block limits, hot box indications, and work to be performed en route. It is desirable that the authority to proceed be printable for the engineman's retention, possibly as part of the procedure by which the instruction is acknowledged to the control point.

The existence of a core store of all pertinent information will be useful for other purposes. For example, the maintenance-of-way officer could apply a slow order when track work is complete by the use of a portable terminal capable of printing out the controller's acknowledgment of the revised instruction.

The enforcement of speed restrictions is not new. Swedish National Railways has employed a system for some years capable of applying the brakes if the train speed exceeds the maximum permissible, including both permanent and temporary restrictions at specific locations. But until the automation of train handling is complete, such applications will only be used as an emergency measure.

In summary, the advanced systems will provide a powerful new tool for controlling the traffic across the entire network. Whereas present control systems are permissive in the sense that they combine the maintenance and safe separation between trains and the enforcement of maximum speeds, primarily through signal indications, operating rules, and written instructions, these new systems will be automated in that they will also be capable of enforcing instructions and maintaining train speeds at levels computed as the most desirable from a systems standpoint. Every aspect of train movement will be part of a single system under unified control and in which the loop of instruction and compliance is verifiable and complete.

ORGANIZATIONAL PRINCIPLES

The principles on which the project has been organized differ in some important respects from customary railroad practice, drawing partly on that used in space and military projects and in some other respects on procurement in the air transport industry.

The first principle was that railroads representing a substantial proportion of users should, as previously stated, write their requirements and that they should eschew expression of their technical preferences in so doing.

The second principle is that the project should be self-financing. To achieve this it will be necessary for suppliers to convince themselves that the market is sufficiently large and the economics of the project sufficiently favorable for them to design and manufacture the component parts with their own venture capital. Railroads in turn must be convinced that their own investment in meeting the cost of engineering the basic characteristics of the system can be justified.

A team of system engineers is currently estimating the cost of the project in some detail, and a team of economists drawn from major railroads is estimating the benefits in terms of the savings in labor and fuel; reductions in the cost of maintaining track, cars, and power; the near-elimination of accidents; together with increases in traffic capacity and equipment utilization. The return on investment is being estimated from these two studies. It is expected to be large.

The third principle is that the industrial base should include skills representing the state of the art in every technological field, including communications, computing, software, fail-safety, and human interface in addition to traditional forms of train control. To this end, a substantial advertising campaign drew representatives from around 140 companies to attend a presentation in Toronto in June 1984 concerning the purpose and organization of the project, supplementing the outstanding skills of the railroad signaling industry. About 100 are now involved in the project.

Last, a consortium of system engineers headed by ARINC Research Corporation of Annapolis, Maryland, and including Transportation and Distribution Associates, Inc., of Philadelphia, Pennsylvania, and Philip A. Lapp Limited of Ottawa, Ontario, began work in February 1985; they are currently identifying the technologies that could be used to perform each function in the 39 modules called for in the operating requirements, assessing how well each technology will perform each function, and determining their availability and their cost. They will also review existing train control technology and components already in service with the purpose of determining how much of what exists today can be adapted to meet these new requirements and estimating the need for the development of entirely new components, including both hardware and software.

By combining the results of this initial survey with the railways' own estimates of benefits to them, it will be possible to plan a work schedule to accord the highest priority to producing the performance specifications for those subsystems and modules shown to have the highest rates of return and the fastest payback periods.

The system engineers will then specify the interfacing and connections between modules and components in order to permit components of independent design to operate together, to ensure that when any equipped locomotive runs on any equipped track, any control function of which both locomotives and track are capable should be performable. They will also develop minimum performance standards required to meet railroad standards of safety and reliability. Last, they will identify the scope of the research needed, including a program that the AAR will carry out under the direction of W.J. Harris, Jr., and C.E. Taylor.

The marshalling of a massive industrial base to develop the products is the supply aspect of a supply and demand equation. The demand is represented by the collective efforts of the North American railroad industry. Railroad professions such as communications, signalling, locomotive and track engineering, computer systems, and railroad operating have set up task forces of experienced professionals to interface with the system engineers, who will receive advice from user and supplier alike.

From all this work will emerge the alternative layouts for the new systems in terms of equipment at control points, at trackside and on trains, together with assessments of the overall rates of return on investment that should be obtainable. However, this process will not prevent suppliers from showcasing their products by direct contact with railroads in the customary manner. The system engineers will enable all proprietary and competing products to conform to an orderly plan to develop a system with a common architecture. But who buys what from whom will be a matter for the free market process.

Apart from the inherent advantages of the market process, there are a number of other benefits from carrying out the work in this manner. First, it enables large numbers of specialist companies to contribute in much the manner as in the various U.S. aerospace programs. Second, the system is especially tolerant of new technologies that may emerge after the initial system has been engineered. There is no reason why some specific module should not be replaced by another, using some new technology to carry out its function. Third, and most important, with the system engineering approach, the initiation of a quantum advance in technical performance is more readily achievable than with development processes of an inherently evolutionary character.

Last, the Advanced Train Control Systems project has demonstrated both the feasibility and the advantages of international cooperation in large research projects involving not only railroads of the United States and Canada but a wide range of high-tech designing, engineering, and manufacturing organizations.

PROJECT TIMING

ARINC and their partner companies will complete their technology assessment by September 1985. By that time, each railway will be receiving proposals from the companies that want to build complete systems; indeed some have received proposals already. Before the end of 1985, the first of the performance specifications for the components of the systems will be available and all should be available by the end of the first quarter of 1986.

During 1986, the first trial installations that meet these specifications and comply with the system architecture will be taking shape. They will probably be some of the more simple versions of the system. Will they be based on transponders and radio, on satellites, on conventional track circuits and cables, or on some of them or on all of them? It is just too early to say.

What can be said is that every technology will have been evaluated and every aspect of the environment in which they will operate will have been taken into account. The choices will have been reviewed with all participating suppliers and their views will have been carefully considered. Appropriate test procedures and any research found necessary will be carried out before these choices are made.

During the period 1986-1990, Advanced Train Control Systems will be installed on a large scale, sometimes standing alone and sometimes overlaid on existing signals to extend the range of the functions that they currently perform. Expenditure is likely to exceed $5 billion U.S. and may well reach $10 billion U.S. by the early 1990s.

SOME FURTHER THOUGHTS

The significance of the Advanced Train Control Systems project extends far beyond a massive effort to procure new control equipment. It will engender the notion that every aspect of investment in control equipment, track, motive power, cars, and other plant will soon become part of a closely integrated strategy, to be evaluated only in terms of the overall stream of benefits for the overall stream of expenditures.

But Advanced Train Control Systems are not the last word in train management technique. Rather they are the first word--the first word in a new generation in which the vast knowledge and power of the microprocessor and communication industries will be brought to bear in applying a progression of new generations of higher-level control software.

The progressively more cost-effective deployment of the railroads' principal resources--of labor, capital equipment, and material--may well restore the high rates of productivity growth that followed the introduction of the second-generation diesels and the "100-ton car" in the early 1970s. This achievement can only be brought about by the massive cooperative effort that has been described.

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