Mutual Design of Overhead Transmission Lines and Railroad Communications and Signal Systems

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ABSTRACT

From February 1981 to June 1983, the Electric Power Research Institute funded IIT Research Institute to examine the problem of interference to railroad communications and signal systems from high-voltage, overhead, alternating current (ac) power lines. A key goal of this project was to develop means to accurately forecast whether or not a planned power line to be located near a railroad will cause interference problems. A second important goal was to develop means to perform accurate cost-versus-benefit trade-off studies for mitigation if interference is expected to be a problem. In this paper the approaches used by IIT Research Institute in attaining these goals are discussed, and the project accomplishments, principal findings, and principal remaining problems are summarized.

In the past few years electric power utilities across the United States have experienced increasing difficulty in obtaining rights-of-way for their high-voltage overhead transmission lines. Under the current regulatory process, all feasible routes for new lines must undergo examination by government agencies, landowners, utility customers, and the public in general. The final route selection is based on overall cost, environmental impact, present land use, and a host of other factors. These factors have combined to prompt the electric utilities to use existing rights-of-way whenever possible.

Because many existing rights-of-way are occupied by railroad systems, and because an electric power line may affect the performance of an adjacent railroad communications and signal (C&S) system, the problem of compatible operation of the power and railroad systems arises. Examples of compatibility problems have led to a wary attitude on the part of many railroad C&S personnel toward construction of a power system in or near their rights-of-way. A relative lack of data and theoretical developments has served to heighten this caution and decrease cooperation between the power and railroad industries.

Whenever a power transmission line route is selected that parallels a railroad, it may be as disturbing to the electric utility as it is to the railroad company. Nevertheless, the technical people from both industries have the job of solving any problems imposed by close parallel operation with designs that are both economical and free of excessive interference. In this effort many organizations need to cooperate to develop optimum, mutually acceptable designs.

This is not a new area of technical investigation, and much work precedes the present project. The classic paper by Carson (1) delineated the basic theory of low-frequency magnetic coupling from earth-return transmission systems such as power lines.

Sunde (2) applied and expanded Carson's work to develop analytical expressions for coupling to buried conductors and conductors near the earth's surface. The International Telegraph and Telephone Consultative Committee (CCITT) addressed the general effects of power system coupling to nearby, principally aboveground, wire lines and cables (3). Bell Laboratories (4) addressed many of the same issues from the perspective of the Bell System. The work of Dabkowski and Taflove (5), published under the auspices of the Electric Power Research Institute (EPRI) and the American Gas Association (AGA), advanced the work of Carson and Sunde to provide workable prediction and mitigation tools for gas pipelines located near power systems. An excellent document that dealt directly with railroad rights-of-way (6) was the result of a team effort by representatives of the Association of American Railroads (AAR) and the Edison Electric Institute (EEI). In a related area, the proceedings of a recent symposium (7) sponsored by the AAR, the IEEE, and the American Railway Engineering Association (AREA) offered more data on railroad rights-of-way.

The present research program (8) resulted from a request by EPRI's utility sponsors to provide better information on transmission line design parallel to railroads, because recent projects, such as that reported by Dabkowski and Taflove (5), emphasized the need for better design tools. A key goal has been to expand the technologies contained in the 1977 joint study by AAR and EEI (6).

PROGRAM OBJECTIVES

The objective of the present research program was to develop mutual design methods and criteria for overhead alternating current (ac) transmission lines and adjacent railroad systems. This project has addressed basic engineering issues that govern the operation of railroad C&S systems under conditions of interference from nearby overhead ac transmission lines. Data and techniques have been compiled and developed to contribute to the achievement of electromagnetic compatibility in a manner that is acceptable to both the power and railroad industries. In this regard, the involvement of the railroad industry and its suppliers has been sought to provide this project with guidance and key operating data.

Specific program objectives have been to

1. Consolidate known data concerning mutual effects arising from transmission lines and railroads that have close sitings,
2. Develop means to accurately forecast whether or not a planned power line that is to be located near a railroad will cause interference problems,
3. Develop means to perform accurate cost-versus-benefit trade-off studies for mitigation if interference is expected to be a problem, and
4. Investigate both existing techniques and possible new techniques to mitigate interference problems.

Overall, a major goal of this project is that designers of both power and railroad systems can equally use, and benefit from, the data and methods that have been developed to enhance cooperation in future joint sitings.

PROGRAM ACHIEVEMENTS

Worldwide Literature Review

A computer-based search of United States and foreign literature was conducted to compile a comprehensive survey of railroad C&S facilities operation and susceptibility to interference. This search encompassed virtually every aspect of railroad facilities operation relevant to susceptibility to electromagnetic interference, methods for prediction of interference levels, identification of acceptable levels of interference, and development of mitigation methods.

Key files searched included the Railroad Research Information Service (RRIS) file of the Transportation Research Board, National Research Council; the International Union of Railways (UIC) Office for Research and Experiments (ORE) file; the National Technical Information Service (NTIS); the Smithsonian Science Information Exchange (SSIE); the Engineering Index (Compendex); Inspec/Electrical; the Transportation Research Information Service (TRIS); and the Comprehensive Dissertation Abstracts. An annotated bibliography of approximately 200 of the most relevant items found in this comprehensive search was assembled.

Development of a State-of-the-Art Interference Prediction Method

A basic need to permit planning of new power lines near railroad systems is an accurate means of predicting what the level of ac interference will be. A good prediction tool would also help a power or railroad system design engineer interact with the model, change parameters, gain engineering experience and judgment, and red flag undesirable features before large expenditures of time and capital.

Precisely such a tool has been developed during this project. This tool consists of two user-oriented computer programs designated TRAIN-I and TRAIN-II (acronym for transmission line/railroad analysis of induction). These programs can be applied to model the following cases of power system ac interference to railroad C&S systems:

1. TRAIN-I: steady-state magnetic field coupling, 60 Hz and harmonics; and steady-state electric field coupling, 60 Hz and harmonics; and
2. TRAIN-II: fault current coupling through the earth, 60 Hz and harmonics.

These programs are based on Thevenin's equivalent circuit treatment of the distributed source analysis developed during a predecessor EPRI research program (5). The previous analysis has been extended to rigorously include the mutual magnetic, earth-conduction, and electrostatic coupling phenomena present in realistic rights-of-way, where a number of railroad tracks, overhead wires, buried cables, and buried pipelines may be present. This extension is based on a multiconductor transmission line analysis approach (9,10). The previous analysis is also extended to take into account the recent rigorous approaches to electromagnetic and earth-current coupling to conductors near the earth's surface (11-13). An initial validation of TRAIN-I has been obtained by using the results of the field experiment performed at the Pueblo Transportation Test Center, which will be discussed later.

Measurement of Interference Susceptibility Levels

A second need to permit planning of new power lines near railroad systems is accurate data for the levels of ac interference that upset the operation of railroad components or systems. Such data would help power and railroad system design engineers understand the magnitude of the interference problem, investigate alternative mitigation approaches, and select one that is cost effective and mutually agreeable.

A body of key signal equipment susceptibility data has, in fact, been developed with the technical cooperation of four major U.S. manufacturers of railroad signal equipment. By using an innovative test jig developed during this project, a series of measurements was conducted at two of the manufacturers' plants under the supervision of the respective chief engineers. The same test jig was used to conduct measurements at the IIT Research Institute of the other two manufacturers' equipment, under the supervision of responsible engineering personnel of the respective firms. (The latter two tests were funded by EPRI under a parallel research program in connection with a specific right-of-way inductive coordination study, and were performed under subcontract to Science Applications, Inc.) Highlights of the four batteries of tests included measurement of upset levels for

1. Nine representative, widely-used, track and line relays;
2. Six recent electronic track circuits;
3. Five grade-crossing motion detectors and warning devices;
4. Steady-state 60-Hz and harmonic interference;
5. Simulated fault pulses; and
6. Preliminary mitigating devices, such as filters.

Of great interest were the modes of upset of the equipment or systems for specific nominally displayed signal aspects. Careful attention was paid to the possibility of ac interference causing a less-restrictive indication to appear than desired. In addition, each relay and electronic track circuit receiver was characterized for input impedance (magnitude and phase) as a function of frequency through 540 Hz.

Overall, the tests permitted specification of the Thevenin equivalent circuit of each item of signal equipment, as well as the interference threshold level and mode of upset. This permits a black-box characterization of each item and easy integration of the device characteristics into the ac interference coupling programs (TRAIN-I and TRAIN-II).

Field Measurements of Interference Coupling

In May 1982 a 3-week long test at the U.S. Department of Transportation Test Center in Pueblo, Colorado, was conducted. The purpose of the field test was to develop experimental data for interference coupling to the railroad system that could be compared with the theoretical model. The following tests were conducted:

1. Measurement of transmission line parameters of the track, from 60 to 540 Hz;
2. Measurement of steady-state magnetic coupling from the energized catenary to the track and nearby cables, from 60 to 540 Hz;
3. Measurement of steady-state electrostatic coupling from the energized catenary to the track, from 60 to 540 Hz;

4. Measurement of earth-current coupling to the track, from 5 to 60 Hz;

5. Examination of mitigation concepts such as buried counterpoise and cable shielding; and

6. Identification of potential areas of concern--(a) rail-to-earth and rail-to-rail voltage buildup caused by magnetic coupling, (b) effects of a broken rail, (c) rail insulator electrical breakdown at lower-than-specified voltage, (d) rail-to-earth voltage buildup caused by electrostatic coupling, and (e) mitigation difficulties with heavy shielded cables and buried counterpoise.

Detailed tests of magnetic and electrostatic coupling at frequencies from 60 to 540 Hz were possible because the catenary above the test track was energized by using the high-power wide-band amplifier system that was used earlier for signal equipment interference susceptibility testing. Catenary excitation currents as high as 10 amperes (voltages up to 100 V) were possible in this manner. Currents up to 600 amperes (voltages up to 6 kV) were obtained on the catenary only at 60 Hz by using the available substation supply.

Compilation of Mitigation Methods and Trade-Off Possibilities

Given a reliable and accurate prediction tool for inductive interference to railroad systems, and given data for levels of interference susceptibility of railroad equipment and systems, it becomes possible to intelligently study alternative mitigation methods. A study of mitigation alternatives of this type has been performed during this project. The following elements of the railroad C&S system are considered: railroad track, track relays, line relays, signal system open-wire pole line, electronic track circuits, grade-crossing equipment, and communications circuits.

Development of Tutorial Material

The technical disciplines involved in the study of power line interference to railroad C&S systems are many and varied. To assist engineers and planners from both the power and railroad industries in understanding key technology elements involved in this problem, relevant tutorial material has been developed during this research program. The following list briefly summarizes the tutorial material (8):

1. Key elements of railroad system operation--functions of the train operations system, basic concerns of railroad personnel, performance of specific equipment, and glossary of train operations system terms;

2. Key elements of power system operation--transmission line unbalance under normal operating conditions, variation of transmission line phase currents and unbalance with time, dependence of magnetic coupling on the correlation of the phase-current variations, power system protective relaying, and impact of power system protective relaying practices on the performance of railroad C&S equipment and protective devices during power line fault conditions; and

3. Low-frequency interference coupling mechanisms to shielded cables--transverse electric field, transverse magnetic field, transverse magnetic field fringing at cable shield discontinuities, longitudinal shield current diffusion, longitudinal shield current magnetic field penetrating through shield apertures, longitudinal magnetic field, and impact of using a multiple-grounded cable shield.

Involvement of Responsible Railroad Personnel

In order for this study of railroad electromagnetic compatibility issues to be technically accurate and responsive to railroad industry concerns as well as power industry concerns, it was considered vital to involve responsible railroad personnel in program planning and execution. The following list briefly summarizes this involvement.

1. Railroad personnel helped in formulating the initial program work plan.

2. Administrators from as many as 20 railroad C&S departments attended the two annual project review meetings.

3. Two experienced, retired, railroad C&S department administrators agreed to work as project consultants.

4. Four major U.S. railroad C&S suppliers cooperated in conducting detailed tests of ac interference susceptibility of their main product lines of electronic track circuits.

5. Papers or panel discussions detailing project goals and accomplishments were presented at the 1981, 1982, and 1983 annual meetings of the AAR C&S Division. In addition, a similar but more detailed presentation was made to the Committee of Direction of the C&S Division at the 1982 AAR meeting.

PRINCIPAL PROBLEMS IDENTIFIED AND SOLUTIONS DEVELOPED

In this section the principal problems identified during this research program are reviewed, and the recommendations made to systematically address these problems are discussed. The areas of concern are as follows:

1. Rail voltages and currents induced by ac power transmission lines can reach unacceptably high levels under certain conditions;

2. Previous high-cost mitigation solutions that involve heavy shielded cable are technically inadequate and benefit neither the utilities nor the railroads in many instances; and

3. The railroads and their signal equipment suppliers have little or no data, and no standards, for the susceptibility of their vital railroad signal equipment to ac interference.

These problems are now explained and addressed. Details are provided in Taflove and Umashankar (8).

Problem 1: Possibly High Rail Voltages and Currents

The computer analyses and field tests performed under this research program indicate that the rails can develop unacceptably high levels of voltage and current under certain steady-state and fault conditions of a nearby ac transmission line. These cases will be reviewed separately.

Steady-State Conditions

If track sections are too long, magnetically induced voltages across insulated rail joints can exceed 50 V, a nominal safety limit for railroad personnel (6). A broken rail can cause rail-to-rail voltages to jump to an even higher level, possibly causing either voltage hazards for personnel or the appearance of a false-clear on the railroad signal system, if vulnerable signal equipment is used.

Fault Conditions

The use of common prime-ground connections of lightning arresters at insulated rail joints can lead to a cascaded electrical connection of all of the track sections adjacent to the power line during a fault. This, in turn, multiplies the magnetically induced rail current to a level that may be sufficient to destroy the arresters. Destruction of the insulated rail joints and connected signal equipment is then possible, either immediately or at the occurrence of the next lightning stroke or power line fault.

Suggested Solutions

The steady-state problem can be addressed by limiting the lengths of track sections, and making sure that even worst-case broken-rail voltages cannot cause a false-clear of the connected signal equipment. The fault problem can be addressed by providing high-energy rail protectors and equalizers, which can survive worst-case rail currents and the resulting thermal stresses. Preventive maintenance and replacement of these high-energy protectors are recommended.

Problem 2: High-Cost Mitigation Solutions That Are Not Beneficial

Interactions with utility and railroad industry personnel, as well as project consultants, have suggested that many past mitigation solutions have been costly. Many of these solutions involved the purchase and installation of heavy ferromagnetic-shielded cable (for principally the signal system) as a replacement for open-wire lines. This study suggests that these heavy-cable solutions were generally not needed, and were not an adequate technical response to the real problems of induced-rail voltages and currents, as well as signal equipment susceptibility. Therefore, these heavy-cable recommendations were probably not beneficial to the railroads, either. These conclusions are based on the analyses of railroad system operation, inductive interference, and interference coupling to shielded cables, which are discussed in detail elsewhere (8).

Suggested Solutions for Signal System

For the signal system, most steady-state interference problems can be solved by keeping existing line relays and balancing or shortening existing open-wire signal circuits. If there is a lack of space on existing pole-line cross arms for the new wires needed to implement balanced signal circuits, standard low-cost aerial signal cable can be used. (Such a mitigation approach might be only 10 to 20 percent of the cost of installing heavy, buried ferromagnetic-shielded cable.) Fault surges can be mitigated by installing relatively inexpensive signal-line protectors that have the proper thermal dissipation ratings.

Suggested Solutions for Communications System

For the communications system, the installation of standard low-cost aerial telephone cable can markedly improve circuit balance and provide complete shielding against electrostatic coupling. If required, additional mitigation can be provided by installing isolation transformers, drainage coils, mutual drainage reactors, and neutralizing transformers, as well as inexpensive communications line protectors to deal with fault surges. These approaches are normally much less expensive than installing heavy, buried ferromagnetic-shielded cable, and they can be more effective in reducing 60-Hz and harmonic noise. Long parallels and high-capacity communications needs require consideration of carrier and microwave approaches.

Problem 3: Lack of Susceptibility Data and Standards for Signal Equipment

Surprisingly, the ac interference susceptibility testing performed under the EPRI program represents the first concerted effort to obtain such data for a broad range of railroad signal equipment. The greater than 100 to 1 variability of the measured safe-failure levels found during tests under this program indicates an absence of standardization of ac susceptibility levels in the railroad signal industry.

A key result of the lack of susceptibility data and standards is the current uncertainty concerning the vulnerability of railroad signal equipment to a false-clear condition caused by ac interference. This condition was found outright in one track relay during tests under this program. Further, two electronic track circuits evidenced decoding errors, which might lead to false-clears under certain conditions. For example, one of the electronic track circuits gave a false-clear (red-to-green) failure with as little as 0.10 V rms of harmonic voltage across its rail-to-rail input terminals, if the 60-Hz voltage was limited to less than this level through filtering, and if a suboperating-level green signal was also received.

Suggested Solutions to Utilities

In the absence of railroad industry susceptibility data and standards, utilities are advised to work with the railroads to set up measurement procedures (or procurement standards) to test each item of vital railroad signal equipment that may be subjected to ac interference. Both safe failures and false-clear failures should be tested. In this manner, equipment with relatively satisfactory interference behavior, such as certain conventional electromechanical relays, could be specified for installation. Equipment with relatively unsatisfactory or unsafe interference behavior could be pinpointed.

If electronic track circuits are considered, a careful check of the following possible decoding-error modes should be made:

Mode 1--low-level 60-Hz and harmonic interference voltages, which add to a suboperating level of signal voltage to generate a detector output when no output should be obtained;

Mode 2--high-level 60-Hz and harmonic interference voltages, which cause a brute-force change of the detector output to a less-restrictive state than desired; and

Mode 3--fault-pulse interference, which causes splitting of signal code pulses to temporarily shift the detector output to a less-restrictive state than desired.

The present EPRI research program has conducted insufficient tests of modes 1 and 3 to resolve all uncertainty. More detailed tests are called for, in addition to tests of a number of devices of each type to obtain a level of statistical confidence in the results. In addition, the effects of equipment aging, exposure to extreme environmental conditions, and variable track source impedances should be tested.

Suggested Solutions to Railroads and Their Signal Suppliers

Sound measurement procedures and standards for the susceptibility of vital railroad signal equipment to ac interference are clearly needed. Observed possibilities for decoding errors suggest that all electronic track circuits on the market should be thoroughly tested for vulnerability to such errors.

SUMMARY

The EPRI research program has attempted to address the principal technical issues involved in providing for a compatible cositing of an ac power transmission line and a railroad C&S system. Significant progress has been made in the areas of

1. Developing a state-of-the-art theoretical approach for predicting power line magnetic, earth-current, and electrostatic coupling;
2. Developing user-oriented computer programs to implement the advanced theory for complex, real-world rights-of-way;
3. Transferring up-to-date knowledge of low-frequency cable-shielding theory and practice from the nuclear electromagnetic pulse technical community to the ac power and railroad communities;
4. Measuring in a systematic manner the ac interference susceptibility of a wide range of vital railroad signal equipment to both safe and false-clear failure modes;
5. Measuring magnetic, earth-current, and electrostatic coupling to railroad facilities at 60-Hz and harmonic frequencies in a controlled, outdoor, laboratory-like environment;
6. Devising new, or compiling existing, cost-effective mitigation approaches; and
7. Identifying the principal technical problems that can determine the ultimate effectiveness, cost, and safety of a typical mitigation solution.

The principal unresolved technical issues that remain at this point are as follows.

1. Railroad signal equipment has been found to exhibit a wide range of susceptibility to ac voltages leading to safe-failures. There is a need for testing all such equipment for ac susceptibility, and setting some standards for their performance under conditions of ac interference, both 60 Hz and harmonics.
2. Some railroad signal equipment has been found to exhibit a degree of vulnerability to possible false-clear failure modes under certain conditions of 60-Hz and harmonic interference. Rigorous testing for such failure modes is necessary by using procedures that are acceptable to both the signal equipment firms and the railroads. All vital signal equipment should be tested for possible false-clear failures, regardless of manufacturer.
3. Grade-crossing equipment remains largely untested for ac susceptibility. Both safe and unsafe failure modes should be tested for all such equipment, regardless of manufacturer.
4. High-energy track protectors suitable for dealing with the stresses of power line faults are currently available only as special-order items. Further development and testing of these protectors are required so that they meet relevant technical requirements of the railroad industry, such as the fail-open criterion. Wider availability of these protectors is needed.
5. Researchers are encouraged to use the computer programs TRAIN-I and TRAIN-II (developed under this research effort) to identify the range of application and validity of these predictive tools.

This research program has been conducted by IIT Research Institute in a manner that has favored neither the electric utilities nor the railroads. It is believed that both industries must share responsibility for contributing to future cooperation. It is earnestly hoped that the final report (8) will contribute to the technical basis for such cooperation.

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expenditures (4). An industry in the doldrums is not likely to risk, or even attract, investor confidence.

Why then should electrification be discussed at all? If there is neither reason nor desire for it, why bother?

WHY?

Of greatest urgency, for many valid reasons, is the need to sustain the national railroad system successfully. It is unequivocally essential. The Penn Central bankruptcy required government intervention on an unprecedented scale. Each national railroad strike has required immediate presidential intervention, often followed by remedial legislation. The nation obviously needs its railroads much more so than it needs most other private businesses. But why? As former Secretary of Transportation William T. Coleman said, "They are 100 years old. We need something new."

Energy conservation, price inflation, and the need for economic productivity are all high priority national concerns that drive public policy. Railroads excel, at least in theory, at optimizing all three of these fundamental requirements. Railroads are by far the lowest cost producer of overland transportation for a wide range of basic commodities and, sometimes, even people. Railroads do more freight work than any other single mode of movement in the United States, but they are paid only one-sixth of what the trucking industry is paid for the lesser amount of work trucks do (4). In simplistic terms, rail transportation costs less than $0.04 per ton mile, where truck transportation costs $0.08 for similar freight, and $0.12 for typical freight that trucks carry (3). The nation could not tolerate the tripling of its national freight bill should railroads not survive. This does not even consider the hundreds of billions of dollars of added cost for highway strengthening and expansion if all rail freight were shifted to the highways. The diversion of rail movement to the highways and waterways would be inflationary in the extreme.

To move a loaded freight car by rail requires but 0.2 gal of diesel fuel per mile, about the same quantity that is consumed by an over-the-road tractor-trailer, but the rail carload averages nearly 3 times the load (2). Rail movement is 3 times more energy efficient than highway movement where direct rail lines exist. Rail fuel efficiency is equal to that of water transportation when compared on an origin-to-destination basis for similar commodities.

Rail transportation can be more efficient for passenger movement, despite Congressional Budget Office (CBO) and Office of Management and Budget (OMB) findings to the contrary. An 84-seat intercity rail coach can go 3 miles per gallon of fuel (2). An intercity bus will cover 6 miles on the same fuel, but is contains only half as many seats. There is little actual difference.

In reality the energy conservation of rail passenger service is not going to be realized by competing with buses. Rail travel excels in comparison with automobile and air travel. The bus has only 2 percent of the travel market (2). Rail passengers come, and more will come, from the other 97 percent of the high energy market. People will ride trains in large numbers where service is competitive in major markets. U.S. railroads (excluding rail transit) transport 50 percent more passengers than U.S. commercial airlines (3). Commuters account for much of that volume, but commuters are largely automobile oriented and ride only by choice. The service must appeal to them.

Most automobiles carry only one passenger, despite carpools and vanpools subsidized by business and government. The most fuel-efficient automobiles usually used on longer trips will not average much more than 25 miles per gallon. In contrast, a rail passenger coach, with only half of its roomy seats occupied, will produce 126 passenger miles per gallon, which is 400 percent better than a typical automobile and 500 percent better than commercial jet aviation on flights less than 500 miles. With America's huge unfavorable balance of payments for foreign oil, rail transportation has a tremendous advantage for energy conservation and cost reduction.

Productivity has repeatedly been cited as the key factor for regaining a competitive advantage for the United States. Recent losses and slow improvement in productivity have hurt the national economy and have promoted inflation and unemployment. Rail productivity is an essential element for regaining preeminence.

Rail labor costs a great amount of money, and archaic practices cost more than necessary, but it is not true that rail labor productivity is unsatisfactory. A truck driver with a typical intercity load can produce only 6,500 revenue ton miles for a day's pay, at a direct labor cost of about $0.015 per ton mile after fringe benefits are included:

18 tons x 9 hr x 40 mph = 6,480 ton miles.

6,480 ton miles for $98 compensation = $0.015.

In stark constrast, a standard three-person train and engine crew supported by a three-person yard crew can and does produce 300,000 revenue ton miles for their day's pay, that is, 50,000 ton miles per employee, which is 850 percent more than the output of a truck driver at a labor cost of only $0.0025 per ton mile.

3,000 tons x 100 miles = 300,000.

$750 ÷ 300,000 = $0.0025.

Such productivity is worthy of national attention and implementation.

ELECTRIFICATION

What has the preceding discussion to do with railroad electrification and synergism? The following paragraphs will help clarify this discussion.

Railroads have the potential to perform an essential array of transportation services at a potentially economical cost. The restraint is commercial and institutional rather than technical. Railroads must offer the kinds of services desired by more consumers at prices they are willing to pay. This is where the railroads are failing, and where electrification can provide a solution in those areas where it is best suited.

More and more, railroads have been discarding higher-valued freight and passengers and are concentrating on low-rated bulk commodities and on low profit trailer-on-flatcar (TOFC) movements (5). Electrification can provide the proven and economical technology to reverse and improve the current low state of affairs by returning dollars to the railroad much faster than tonnage increases.

SYNERGISM

Trucking companies are earning up to $0.60 per ton mile on middle-distance less-than-truckload (LTL) shipments (4). Express rates are higher. With short,

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Economic Synergism in Railroad Electrification

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ABSTRACT

Railroad electrification has been generally accepted as the optimum method of propulsion for trunk lines in most developed nations of the world, except for North America. But in North America repeated studies have shown above-average rates of return on investment, greater efficiency, and faster operation. In this paper the possible reasons for North America's failure to develop railroad electrification, the advantages and disadvantages of electrification, and possible means for obtaining the benefits of electrification in North America are addressed. Because electrification requires a major increase in investment, synergism may be necessary to render electrification economically practical. Low-rated bulk commodities in volume can move more economically with electric power, but not always sufficiently so to induce private capital to make the effort or to take the risk. Other nations provide government funding to gain the substantial benefits of electrification. High-rated competitive movements seldom go by rail today, but they more likely would if the speed and economy made possible by electrification were made available to users. If high-rated goods were moved by rail, the added volume would reduce the unit costs of fixed expense, thereby reversing the downward slide of carloadings, which provokes rate increases, causes lower traffic volumes, results in reduced service, and repeats the downward cycle. In addition to freight, passengers, mail, and express also have profit potential under electric operations and offer the opportunity to make the total railroad operation more cost effective and useful than a single-purpose bulk commodity facility.

Except in North America, most developed nations of the world have progressed railroad electrification to a highly developed and extensive degree. The question must be asked, What is so different about North America that denies conventional wisdom favoring railroad electrification?

Most important is the institutional difference. Only in the United States (and partly in Canada) are railroads funded by tax-paying private investors in search of a profit, yet at the same time competing with government-subsidized highway, waterway, and airway facilities. In most other countries railroads are funded by government in the same manner as the other transport modes.

Many recent domestic studies have found highly positive rates of return on investment for American railroad electrification, ranging between 15 and 20 percent for the most promising routes (1). For an industry straining hard and futilely to earn even 6 percent (2), electrification would seem essential, and indeed it may be. Why then is there little progress and actual disinvestment?

WHY NOT?

Railroads are not operated solely for their rates of return. They are too essential and important, both economically and politically, to be liquidated because of their inadequate profits. It is difficult to attract all of the necessary capital in this mixed, or double-standard, economic climate of socialized subsidy funding for all other transport modes. Competition is not conducted with economic equity. After taxes and debt interest, too many of the real benefits of electrification are siphoned off, leaving too little net income to fund the necessary effort with adequate margin or safety factors. Why would an investor risk competing with untaxed, free transportation capital from the government? Gresham's law cannot be repealed. Good business practice in this climate may be bad business practice for the investor.

A second drawback to electrification is operational. Why bother? It is a nuisance. Operating officials prefer a single, ubiquitous, simple, standardized pool of motorized power that can go anywhere and pull anything. Engineering officials do not want to bother with catenary and substation maintenance. Financial officers do not want the added debt and watered stock necessary to fund electrification.

A third significant excuse for avoiding electrification is the declining market share of the railroad industry. Carloads go down, level off, then go down again (3). Piggyback growth is often profitless. Highway, waterway, and air carriers are winning a larger share of the nation's transportation