suggested include (a) increasing the yard capacity at Memphis, Tennessee, and (b) improving the track on the Memphis cutoff to take advantage of the more direct route.

Other impacts of the merger on traffic volumes were made readily apparent by interactive graphic displays of the before and after traffic volumes. Such methods are extremely important in the ongoing strategic planning activities of railroads, particularly in contingency planning. Actual results for the ICG-SOU merger are not given here, principally because they are preliminary results intended only for planning and contingency analysis.

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Transportation Manpower Adjustments to Technological Change Through Collective Bargaining: The Crew-Size Dispute in the Railroad Industry

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Most industries adjust work-force size to technological and economic changes, but the number of brakemen on railroad crews is inflexibly fixed by labor agreements. This paper traces the controversial and still unresolved crew-size dispute from its origins in 1959 through 1978. The dispute was heated between 1959 and 1970 and was punctuated by strikes. The government intervened with a Presidential Railroad Commission, the National Mediation Board, Arbitration Board 282, and Emergency Boards 154 and 172. The federal courts were also involved. The brakemen succeeded in upholding their position and in securing a general rule of two brakemen per crew over management protests that technological changes had made one brakeman sufficient. The research involved in this study was divided into library research and field research. The former consisted of a comprehensive examination of the available literature. The latter consisted of (a) an examination of relevant documentation, including correspondence, and other primary sources of written information in the files of pertinent railroads and their General Committees of Adjustment and (b) interviews with railroad and union officials and with operating and nonoperating employees, as well as informed neutral parties (e.g., mediators and arbitrators). Policy recommendations for labor, management, and the government are also made.

The most protracted labor dispute in the railroad industry over the past 20 years concerns the size of road and yard crews. This still unresolved dispute stems from the 1959 demand by railroad management for the prerogative to specify the number of brakemen on train and yard crews, upsetting the position held by the railroad operating unions that crew size should be subject to the collective bargaining process. This issue highlights not only the labor relations problems endemic to the railroad industry, but also characterizes the larger quandary facing all the other transportation sectors (trucking, airlines, and longshoring)—the need for rationalization of employee job security with the exigencies of technological progress, which, in turn, is energized by competitive pressures.

The crew-size dispute was heated between 1959 and 1970 and was punctuated by strikes. The government intervened with a Presidential Railroad Commission, the National Mediation Board, Arbitration Board 282, and Emergency Boards 154 and 172. The federal courts were also involved. On June 13, 1977, the industry broke the uneasy truce that had been in effect since 1970 as a reaction to a union wage-increase demand by serving notice of its intention to gain the right to determine crew size. This analysis, therefore, seeks to contribute to an understanding of the critical issues that labor, management, and the government will have to consider in the near future.

Most existing crew sizes include a conductor (engine foreman on a yard crew) and two brakemen (called helpers on yard crews). Management has believed that the second brakeman or helper is unnecessary, whereas the United Transportation Union has asserted that at least two are needed. The dispute thus has a single clear-cut issue: Do some (management claims many) crews have an excessive number of brakemen? The ramifications of this basic issue are extremely complex.

It has been traditional for the number of brakemen

and helpers on railroad train and yard crews to be determined by quid pro quo bartering at the collective bargaining table. That is in contrast with the practice in most industries of management's having the authority (frequently described as "management prerogative" or "management right") to determine unilaterally the size of a work force. It is common in such cases for employees to be protected against a possible abuse by management of its authority, particularly in the two key matters of safety and work burden, by a grievance procedure, coupled with provision for grievance arbitration.

In 1959, pursuant to the procedures of the Railway Labor Act, the railroad industry announced its intention to regain the management authority over crew sizes that had gradually been bartered away over many decades in exchange for union concessions deemed desirable by the industry at the time. Negotiations on the announced intention, which were required by the Railway Labor Act, were fruitless and, because of the tension between the industry and the brakemen's union, the Brotherhood of Railroad Trainmen (BRT), which is now part of the United Transportation Union, the government intervened in 1962 with a Presidential Railroad Commission that proposed additional negotiations. In 1963 Emergency Board 154 made a similar recommendation. The Commission and Board 154 did not cool the dispute. In 1963, Arbitration Board 282 recommended a continuance of negotiations and imposed certain provisions that had the force of law. For two years, effective January 24, 1964, all crew members then employed would be "protected" in their jobs against layoff and discharge and a breakdown in negotiations on an individual railroad was to be followed, at the request of either management or the union, by compulsory arbitration—the first peacetime compulsory arbitration in this country.

The BRT feared such arbitration, although many railroads looked forward to it with high hopes and invoked it. Numerous one-brakeman (helper) crews were authorized by arbitrators during 1964 and 1965. In the arbitration cases the railroads had asked that 5571 jobs be eliminated and were granted a reduction of 4855; the highest figure, which applied to the Illinois Central Railroad, was 98.3 percent.

Of all the nation's railroads, the Illinois Central had been the most adamant in insisting on management's right to determine the size of crews and the most innovative in pursuing that objective. During 1964-1965, with arbitrators authorizing crews to be reduced but with Board 282 "protecting" the affected employees against layoff or discharge, the Illinois Central had eliminated numerous surplus employees by offering them voluntary severance pay scaled to age and earnings.

The crew-size dispute is far from settled. A truce since 1970 was broken on June 13, 1977, by industry management in formal action, pursuant to Section 6 of the Railway Labor Act, which reinstated its 1959 claim that crew size is properly a matter of management's authority. The future of the dispute is difficult to predict.

What has been the position of the two parties regarding the major areas of disagreement in this dispute over the past 20 years? Union and management have agreed that there have been significant technological changes in railroad operations; they have differed, however, as to the extent to which the introduction of technological changes has affected employees' duties, responsibilities, and workloads.

The railroads have said that technological changes have increased safety but have diminished the job content of crews, their work requirements, and the major responsibilities of individual crew members. They have pointed to such technological improvements as centralized traffic control, automatic block signal systems, communication equipment, and the improved quality of rolling stock, all of which enable work to be done properly with fewer employees. Furthermore, they have complained that existing crew-size rules, agreements, and practices prevent them from realizing potential productivity gains from such technological progress.

The union has argued that most employees' duties have not been lightened but have been increased. Furthermore, technology has intensified the burden of responsibility carried by crews because of increased speeds, increased train lengths, and increased car weights, all of which have increased employees' need for alertness against equipment failures and accidents. Thus, the union has insisted that management's desire to reduce crews would increase employees' work burden and the dangers inherent in railroad operations.

The railroad industry today is substantially in the same position it was in at the beginning of the crew-size dispute in 1959, with the exception of the Milwaukee Road. On April 1, 1978, the United Transportation Union and the Milwaukee Road reached agreement on train crew reduction. The terms of the agreement provide for reducing present three-member road and yard ground crews to two members based on straight and pure attrition. No employees will be laid off or transferred, but reductions in crew size will occur as present employees retire, resign, are promoted, or leave the service for other valid reasons. The carrier and the union estimate the current attrition rate at 5-8 percent annually.

When crews in yard and road service are operated in the "reduced" status (road trains subject to train length limitations), each crew member will receive a special allowance of $4 as compensation for the additional service and responsibilities consistent with the operation of a reduced crew. This $4 allowance is subject to applicable cost-of-living and basic wage increases. In addition, each time a reduced crew is used, the company will deposit $48.25 into the employees' productivity fund. At the end of each year, this fund will be divided by the employees eligible to participate, according to the number of tours of duty they have worked in road freight or yard service that calendar year. Interest earnings of the fund will be added to the carrier deposits for the sole benefit of the participating employees.

The year-end division will increase each year until the maximum of one-third total compensation for that calendar year is reached for each protected employee. The employees may leave their individual bonus or shares in the fund for future interest growth as a savings fund or a supplemental pension or may elect to withdraw it at the time of the annual division.

The new agreement also allows operation of non-revenue trains, such as work trains and snowplows, and the operation of new business trains, handling only business not previously handled by this line, with reduced crews.

The Milwaukee agreement, which could spread to other lines, reportedly caused shock waves among negotiators for the nation's railroads currently bargaining with the unions over proposals for new labor agreements. Some spokesmen for the carriers complained that the productivity bonus was too generous and that the clause limiting the agreement to 70 cars or less was too restrictive.

The crew-size issue has thus been the cause of 20 years of intermittent impasses, strikes, and intervention by government boards. Although a few rail-

roads have dealt effectively with the crew-size problem, most railroads still have not eliminated numerous trainmen whom they consider unnecessary with respect to the safe and efficient operation of train and yard activities.

LESSONS TO BE LEARNED

Some of the lessons to be learned from the crew-size dispute are of interest primarily to the railroad industry, but, on a broader basis, much is applicable to labor-management relations in the other transportation sectors.

Relative Economic Power

At the collective bargaining table, the relative economic power between a union or a group of unions and a railroad or a group of railroads tends to be felt in terms of the degree of concern generated by a strike threat. That is, both union and management weigh their individual capacity to endure a dispute and the probable endurance of the other party. In order to adjust the scales, groups of unions or groups of employers may band together. In the crew-size dispute, the union's strike tactic was the use of the selective strike in which one railroad at a time is struck. When a selective strike is properly planned and executed, the relative economic power, given the conditions in the railroad industry, is definitely on the side of the union.

One reason for relative economic power tending to be in favor of the unions is that the railroads are "time sensitive," i.e., they quickly lose their customers to competing modes of transportation during a strike, and in some instances the loss is permanent; unlike a manufacturer, they cannot stockpile inventories in anticipation of a strike, and opportunities to recover losses after a settlement are limited. Thus the capacity of a railroad to resist, which is not too substantial, may not be as great as total union strength, and the unions may force uneconomic settlements on the railroads. In disputes, then, which involve an individual railroad, a major union may be deemed on balance to have somewhat greater economic power than an individual railroad.

In the railroad industry the strength of a union in a strike so outweighs the ability of an individual employer to endure a strike that collective bargaining can become a mockery. Although agreements are reached, they may not necessarily be equitable. The economic plight of the railroad industry creates a serious imbalance of power between labor and management. The limited finances of most railroads and the relative ease with which other railroads and particularly the truckers can take business away from a struck railroad make railroads susceptible to strikes, and labor takes advantage of this situation at the same time that they may be maneuvering to avoid triggering emergencies that would result in government intervention unfavorable to a union.

Economic Environment

In the economic environment of the railroad industry, both labor and management feel the severity of competitive pressures, which necessitate improved service, increased efficiency, and the reduction of costs. Where such pressures are strong, management can be expected to pressure unions to accept newer techniques or to modify restrictive practices. Conversely, where market pressures are relatively weak, management is less inclined to risk confrontations with unions by pressing for change.

Although the unions feel the severity of competitive pressures, it is essential to note that they do so only indirectly, namely, as a result of management action at the collective bargaining table, of reduced calls for new employees, and of employee layoffs. Consequently, it is likely that the unions do not sufficiently appreciate the pressure that competition and other economic factors put on management, particularly inasmuch as the unions do not have a direct interest in the interpretation of comparative financial statements. At the union level that interpretation is a tenuous one that, at best, usually requires some time for its severity to be recognized. Thus, the unions tend to blame management for its insistence on technological change rather than to concede that management is merely reacting to intermodal competitive pressures in the transportation industry.

Lack of Creative Thinking in Board Decisions

The only contribution of intervening government agencies was to postpone a final settlement of the crew-size dispute. There was no originality of any significance in the proposals of the Presidential Railroad Commission and the Emergency Boards, at least as far as the pursuit of a final settlement was concerned. Those intervening agencies appeared to have but two objectives in view: to avoid strikes and to maintain the status quo ante. They all told the parties to go home and bargain some more.

Management Authority

The great issue in the 20-year-old crew-size dispute is whether crew size should be subject to management authority or to collective bargaining. A railroad crew is merely one kind of work force, and the broader issue is whether the size of work forces is properly subject to management authority or to the barter of the collective bargaining table. I take the former view, and I see a line in labor-management relations: On one side of that line there are subjects that belong in the area of management decision making, and on the other side there are subjects that belong in the area of collective bargaining, that is, subjects to be settled by a process of barter, of an exchange of concessions, of a giving of quid pro quo, and, in extreme situations, of the parties' recourse to their economic strength—labor's strike and management's lockout.

Basically, it is my view that the size of a railroad crew or any other work force is a matter for determination in an industrial engineering analysis, with the industrial engineer paying attention to considerations of safety and the work burden. Such an analysis is on management's side of the line and any resulting grievances are on labor's side of the line.

Collective Bargaining Structure

Where several unions negotiate for closely related employee groups, it is often more difficult for one union to adopt a more receptive attitude toward change than the others. Conversely, if bargaining is carried out only by one union, or with a high degree of coordination among several, the possibility of accommodation to change will be greater. There are two reasons for this; one is economic and the other political. From an economic point of view, the presence of several unions bargaining separately make it very difficult for any one of them to consider the possible favorable impact of its own policies on the demand

for its own members' services. If the policies of the unions were coordinated, however, or if only one union represented all or a very large proportion of the work force, it would be able to give more serious weight to the possible favorable effect on employment of a more willing acceptance of technological change. From a political point of view, the presence of several unions in an industry presents the danger that any one union that adopts a more receptive attitude than the others will open itself to charges of failing to protect the interests of its members. Again, where only one union is involved or where all the unions are adopting a similar approach, this danger is reduced.

The craft unionism of the railroad industry, as differentiated from the industrial unionism of the manufacturing industry, is one of the most important variables in the railroad industry's collective bargaining structure; a craft union is characterized by the possession of cherished traditions in the way things are done, a circumstance that is not conducive to flexibility in the acceptance of innovations. To some extent, however, in the instance where there is multicraft bargaining on an issue, such bargaining provides a kind of half-way house between craft and industrial unionism.

One additional implication of the union bargaining structure deserves emphasis. It has been noted above that there is a high degree of substitutability between railroad and trucking service; this suggests that the introduction of greater efficiency, particularly in the form of faster and more dependable railroad service, could considerably improve the volume of freight handled by rail and hence improve the employment situation for railroad labor. Because of the large number of individual unions involved in negotiations, however, it is very difficult for any one of them to have a significant impact on overall operations to take this relationship into account. Were only a few unions involved, or greater coordination achieved among them, the relationship between their policies and employment might be considered more directly.

The craft unions in the railroad industry are thus like a jigsaw puzzle. Their number and their competitive interests have contributed to labor unrest and strikes, and they create rigid work-rule restrictions blocking responsiveness to the need for technological change. The multiplicity of unions and their frequent jurisdictional rivalries have hurt the railroad industry particularly in its efforts to compete with other modes of transportation. Further, the fractionalized union structure contributes to fractionalized response on the part of railroads, singly or in groups.

Craft loyalty is intensified whenever a craft is threatened by the contraction of employment opportunities in the declining industry, particularly in the case of abrupt technological changes. Not only do the railroad unions adhere tenaciously to their traditional jurisdictional claims to jobs on a craft basis, even where technological or other changes have blurred lines of demarcation between the original crafts, but, furthermore, the principle of seniority creates problems when employment is reduced; job security becomes a highly sensitive issue, with union emphasis on traditional work rules impeding management efforts to effect changes in those rules necessitated, in management's view, by changed conditions. A prime example of this situation is the crew-size dispute. In addition, as the average age of those retained in employment rises, job security issues become more serious in each craft's negotiations.

Employer Attitudes and Policies

In the crew-size dispute the principal feature of management's attitudes and policies has been the lack of uniformity in the industry. Some railroads were not particularly interested in reducing crews, others merely followed the lead of a few influential railroads in signing agreements regarding crew size during the dispute, and only a handful fought aggressively for management's 1959 claim that crew size is a matter of management authority and not subject to determination by negotiation. It can be expected that the union will continue to take advantage of the general lack of energy and cohesion in the industry in later phases of the dispute.

Facts Regarding Safety and Work Burden

In reviewing the 20-year history of the crew-size dispute, one of my principal criticisms is that, during all that time, with the exception to some extent of the arbitrators during the Arbitration Board 282 period and the Presidential Railroad Commission, neither the parties nor government boards walked out onto the tracks to assess two key factors—safety and work burden.

The industry's position was that it could not afford the expense of what it deemed to be unneeded brakemen; the union's position was that they were needed because of considerations of safety and work burden. Such claims cannot be settled in conversations across a labor-management conference table. The facts can be determined only by going out onto the tracks and into the yards and observing crews at work and analyzing that work in accordance with the principles of an industrial engineering study.

Government Regulation

Railroads have not had the freedom to respond to many competitive challenges because government regulation restricts the industry as a quasi-public utility, although the essential feature of a true utility—namely, its monopolistic character—is not present in the railroad industry.

Regulation circumscribes the freedom of management to adapt operations to evolving markets. For example, it seriously encumbers rate making, a vital competitive marketing tool vis-à-vis crew size. Regulatory procedures and decisions have delayed the abandonment of services that no longer attract patronage sufficient to defray their costs, such as light-density branch lines. Mergers, provisions for ancillary trucking or barge lines, and other basic responsibilities that are normal prerogatives of management in other industries have been subject to detailed regulatory scrutiny and prohibitions. Furthermore, government approval of some changes often entails years of delay and costly legal procedures at both the state and federal levels.

The long-term effect of such intensive regulatory control has been to discourage innovative progress and to blunt management incentives and initiative. Government regulation has produced a sense of helplessness and despair on the part of railroad management regarding its ability to control and improve the destiny of the industry and even to save the industry without turning it over to the taxpayers under nationalization.

Perfunctory Negotiations

Many observers subscribe to the thesis that the Railway Labor Act by its very nature was certain to preclude settlement of the crew-size dispute through collective

bargaining. This was so because federal assistance, including mediation by the National Mediation Board and factfinding by emergency boards, cannot practically do more than merely delay the parties' final step in collective bargaining, namely, "self-help" such as a strike or a threat of a strike, which is acknowledged as an intrinsic and legitimate extension of the collective bargaining process. Furthermore, the writing of the status quo ante into law (all the way until 30 days subsequent to the report of emergency board if one is convened) shows an obvious bias in favor of the status quo ante that reinforces the ever-present influences opposed to change in the industry's collective bargaining system. Finally, it is asserted that collective bargaining cannot function as it should with statutory and extrastatutory government intervention on the horizon; why bargain away something that, hopefully, government intervention of one sort or another might later grant?

The public interest emphasis on the maintenance of labor peace in the railroad industry limits the parties' freedom to engage in self-help. Strikes are discouraged as are changes made by management that would precipitate strikes. Because the government will not accept a major railroad strike as an acceptable extension of the collective bargaining process, disputes have tended to shift to the political arena, imposing an untested set of criteria on the settlement process. Equity has become dependent on the political process; some settlements have been achieved only after political pressure has been brought to bear on the parties. There is little question that substantial progress toward labor relations peace cannot be assured by requiring employers and employees to behave toward each other in a manner mandated by the government. Such measures can postpone but not necessarily prevent crises; for example, settlement of the 20-year-old crew-size dispute has been delayed, if anything, by various government interventions.

Critics note that, if the result of an impasse in collective bargaining is to be the appointment of an emergency board or the imposition of some other form of government required status quo rather than an immediate work stoppage, the consequences of nonagreement are materially changed. A work stoppage, or a threat of one, is generally acknowledged as an integral part of the collective bargaining process, as is a lockout by management. Thus, a basic assumption underlying the bargaining process is that a built-in automatic stimulus for settlement exists that will become operative when the costs of nonsettlement become too great for one party. Although this is an ultimate recourse—not to reason but to force in the collective bargaining process—it is a legitimate recourse in the free enterprise system. If such costs are absent, there is no inducement for either of the parties to change its position. Congress stands ready to eliminate the costs of nonsettlement by special legislation whenever major interruption of railroad service threatens the economy; pending such an eventuality, the parties tend to jockey at the collective bargaining table toward placing themselves in strong positions that can be argued before an emergency board.

Consequently, the RLA procedures and their concomitant political environment have eroded the collective bargaining process in the railroad industry because the parties are deprived of incentive to reach agreement prior to the exhaustion of RLA procedures and the report of an emergency board. Even then, good-faith bargaining is unattainable if only one party welcomes congressional intervention.

Union Leadership

In the context of the crew-size dispute, the primary characteristic of the union's leadership has been its indifference to the financial plight of most of the railroads. The record indicates that fear rather than hope has dominated the union position. This fear has been manifested in adherence to old traditions: large-sized crews, crew changes at closely spaced seniority district boundaries, transfer of trains from road to yard crews on entering a yard (known as the road-yard distinction), the prohibition against interdivisional runs of trains, and retention over the years of pay practices developed to suit a set of circumstances that no longer apply.

This contrasts with the attitude held by other union leaders, such as some West Coast longshoremen, who felt it to be in the best long-run interest of their unions to work cooperatively with management in improving business conditions. The West Coast longshoremen's 1960 Mechanization and Modernization Agreement grew out of their realization that the best interests of their union lay in cooperating with management in assuring the health of their industry by means of technological change and relaxation of restrictive work rules.

RECOMMENDATIONS

The following actions are suggested where appropriate by either labor, management, or the government, or in combination as required, in order to promote a healthy and viable railroad industry capable of paying good wages and providing maximum job security.

First, it is important to note that, in contrast with most other industries, government policy covering the railroad industry regulates many aspects of the underlying economic environment, including the rates to be charged for freight service, the ease or difficulty of merger attempts, and the extent and nature of intermodal transportation competition and cooperation. Such types of regulatory control have made intermodal competition an important factor contributing to the pressures on management to improve efficiency, and these pressures have in turn caused management to adopt aggressive policies in collective bargaining directed at inducing the unions to accept changes. This suggests, therefore, that an important aspect of public policy should be the adoption of a regulatory policy that will maintain a relatively high degree of price and service competition among the railroads, truckers, barge lines, and airlines.

Second, more experimentation is required in the use of short trains because of the promise that they hold of eliminating the disadvantages of long trains. In the manufacturing industries, minimum inventories are essential in order to conserve working capital, and such inventories require fast and frequent transportation service. The trucking industry stepped into this gap and provided such service, but at a higher price that was preferable to enlarged inventories. It is obvious that the longer the train, the greater the delays in terminals. It is at this stage that the railroads have been losing the traffic battle to truckers. On the other hand, it is not possible to operate a short train with standard crews, including the yard crews handling it, and to cover its expenses out of income. Yet the short train has a high potential for meeting truck competition if the United Transportation Union will waive present agreements covering crew size, remembering particularly that the short train's purpose is not to replace existing crews but to give new crews employment by securing new business. The future of inexpensive high-priority

freight movement for many commodities could belong not to the truckers but to the short train.

One advantage of a contemplated change from long trains to short trains for selected shippers is that the change need not be a radical move; initially, it can be made on a purely experimental basis so that both the railroad and the union can be fully satisfied as to the impact of the change on them before any full-scale operations are initiated. Its objectives are clear: a more marketable transportation service, an improved share of the transportation market, and enhanced job security in a healthier industry. Complete implementation of the short-train concept will require, in addition to identification of current barriers to railroad efficiency and service reliability, commensurate modification in management and union policies and practices, and preliminary experimentation with government cooperation, particularly in granting the railroads flexibility to design competitive freight rates relative to the truckers' rates.

Finally, every effort should be made by responsible union leadership to broaden the base of collective bargaining in the railroad industry. At present a railroad may deal with as many as 20 unions, which are splintered by craft distinctions. The continuing existence of the Brotherhood of Locomotive Engineers outside of the four operating brotherhoods that merged into the United Transportation Union has complicated negotiations materially and made the adoption of progressive policies toward technological change more difficult. The strongest type of union for weathering the storm of technological and economic changes would be a multicraft or semi-industrial union; with such a structure each craft would have a greater chance to forestall total displacement in changing times. Thus, I urge more union mergers within both the operating and nonoperating crafts.

CONCLUSION

The size of a work force is properly a function of management and employees can adequately be protected against management's possible abuse of its authority by a grievance procedure, culminated if necessary by grievance arbitration. This is the general rule and practice in the economy, which has proven to be an effective and enforceable safeguard against unsafe working conditions.

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Parametric Study of Track Response

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This paper presents the results of a parametric study of track response using a comprehensive track analysis model. Track response parameters include rail and tie bending moments, rail displacement, tie rail-seat load, and the distribution of stresses in the ballast and subgrade. The effects of variations in tie size, tie spacing, ballast depth, and rail fastener stiffness are presented in graphs suitable for track design trade-off studies. Alternative wood and concrete tie track configurations are evaluated using equivalent maintenance criteria.

Experience from several foreign countries indicating advantages of longer tie life and reduced track maintenance for concrete versus wood ties has aroused considerable interest in developing concrete ties for main-line use in North America. However, few quantitative data are available for comparing wood and concrete tie loads and roadbed stresses, or long-term performance, as a basis for evaluating the technical and economic feasibility of alternative track and tie designs.

Current and past research has shown that the evaluation of track performance and design for vertical loads requires a capability for predicting realistic pressure distributions at the tie and ballast interface and at the ballast and subgrade interface. This requires a track analysis model that includes the effects of many track parameters.

The main purpose of the work presented herein is to use a MULti-Layered Track Analysis (MULTA) model for vertical loads to develop track design guidelines that include the effects of various tie and fastener characteristics, tie spacing, and ballast depth on track response. Alternative wood and concrete tie track configurations based on equivalent maintenance criteria are evaluated for use in future life-cycle cost analyses.

DESCRIPTION OF TRACK ANALYSIS MODEL

The analysis model selected for this program is a combination of an available multilayer model for the ballast and subgrade and a finite element model to combine the loads for individual ties and rails (load combination program). The load combination program was developed by the Association of American Railroads (AAR). It was modified by Battelle's Columbus Laboratories to incorporate influence coefficients from the multilayer roadbed model to provide a complete track model.

Figure 1 shows a schematic of this combination model known as MULTA. This provides a linear track