Development of Enabling Technologies for Heavy Axle Load Operations in North America

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ABSTRACT
Technology development has contributed to significant efficiency and safety improvements in the North American railroad freight transportation system. The heavy axle load (HAL) implementation and equipment-related research programs conducted under the Association of American Railroads’ (AAR) Strategic Research Initiatives (SRI) Program have been extremely successful in addressing the problems of heavy haul railways in North America and HAL issues in particular. Through testing and analysis, the research conducted by Transportation Technology Center, Inc. (TTCI) has helped the North American railway industry to safely and efficiently realize the economic benefits of larger capacity cars. In conjunction with the improvements in track structure and track component design and construction practices, enhanced inspection, staff training, and maintenance procedures, the U.S. rail industry has successfully addressed the challenge of safe and efficient operation of 33-tonne (36-ton) HAL traffic. The implementation of HAL has been smooth, safe, and highly beneficial to the industry. This paper addresses the following enabling technologies for successful operation of HALs:

- New and improved track components such as premium rail steels and tie/fastener systems
- Methods of reducing stress of the railroad using improved truck suspension systems, friction control, and wheel/rail profile designs
- New special trackwork designs and maintenance practices such as flange bearing crossing diamonds, improved turnout designs and materials, and maintenance methods
- Bridge life extension methods, maintenance procedures, and advanced bridge designs under HAL such as the hybrid composite span concrete bridge
- Performance based track geometry and track strength inspection systems
- Improved rail and rail joint bar inspection systems
- Bridge condition monitoring
- Effective design and maintenance of track substructure

INTRODUCTION
Since the late 1950s, there has been a constant pressure in the marketplace to increase train weight and axle loads in order to reduce operating costs and increase capacity. For North American freight railroads, the issue of productivity improvements achievable through increased freight car capacity is not a new one. A close examination of the history of U.S. freight railroads shows a pattern of increased axle loads as developments in technology, network rationalization, equipment productivity, and expanded engineering knowledge have made such increases possible. The capacity of the average freight car has risen by about 80 percent since 1960 and reached 92 tonnes (101.1 tons) in 2010. In the 1970s, 91-tonne (100-ton) capacity cars replaced 64-tonne (70-ton) capacity cars. Since the early 1990s, coal car capacity rose from 91 to 102 tonnes (100 to 112-tons) or to 109 tonnes (120 tons) with lightweight cars. Even though the economic efficiency of the 286,000-pound car reduced railroad operating costs, the additional wear and tear on the track structure because of axle load significantly increases track costs.

The U.S. railroad industry has developed a systems-engineering approach to evaluating the engineering and economic tradeoffs, through the AAR’s SRI program, over the past several decades.

With continued improvement in vehicle suspension systems and predictive and proactive car health monitoring aimed at reducing the forces and stresses at the wheel rail interface, and/or more robust track components and maintenance procedures, the SRI program has proven that 3.5.5-tonne (39-ton) axle loads are safe and technically feasible. The development of best practices and components, through continued use of the Facility for Accelerated Service Testing (FAST) to test new materials and techniques for strengthening the track structure as well as reducing the stress state under HALs, continues to benefit the North American industry. Figure 1 shows test trains used at FAST.
The long-term outlook for the North American railway industry is that demand for railroad freight and passenger service will increase at rates beyond the growth of the gross domestic product. With the railway network expected to be at capacity on some segments in the near future, it is imperative that research targeted at improving safety and efficiency be accelerated. The SRIs and FAST are vital in enabling the industry to meet the objectives identified by the AAR in a recent effort to prioritize research and technology goals in the 21st century.

Figure 1. (l) 15,500-tonne (17,000-ton) Train Operated at FAST (110-car train with 35.5 tonne (39-ton) cars and (r) Test Train at FAST Traversing the Hybrid Concrete Span Bridge

KEY ENABLING TRACK TECHNOLOGIES FOR HEAVY AXLE LOAD OPERATIONS

While the marketplace demands capacity at a reasonable price, it is the application of engineering technologies that helps achieve these overall business goals. If the axle loads are increased without fully understanding the technical and economic impact of the increases, severe operating problems may result.

A coordinated, systems-engineering approach has been implemented in North America to achieve cost effective rail transportation using HAL trains. The AAR and TTCI’s approach has been to work closely with the rail carriers, railroad suppliers, and the U.S. Department of Transportation’s Federal Railroad Administration (FRA) to address the problems of heavy haul operations and HAL issues. A discussion of the technical issues and technology solutions in the area of track, equipment, and operations is presented in the following section.

Track Design and Construction

The focus of track design for heavy haul and high speed rail is to mitigate the effects of dynamic loading and lower the stress state of the railway. This can be accomplished by elimination of discontinuities in the track, such as flangeway gaps at frogs, optimization of contact stresses by wheel and rail running surface profile, and smoothing track transitions, such as at bridge approaches.

Rail Wear and Fatigue Performance

Rail performance continues to improve through a combination of design and maintenance changes. These run the gamut from steelmaking practices to larger rail sections to better friction control. The series of changes made has shifted predominant failure modes from internal railhead fatigue to wear and rail surface fatigue (i.e., rolling contact fatigue or RCF).

Enabling metallurgical technologies that have increased rail service life include: clean steelmaking processes, which have reduced the size and number of inclusions in rail, increasing internal fatigue resistance significantly; development of high carbon (hypereutectoid) pearlitic steels, 1 percent and above carbon steels that have increased strength and wear resistance; and expertise in thermal-mechanical processing of steels (use of thermal mechanical processing (TMP) analysis), which has allowed better understanding of factors beyond carbon content that affect performance.

These tools are being applied to the RCF problem, so that improvements in wear and internal fatigue can be retained with improved RCF resistance. Figure 2 shows a comparison of strength properties for a prototype steel, developed using TMP analysis, versus premium rail steels in use today.
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Special Trackwork

The performance of special trackwork under HAL has improved dramatically in the past 25 years. This has been accomplished by teams of track engineers, suppliers, and analysts working together to move from static design to vehicle-track dynamics based designs. Elimination of discontinuities in the running surface is a current focus. Implementation of flange bearing frog technology has begun in North America. Elimination of unsupported wheels across flangeway gaps has resulted in reduced frog maintenance, fewer speed restrictions, and increased component service lives. Work towards dynamic design improvements in mainline turnout performance is underway. This includes improvements to running surface profiles to minimize contact stresses, optimized lateral stiffness in switches to minimize lateral forces, improved frog foundations to lower vertical forces, and the development of continuous mainline switches to eliminate discontinuities.

Turnout frogs that use flange-bearing design to virtually eliminate vertical dynamic loads for mainline traffic are being implemented. Figure 3 shows a "lift" frog in service (along with other types of flange bearing frogs). This type of turnout frog is rapidly being implemented in North America, with over 200 in service. Note that the mainline rail is continuous, with no flangeway gaps or running surface joints. A comparison of maximum vertical forces measured for the lift (partial flange bearing) frog and a conventional fixed point railbound manganese casting frog shows that the lift frog has a dynamic load environment similar to open track. In other words, it is nearly transparent to mainline traffic.

Figure 2. (l) Super Pearlitic Rail Microstructure of the Next-Generation Rail developed by TTCI and University of Pittsburgh, (r) Super Premium Rail Steels tested at FAST. (1 ksi=6.9 mpa)

Figure 3. Innovative Special Trackwork Designs for Heavy Haul Applications: (l) A Partial Flange Bearing Turnout, (m) Lift frog Crossing Diamond, (r) Full Flange Bearing Diamond
**Rail Joints**

Rail joints are most commonly used to divide the track into electrical circuits for train presence detection and traffic control. Noninsulated joints are often used as temporary joints when rail flaws have been removed from track. They are also used on many railways as permanent joints to join frogs to conventional rail. These joints are typically weaker than the surrounding track, creating local track alignment issues in heavy haul service. This type of joint was originally designed to allow longitudinal movement of the two rails, relative to each other (i.e., it was designed for jointed rail track). This feature is detrimental in continuously welded rail track, as it can lower rail neutral temperature.

Recent developments in North America have produced changes in joint bars, joint configurations, and foundations that have greatly improved the performance of rail joints in heavy haul service. Improvements in performance attributable to joint bars have come from longer bars of the same shape and bars that are integral to the joint foundation. Figure 4 shows three examples of heavy haul joints that use these concepts. The first is an insulated joint with “wrap-around” joint bars. This bar wraps around the base of the rail and is the bearing surface for the rail. This joint is as stiff as the parent rail and reduces relative movement of each rail with respect to the other rail and the joint bars. The second is a keyed joint (shown disassembled to reveal the mechanical keys). This joint uses mechanical keys between the rail and the joint bar to carry longitudinal and vertical load across the joint. This has advantages over conventional designs, which rely on fastener tension to create a compression joint. The keys are stronger and more durable under the impact and vibrations of railway service. The third is a taper cut insulated joint. This joint is configured as a lapped joint, rather than the conventional butt joint. It is inherently much stronger in vertical bending. The additional third glued surface, between the two rail ends, also makes this joint much stronger in the longitudinal direction. The overlapping rails allow “point slopes” on the rail ends to affect an impact free transition from one rail to the other.

![Figure 4. Advanced Rail Joints in Use in Heavy Haul Lines in North America: (l) Wrap Around Bar Insulated Joints, (m) Keyed Joint, and (r) Low Angle Taper Cut Insulated Joint](image)

**Track Transitions**

Track transitions are largely unavoidable in railway operations. These locations, where the track structure can change abruptly, consume a disproportionate share of maintenance resources. Track transitions include approaches to bridges, highway crossings, track crossings, and cut-to-fill locations. Recent advances in this area include acknowledgement that differential settlement across transitions is often inevitable. Effective transitions can be designed to ramp differential settlement over a longer distance. One such design, using minipiles to strengthen a clay subgrade, was developed for bridge approaches by AAR Affiliated Lab Texas A&M University. Figure 5 shows the prototype track. This design was able to reduce differential settlement and extend surfacing cycles by about 50%.
Concrete Ties

Concrete crossties have enabled North American railways to operate HAL traffic safely and economically in high curvature territories. Current issues with concrete ties include rail seat deterioration and the ability of the track to hold surface to combined high speed and HAL track tolerances. Recent innovations in design include use of more complex shapes that increase the vertical and lateral “footprints” of the tie. These designs increase track alignment and surface durability under the most demanding operating environments. Figure 6 shows half-frame and full-frame tie designs. Analysis of the design suggests it may increase track surfacing life by as much as 600% in HAL applications. The higher lateral strength will result in more stable track and reduced risk of buckling.

In addition, methods of improving the efficiency of the tie/ballast interface have been investigated. Elastomeric pads on the bottom of the crosstie are under HAL testing. These are expected to increase the tie/ballast contact area and reduce particle breakage at this interface.

Ballast Materials

An enabling technology on the horizon for track foundation design is discrete element modeling (DEM). Using this tool, designers can optimize ballast section performance based on ballast particle characteristics. Current design methods treat the ballast as a continuous medium. This simplified assumption limits the effectiveness of attempts to design ballast gradations and materials. Under the AAR Affiliated Lab Program, University of Illinois has developed a DEM ballast model. The model
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has been used to explore the effects of ballast material, particle shape, and gradation on track surface performance. TTCI is currently running model calibration/verification tests using ballasts from BNSF, CSX, Norfolk Southern (NS), and Union Pacific (UP) railways. The model will also be helpful in evaluating ballast/tie interface designs and maintenance procedures, such as tamping/consolidating frequencies.

Bridge Designs

Railway bridge designs differ from highway bridges because of the much higher live loading on railroad bridges and the differences in operating philosophies. Many railway bridges in North America were designed and built before 1920 (Figure 7). They were built with smaller and simpler equipment than typically used today. As a result, there are many short, simply supported spans. These bridges make the railway highly reliable and repairable following emergencies. Spans can be replaced and bridges returned to service in hours or days, as opposed to weeks or months for highway bridges.

As a result of this philosophy and the age of the bridge inventory, we have not fully exploited advances in materials and construction technologies. One attempt to do so is the hybrid composite beam (HCB) span being tested at the Transportation Technology Center (TTC). The span consists of beams that are tied concrete arches. This design has appeal in that it is lighter weight than a conventional voided box girder design. The potential to replace three timber spans with one HCB span, rather than two timber spans with one voided box girder concrete span, using the same construction equipment exists. Figure 1 (page 2) shows a 9.2-meter (30-foot) HCB span in service on the High Tonnage Loop at FAST. Initial testing of the span for 227-MGTonne (250 MGTon) has produced promising results. The next generation hybrid composite beam design will be a longer span (12.8-m [42-feet]) and will be tested at FAST in 2011 and then at BNSF Railway in 2012.

Figure 7. Examples of Heavy Haul Bridges used in North America: (l) State-of-the-Art, High-Strength Concrete Bridge Spans under Test at FAST, and (m) Revenue Service Bridge Structures at CSX and (r) UP railroads

Track Inspection and Maintenance

Durable track is one of the key enablers for heavy haul operations. Early studies conducted at FAST showed that in-track forces and stresses resulting from the HAL operations would accelerate and increase track degradation and track maintenance. In order to make sure that track remains a reliable supporting structure for heavy axle vehicles, proper maintenance and inspection procedures are required. The following sections describe the common track maintenance and inspection procedures implemented by the heavy haul railways in North America.

Track Geometry

The conventional method of measuring track geometry to ensure that track meets safe operating standards typically uses dedicated measurement equipment. Measured geometry parameters are compared to set limits to determine whether safety or maintenance limits have been exceeded. Track geometry evaluation cars perform testing on heavy haul lines two to three times a year, depending on annual tonnage (Figure 8). Heavy tonnage mainlines are inspected more frequently than this.

Track geometry defects identified using track geometry cars do not always relate to poor vehicle performance. Performance-based track geometry (PBTG) algorithms and models can predict which geometry defects are likely to produce anomalous vehicle responses. The combination of geometry
data and PBTG is effective in identifying problem geometry. But conventional geometry measurements are sometimes too infrequent to capture rapidly changing conditions at their onset. Automated systems (either locomotive or car mounted), as Figure 8 shows, left, operate unattended in revenue trains and can be used for frequent track inspection identifying geometry problems that produce anomalous vehicle responses before they result in damaging vehicle/track interaction.

**Figure 8. (l) Enesco VTI System installed on a NS Truck and (r) Typical North American Track Geometry Measurement Car**

**Rail Flaw Inspection**

The FRA requires that track in the U.S. is inspected for rail flaws in intervals based on track class and annual tonnage. On very heavy tonnage lines, U.S. railroads test track every three to four weeks. Crossovers are tested at least once a year using ultrasonic rail inspection systems (Figure 9). The defect data is transmitted by radio and downloaded to a database each night. Local maintenance crews review the defect report for their territory every morning and schedule repairs.

Rail flaw detection continues to be one of the highest priority research areas for North American railroads. Certain types of railhead flaws are difficult to detect with current equipment because of their shape, size, or orientation, and flaws in parts of the rail base cannot be detected. Furthermore, there are common rail conditions that can mask flaws or impede defect detection, which include rolling contact fatigue damage, rail shells, and excessive rail lubrication. A system with the potential to overcome these difficulties; for example, noncontacting defect detection system, should result in fewer service failures. Figure 9, right, shows the noncontact, laser-based rail inspection system being developed by TTCI.

**Figure 9. Advanced Track Inspection Systems for Heavy Haul Operations: (l) Typical North American Rail Flaw Inspection Car and (r) Laser-Based Rail Flaw Inspection System being developed by TTCI**
**Track Condition and Gage Strength**

In conventional track, the ties (sleepers) and their fastening systems are what hold the rails at the proper gage. Ties to be replaced have historically been identified by inspectors who walk the tracks and identify ties needing replacement. They then report the locations of bad ties to the appropriate personnel. This system is generally effective, but time consuming, and visual inspections does not always reflect tie strength. There are two general approaches for replacing this type of inspection. The first is an automated version of the traditional inspection methods. Vehicle-mounted machine-vision systems evaluate the conditions of the ties and fasteners (and the rest of the track). These systems can inspect much more track than an inspector walking the track. The systems range from those which simply record images for later human analysis and interpretation to those that perform some of the analysis and interpretation. Future systems will further automate the process, increasing efficiency and reducing subjectivity. A second approach is to measure track strength directly. Specialized vehicles are increasingly being used to do this. These vehicles apply known loads to the rails and measure rail response. These measurements allow the vehicles to locate weak spots in the track that correspond to locations of inadequate tie or fastener strength. This type of system can also increase efficiency and reduce subjectivity compared to walking inspections.

**Rail Grinding and Profile Control**

Rail grinding is commonly and effectively used by railroads to remove rail surface defects and to restore or produce a rail profile that is conducive to proper wheel/rail interaction. Most U.S. railroads prefer minimal-pass, preventive maintenance grinding to reprofile the rail shapes and to remove surface damage on their heavy tonnage territories (Figure 10). The objective is to extend the rail life with reduced risk of internal rail fatigue defects and to improve truck steering by matching the wheel and rail profiles.

Effectiveness and efficiency are two key metrics in assessing rail profile grinding. Effectiveness measures how well the grinding objectives are reached. Objectives include low-contact stress, good curving performance, lateral stability at high speed, and surface defect removal. Grinding costs are related to efficiency; factors include amount of metal removed, grinder speed, grinding interval, and initial accuracy of grind patterns. A pre-grinding inspection using an electronic profile measurement system along with profile analysis software can recommend grinding patterns based on local conditions, including typical wheel profiles. These recommended grinding patterns can minimize the amount of metal removed and reduce the number of grinder passes needed to produce the proper rail profile. Rail profiles properly designed to be compatible with the wheels that traverse the track will improve the effectiveness of the grinding. Trials of such a system have been conducted by TTCI and NS and have demonstrated its effectiveness.\(^\text{15}\)

\[\text{Figure 10. Heavy Haul Rail Maintenance Procedures: (l) Rail Grinding to Remove Surface RCF Defects at UP’s Heavy Haul Lines and (r) Top-of-Rail Friction Control at UP}\]
Friction Control

The effectiveness of friction control, both top-of-rail and gage-face, in reducing rail wear, wheel wear, fuel consumption, development of rolling contact fatigue damage, and curving forces has been demonstrated. However, difficulties in the implementation of the technology have limited its use and effectiveness. Incorrect application rates or machines that are not working properly can mean that full benefits of friction control are not realized. Current friction control application systems require track inspection and assessment to determine the effectiveness of operation. Figure 10 shows a top-rail friction control system commonly used in North America. Sensor technologies, capable of detecting changes in friction conditions (not just application rates) along with software and hardware that can use the information to monitor and adjust the performance of wayside based applicators, would enhance the benefits of friction control.

Bridge Strengthening

Bridge capacity can be a major constraint for HAL traffic, in part because of bridge longevity. It is not uncommon to find bridges that are over 50 years old on potential HAL routes in North America. Operation of heavier cars over these bridges is likely to shorten remaining fatigue lives and increase maintenance costs. These bridges may have to be strengthened or even replaced to enable safe, economical HAL operations. A study of bridge spending on three major North American railroads showed that capital investment in bridges is required for a significant increase in HAL traffic. Selective member replacement can be an effective strengthening methodology, but in many cases the entire bridge may have to be replaced. Science-based inspection methods and advanced fatigue models and analysis tools are needed for the development of cost-effective strengthening or replacement plans. High-strength, lightweight materials, such as composites, have the potential to improve the effectiveness and economics of either strengthening or replacement.

Improved Surfacing and Tamping

Traditional maintenance methods, such as tamping and lining, undercutting, and shoulder cleaning, are employed to clean and replace fouled ballast (Figure 11). Proper ballast and subgrade maintenance allows ballast to last longer, better support and distribute vertical load, maintain track geometry, act as a medium for good drainage, and facilitate correction of track geometry. Tamping and lining are commonly used to correct track profile. Generally, an out-of-face surfacing cycle is established based on tonnage. The frequency of high-speed tamping and lining depend on annual tonnage, ballast and foundation condition, and whether the track has wood or concrete ties. Very heavy tonnage lines carrying more than 181 MGTonne (200 MGTon) per year undergo high-speed surfacing and lining several times a year. Track time available for maintenance generally decreases as tonnage and axle loads increase. Increased speed of operation, automation, safety, reliability, and ease of maintenance allow more work to be completed in less time. Collecting and diverting surface water away from the track structure is also one of the most important ways of maintaining good track structure. Undercutting operations are implemented to remove the fouled ballast from problem areas. Off-track machines are used to perform spot undercutting, tamping, and tie insertion operations.

Figure 11. Heavy Haul Rail Maintenance Procedures: (l) Rail Laying and Lining Machinery and (r) Track Tamping Machinery
**Detection and Remediation of Inadequate Track Substructure**

The condition of track substructure strongly influences track performance. Poorly performing substructure not only results in high rates of track geometry degradation but also promotes higher rates of track component degradation. Track substructure problems are typically associated with poor drainage, fouled ballast, or inadequate support materials. Any or all of these can result in substructure failure or deformation. Higher axle loads tend to exacerbate track problems caused by poor substructure. Increased understanding of track substructure behavior and performance will allow for the design and maintenance of track substructure that is capable of supporting HAL traffic. After substructure problems have been identified, they have to be corrected. There are effective remediation methods currently available; unfortunately they typically require track removal for implementation. Methods that can be applied with the track in place have been only partially effective. Better remediation methods that can be implemented with the track in place are needed.

Further development and utilization of inspection technologies, such as ground penetrating radar (GPR), and the incorporation of the technologies into an integrated substructure maintenance management system is currently underway as part of a cooperative AAR and FRA research program. GPR is currently being used as a ballast and subgrade inspection tool, but impediments to further implementation remain. New equipment and analysis tools are needed before the promise of GPR can be more fully realized. Research is also underway to determine the root causes of geometry deterioration through field inspections and to develop improved laboratory test capability to quantify substructure material strength and permeability. Too often, the symptoms of geometry deterioration are treated rather than the causes. Training field personnel and providing them with the necessary tools to identify the root causes of geometry problems will enable them to more effectively address the problems.

**Improved Welding for Both Rail Joining and Special Trackwork Repairs**

Rail joining technology must be further improved to enable HAL and HSR implementation. Thermite welds are very appealing because they do not consume rail. They can be used to join rails that are in place in track, and they do not require expensive equipment. However, their lives are often less than the life of the adjoining rail, especially under HAL conditions. Considerable effort is being made by researchers and suppliers to improve the performance of thermite welds in HAL service. Among the most successful improvements are wide gap welds and head repair welds. The wide gap welds are 5.1 cm (2 inches) to 7.6 cm (3 inches) wide and allow replacement of a transverse defect or defective weld with a single thermite weld. The head repair welds allow replacement of a transverse head defect with a thermite weld of the head of the rail only.

A new thermite weld mold is being designed. Modeling indicates that its improved metal flow characteristics may reduce entrained porosity and inclusions and could produce narrower heat affected zones in the railhead. Advanced weld treatments, such as vibration or controlled cooling, could also increase weld life. However, the advanced treatments increase the time needed to complete a weld. As an alternative to thermite welding, in-track flash welding is used in rail replacement and defect replacement operations. Reduced consumption flash welds have made the process of making a closure weld in track more economical. Ultimately, an alternative to currently available rail welding methods may be needed for very HALs. A system that produces welds at least as good as an electric flash butt welder (EFB), at costs and efforts no greater than EFB, while consuming no rail when producing a weld, would be extremely beneficial.

Similarly, weld repairs to special trackwork castings have lives that are shorter than the parent materials. These welds and castings can be subject to impact loads greater than four times static loads because of the running surface discontinuities and gaps inherent in many types of special trackwork. Weld consumables with the increased hardness and toughness requisite for improved performance are needed, for both existing casting materials and new materials being developed.

**ECONOMIC IMPACT OF INCREASED FREIGHT CAR CAPACITY**

Increased productivity in freight transportation can be accomplished in a number of different ways: (1) increasing the physical dimensions of traditional equipment to greater capacity, (2) overloading the
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existing capacity cars to greater weights, provided that the car components are not compromised. (3) using innovative new equipment designs to accommodate higher train capacity for a given length, (4) using longer trains equipped with existing capacity cars, provided that the physical plant and the sidings can accommodate increased lengths, and (5) increasing train speed. However, the practical constraints on vehicle stability, braking capability, and locomotive power requirements and fuel consumption place limits on higher speed operations.

Regardless of the approach employed, increasing the car size (axle load) is of value only to the extent that the total costs, per net ton, of train operations are reduced. Obviously, the required economic assessment depends on the relationship between car size and transportation costs. The negative impacts of increased axle loads occur primarily in the areas of track and bridge maintenance and renewal, and freight car maintenance.

Increasing car capacity and axle loads while retaining the two-truck, four-axle car design has proven to be the least cost option for bulk commodity operations in North America.

The use of higher capacity cars in North America has led to capacity improvements through accommodation of additional trains without track mileage increases. For higher tonnage lines, increased axle loads resulted in improvements in trip time and reduced train delays relative to the base case. The reduced fuel consumption, reduced car and locomotive miles, reduced number of trains, reduced number of crews, reduced switching activity, and improved net-to-tare ratio has led to additional savings.

The HAL economic analyses conducted by TTCI have estimated the costs of operating both of these cars as well as an intermediate option, a 130,000-kg (286,000 lb) capacity freight car. The results show that operation with axle loads greater than 30 tonnes (33,000 tons) are technically feasible and economically desirable. Operations with 33- (36-) and 35-tonne (39-ton) axle loads result in additional track maintenance, but require fewer trains for the equivalent net traffic under 30-tonne (33-ton) axle loads. The benefits of HAL operations are highly route specific. Therefore, it is recommended that individual railroads carefully analyze their specific service alternatives.

CONCLUSIONS

Over the past several decades, TTCI has devoted a great deal of research to understand the technical, safety, and economic issues related to track performance for high tonnage freight traffic and heavy axle loads. Much of this research has been conducted at FAST in Pueblo, Colorado. In addition, many enabling technologies developed and/or currently being developed under the AAR Strategic Research Program have helped the safe and efficient introduction of HALs in North America. Achieving lower unit costs for each ton carried by the North American railway industry was facilitated by carefully reviewing and studying the effects of 33 (36-) and 35-tonne (39-ton) axle loads before the final decision was made to go with 33-tonne (36-ton) axle loads. The net benefits of the 33-tonne (36-ton) axle load operations are estimated at billions of dollars.

FAST continues to serve as a proving ground for improved track components, inspection and maintenance procedures, as well as for test and evaluation of other enabling technologies. Continued use of the FAST environment to test new materials and techniques and to strengthen weaker links in the track structure is planned.

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