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INTRODUCTION OF HEAVY AXLE LOADS BY THE NORTH AMERICAN RAIL INDUSTRY, 1990 TO 2012

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ABSTRACT

The Association of American Railroads initiated the Heavy Axle Load (HAL) Research Program in 1988 in order to "provide guidance to the North American railroad industry about whether to increase axle loads and to determine the most economic payload consistent with safety"(1). The research, which is still on-going, has demonstrated the technical feasibility and economic desirability of increasing axle loads and the ability of technology to mitigate the adverse effects of heavier loads.

As a result of the initial phases of the HAL Research Program, the industry decided in 1991 to accept cars with 286,000 lb. gross vehicle weight (GVW) in interchange service. Since then, more than 90% of all bulk equipment acquired has been rated for 286k GVW. Today, nearly 100% of coal traffic and approximately 30-40% of general freight moves in 286k loads. Annual benefits of HAL operations to railroads, suppliers, and their customers now exceed $1 billion. Benefits include reduced capital and operating expenditures for bulk equipment, increases in net tons per train mile, better fuel efficiency, and increases in line capacity. Further benefits are now being realized by the introduction of shorter cars that retain the 286k GVW limit, while gaining most of the cost and capacity benefits of heavier cars.

Technological improvements resulting from the HAL research program have been critical in enabling the industry to reduce costs of 286k operations. Some of the most important advances have been the use of better metallurgy, grinding and lubrication to control rail fatigue and extend rail life. Other technological innovations have extended the design and the life of turnouts and wheels. Bridge costs did not increase as much as was expected, in part because of technological developments and in part because of a better understanding of the ability of track and structures to withstand HAL loads.

This paper begins by reviewing the motivation for and the results of the initial HAL research, including a summary of the expected costs and benefits of HAL implementation. It then documents the rate of implementation by showing the increases in average tons per carload for bulk commodities between 1990 and 2012. The greatest benefits have been achieved for coal, as this is the dominant bulk commodity handled by rain and the average tons per carload increased from less than 100 to more than 115 over this period. Estimates of benefits and engineering costs are based upon the framework established in the economic analyses of Phases I and II of the HAL Research Program and the results of subsequent studies related to HAL implementation.

(1) Semih Kalay and Carl Martland. "Five Phases of HAL research bring billion dollar savings." Railway Gazette International. June 2001. pp. 408.

OVERVIEW OF THE HAL RESEARCH PROGRAM

Strengthening track to allow larger, heavier cars has long been a major factor helping railroads improve their productivity (Hay, 1982; Chapman and Martland, 1997 and 1998). If cars can carry more freight, then fewer cars, trains, crews, and gallons of fuel are needed to carry any given amount of freight. Decisions to increase load limits must balance these operating and equipment benefits against potentially higher infrastructure costs and risks of accidents. Increases in limits on gross vehicle weight (GVW) will increase stresses on the infrastructure, which is likely to increase the costs of maintenance and require stronger components for track and structures.

During the 1970s, the widespread introduction of the 100-ton car (GVW of 263,000 pounds) caused havoc with the track structure for many railroads in North America. Rail that was adequate for 70-ton cars (GVW of 200,000 pounds) was unable to withstand the higher forces associated with 100-ton operations. Instead of replacing rail because of wear or battered joints, the heavier loads necessitated early rail replacement because of fatigue and risks of accidents caused by broken rails. An AAR study (Zarembski, 1981) concluded that fatigue would become the dominant factor affecting rail life on tangent track, reducing rail life from 580 million gross tons (MGT) under mixed freight to 416 MGT under 70-ton unit trains and to 267 MGT under 100-ton unit trains. Until the rail life problem could be resolved, it was impossible to consider any further increase in GVW.

During the 1980s, the rail supply industry and the railroads addressed the fatigue problem by developing and installing harder rails and by developing better maintenance techniques. In June 1987, the Transportation Research Board's Committee on Railway Maintenance sponsored a conference on "Rail: Replacement Strategies and Maintenance Management" at the University of Illinois that featured presentations by AAR and DOT researchers, steel manufacturers from Japan and Europe, other suppliers of maintenance services, rail engineering officials, and consultants. Roger Steel, the chief metallurgist for AAR's Research and Test Department, chaired a remarkable session in which he allowed steel manufacturer's from Japan and the UK to describe what they were doing, then challenged them to develop better steel more attuned to the needs of the heavy haul railroads. The discussion indicated the high level of interest in using models and field research to understand rail life, as well as the great uncertainty as to which maintenance practices are best.

At that time, Burlington Northern Railroad (BN) was the leader in the introduction of better rail and better maintenance, because its coal routes were the highest density lines in North America. By the late 1980s, BN knew that its rail in tangent, high density mainline track would last 800 to 1400 MGT and that premium rail in high-degree curves would last 300-500 MGT:

> *Advancements in rail technology (head hardened and fully heat treated rail, clean steel practices), lubrication, road bed improvement (undercutting and shoulder cleaning) and rail grinding have all contributed to this increase in rail life. However, it has been the practice of rail grinding that has allowed the full potential of these improvements and advancements to produce the rail longevity characteristics we now enjoy. (Glavin, 1989, p. 239)*

BN knew that heavier axle loads would increase the efficiency of moving rapidly growing volumes of coal out of the Powder River Basin in Wyoming. They therefore initiated an internal study (Newman, Zarembski, and Resor, 1990) of the feasibility of increasing GVW limits from 263,000 to 315,000 pounds (initially known as the 125-ton car). BN and other railroads were aware that heavier axle loads had already been introduced in Australia (Marich, 1986), but it was unclear whether such loads would be technically and economically feasible under the much different and much more diverse operating conditions of North America. With fresh memories of the troubles from introducing 100-ton cars on inadequate track structures, many senior executives in the North American rail industry were reluctant to undertake any increase in GVW limits without careful analysis of both engineering and economic issues.

The AAR therefore decided to undertake a major research program to understand the technical and economic feasibility of heavier loads. The HAL Research Program focused on coal, as this was by far the highest volume bulk commodity handled by railroads. Moreover, because of the rapid growth projected for coal ton-miles, capacity and cost were major concerns for railroads investing to move more coal.

The HAL research began in 1988 and continued through 2000 in five phases that demonstrated the technical feasibility and economic desirability of increasing axle loads and the potential for mitigating the adverse effects of heavier axle loads by technical advances in track, structures and equipment. Much of the research was conducted at the High Tonnage Loop (HTL) of the Facility for Accelerated Service Testing (FAST) at the Transportation Technology Center in Pueblo Colorado. The HTL/FAST track is a 2.4-mile loop that provides an environment for measuring the stresses on infrastructure and component deterioration rates resulting from the operation of a bulk freight train. Operation commenced in the mid-1980s with a train made up of cars loaded to 263,000 pounds GVW (axle loads of 33-tons). In HAL Phase I, the cars were loaded to 315,000-pounds (axle loads of 39-tons), allowing a direct comparison of stresses and deterioration for 33- and 39-ton axle loads. These tests confirmed that it was technically feasible to increase axle loads. Economic feasibility was examined under the supervision of an industry committee that included representatives of the major railroads with backgrounds in operations, planning, and economic analysis as well as engineering. The economic analysis was based in part upon the FAST/HAL research, in part upon research conducted by individual railroads or government agencies and in part upon experience of other heavy haul railroads. At the end of Phase I, the committee concluded that an increase to either 286,000 lb. or 315,000 lb. gross vehicle weight (GVW) for 4-axle equipment would reduce overall costs for operations over good infrastructure, as the operating benefits would outweigh the engineering costs. The option of increasing to 286,000 GVW (36-ton axle loads) was found to be most cost effective, primarily because costs related to rail fatigue, turnout deterioration, bridge life, routine maintenance, and freight car wheels were predicted to rise more than linearly with axle loads (Hargrove, 1991).

In 1991, the major railroads began to introduce 286k GVW loads in interchange service via bi-lateral agreements, but the pace of implementation was limited by concerns about bridges and the ability of premium components and better maintenance to limit cost increases. These two issues therefore became the focus of HAL Phase II. New tests at FAST and sophisticated engineering analyses addressed the life cycle costs of rail, turnouts, field welds, bridges, and other areas most sensitive to increases in axle loads. Phase II concluded that a) bridge costs would be manageable, b) the net benefits would be somewhat greater than predicted in Phase I, because of technological advances in track components and a better understanding of deterioration rates and c) the best option would still be to increase GVW limits to 286,000 pounds (Hargrove et al. 1995). In 1995, based upon these conclusions, the industry adopted a design specification (known as S-259) for cars that would be accepted in interchange service.

HAL Phases III and IV focused on equipment design. The basic research question was to determine the extent to which improved suspension trucks could ameliorate the stresses associated with 39-ton axle load operations. Phase III therefore repeated many of the Phase II tests using upgraded equipment running over the same infrastructure as in Phase II. One of the benefits of improved suspension trucks was to reduce curving resistance and therefore the need for lubrication. Phase IV therefore tested 39-ton operations for the upgraded equipment over dry track. Although the industry did not choose to implement the types of improved suspension trucks tested in Phases III and IV, the railroads did introduce an improved version of the standard three-piece truck, which was installed in the FAST equipment for Phase V.

Following the completion of Phase V, the HAL research program continued as one of the AAR's Strategic Research Initiatives (Kalay, LoPresti and Davis, 2012). As a result of this continuing research, the industry adopted new recommendations and specifications for track components, structures, and new design specification for 286k equipment as well as new procedures for inspection and maintenance of track and structures. In 2003, the industry adopted a new design standard (M-976) for trucks to be used on 286k equipment, and in 2004 the industry adopted a new design standard (S-286) for 286k equipment used in interchange service. The basic results of the HAL research have been to strengthen rail infrastructure, upgrade rail equipment, and enhance the safety and efficiency of heavy haul railroading in North America.

This paper has two major objectives. First, it estimates the net benefits achieved by increasing the maximum GVW to 286k, taking into account the impacts on both operations and infrastructure. Second, it provides a review of the literature related to the economics of HAL operation. The industry's decision to adopt heavier axle loads was taken only after thorough engineering and economic analyses, and this paper is the first to provide a comprehensive review of the literature related to this decision and to the technological developments that helped to mitigate the infrastructure costs resulting from heavier axle loads.

The economic analyses conducted for Phases I to V of the HAL research encompassed the following steps:

- Determine the characteristics of freight cars, locomotives, and trains used to transport coal, assuming GVW of 263k, 286k and 315k.
- Define the characteristics of a set of coal routes: generic eastern and western coal lines were examined for each phase of the research; in Phase I four additional routes were studied (actual eastern and western coal lines, an exceptionally level route, and an exceptionally mountainous route).
- Use models developed by and for the AAR to estimate engineering costs per 1000 net ton-miles for operating coal trains over each route, given typical industry data for the generic studies and railroad data for the two case studies. (1)
- Estimate operating benefits for each route using AAR models. (2)
- Estimate net benefits/1000 NTM for each route.

The major sources of information concerning the economics of heavy axle loads are the HAL Economic Analyses completed at the end of Phase I (Hargrove, 1991), Phase II (Hargrove et al. 1995; Hargrove et al. 1996), Phase III (Guins et al., 1998), Phase IV (Martland, Guins, and Hargrove, 1999), Phase V (Kalay and Martland, 2001), TTCI's thorough review of research results and benefits from Phases I, II, and III (Kalay and LoPresti, 2000), and a subsequent TTCI summary of HAL research (Stone and Conlon, 2004).

The HAL economic analyses predicted what would happen if HAL loads were introduced. The potential operating benefits of HAL operations were clear; with more tons per load, fewer cars and less fuel would be needed to transport a given amount of freight, and more net tons could be handled without increasing the number of train-miles or crews. Once HAL operations began, these savings would begin. What was unknown at the outset were the rate and extent of HAL implementation, the actual impacts on track costs, and the ability of equipment to withstand heavier loading. Now that HAL loads have been operating for more than 20 years, it is possible to document the nature and extent of implementation, to estimate the benefits of HAL operations, and to determine whether or not the lifecycle costs of infrastructure increased following the implementation of 286k operations.

IMPLEMENTING 286K GVW OPERATIONS

Initial Steps toward Implementation (1991 to 1999)

Following the completion of HAL Phase I, railroads began to allow 286k GVW cars in interchange service. As will be seen in this section, some railroads made this decision only after extensive studies, others were ready to make changes based upon the AAR's research and the high quality of their infrastructure, and some proceeded cautiously until they were sure that their infrastructure (especially bridges) could handle the loads. Today, nearly all coal moves in HAL loads, along with substantial amounts of grain and a few other bulk commodities.

Concurrently with Phase I of the HAL program, Burlington Northern conducted a thorough, independent study of the potential costs and benefits of HAL operations (Newman, Zarembski, and Resor, 1990). The study, which was conducted by Zeta-Tech, used an approach similar to what was used in the AAR's HAL Economic Analysis for Phases I and II. As an internal railroad study, it was based upon detailed route-specific data and costs, and it also addressed implementation issues, including bridge costs. Based upon their review of the Australian experience, they anticipated that increases in bridge maintenance and the need to strengthen or replace bridges would be the major factors that would ultimately cause maintenance costs to rise with axle load. Although their models and assumptions were not always the same as the AAR's, they also concluded that an increase in GVW to 286k was justifiable.

CN also worked with Zeta-Tech to evaluate potential costs and benefits of HAL operations, using the same methodology that had been used with BN. As of the end of 1992, CN retained a maximum GVW of 263,000 pounds for essentially all four-axle cars, based primarily upon their reluctance to invest heavily in strengthening a large number of bridges to handle a relatively small incremental volume of traffic (Worth, 1993).

CSX Transportation formed an inter-disciplinary team to assess the economics of moving to heavier axle loads (Shughart, 1991). While the strategic planning department was interested in the apparent potential for cost savings for coal traffic, many transportation officers were wary of heavier loads, based upon their experience in the 1970s. The CSX study addressed potential economies that the AAR study did not consider, e.g. fewer waybills to process, more capacity for staging yards for coal traffic, lower costs for loading and unloading, ability to ease strict restrictions on load limits, and fewer derailments as a result of fewer trains. Instead of modeling steady state costs, as was done in the AAR study, CSX projected cash flows, including tax consequences, for a long-term investment horizon. They concluded that the investments required to enable heavier axle loads could be competitive with other CSX projects. By 1991, CSX had begun loading of existing equipment to 270,000 lbs., but had not yet decided whether to purchase new equipment that would allow heavier loads.

Before 1990, NS had already made the necessary investments to bring essentially the entire railroad up to a quality adequate for handling 286k loads (McClellan, 1991). Moreover, they had for many years been operating 286k cars in unit coal trains that originated and terminated on line. They did not feel it necessary to undertake a detailed study such as BN or CSX had carried out, as they were already prepared to move 286k cars in interchange service. NS planned to implement heavier cars gradually as it became necessary to replace their bulk fleet. By 1991, NS had already ordered 286k steel/aluminum cars with 120-ton payloads.

Prior to the HAL research program, UP had made major investments in track and structures to provide the capacity necessary to move large volumes of coal from the Powder River Basin in Wyoming (Wimmer, 2003; Van Trump, 2009). Coal originally moved in 263k equipment with a tare weight of 30 tons, but UP switched to 286k aluminum cars (tare weight of 22 tons) once they were introduced in 1990. To handle the heavy tonnage at lower expense, UP increased their routine inspections and maintenance and improved their standard components, e.g. upgrading to heavier, longer-lived rail and concrete ties for their high density coal routes.

By 1999, all of the Class I railroads allowed at least limited operation of 286k cars. Some accepted any 286 cars, but others accepted HAL loads only for specific routes. Embargoes, where imposed, were based upon bridges and light rail. The benefits of HAL operations were insufficient to justify replacing or upgrading existing equipment. Instead, the railroads were purchasing new 286k cars as needed to replace 100-ton cars that were retired or to provide additional capacity to handle growing traffic volumes.

Extent of HAL Implementation in 2012

The original impetus for HAL came from the railroads that were hauling large volumes of coal, and coal has indeed been the commodity benefiting most from HAL operations. Table 1 shows carloading data for the Class I railroads for bulk commodities with the highest average tons per load. Variations among railroads reflect differences in local conditions, e.g. the age and capacity of equipment, the ability of access lines and customers to handle heavier cars, and differences in density of commodities. Note that the average shown at the bottom of the table is a weighted average of the tons/load for the individual railroads; this is not equal to the average tons/load for the industry, as cars that move over more than one Class I railroad are counted more than once. The final row in this table estimates the extent of implementation. If all traffic were fully loaded to a gross vehicle weight of 286k, the average tons per load would be approximately 112.5 tons in steel cars and 121.5 tons in aluminum cars (see Table 3 below). If half of the cars were steel, then the average tons per load would be about 117 tons. Essentially all coal traffic, which averaged just under 117 tons/car in late 2012, appears to be moving as 286k loads. HAL is not as fully implemented for the other commodities shown in this table, as the average tons/load is less than 112.5 tons for each commodity for each of the Class Is. amount depends upon the cubic capacity of the cars and the density of the commodity when loaded into the cars). For iron ore and crushed stone, there are wide differences in the average tons per load, which is likely caused by the use of old cars for some services. For the other commodities, the average tons/load are less variable across the Class Is. The extent of implementation can be estimated by comparing the average actual tons per load to the tons per load that would be achieved if all traffic moved in cars loaded to 286k. For an older fleet made up primarily of steel cars, the average load would be about 103 tons per car at 25% implementation and about 106 tons per car at 50% implementation. For a new fleet make up entirely of aluminum cars, the average load would be about 113 tons per car at 25% implementation and 116 tons per car at 50% implementation. For a fleet with an equal mix of steel and aluminum cars, the average load would be about 111 tons at 50% implementation (i.e. an average of 106 for steel cars and 116 for aluminum cars) and about 117 tons at full implementation. Coal is known to move in both steel and aluminum cars, and the high average tons/car for coal indicates a very high rate of implementation of 286k loads. The table shows a range of estimates for the other commodities, because the mix of steel and aluminum cars is unknown; the low number assumes a mix of steel and aluminum cars and the high number assumes all steel.

Table 1 Extent of HAL Implementation in 2012
(Commodities with an average of more than 104 tons/load on at least two Class I railroads)

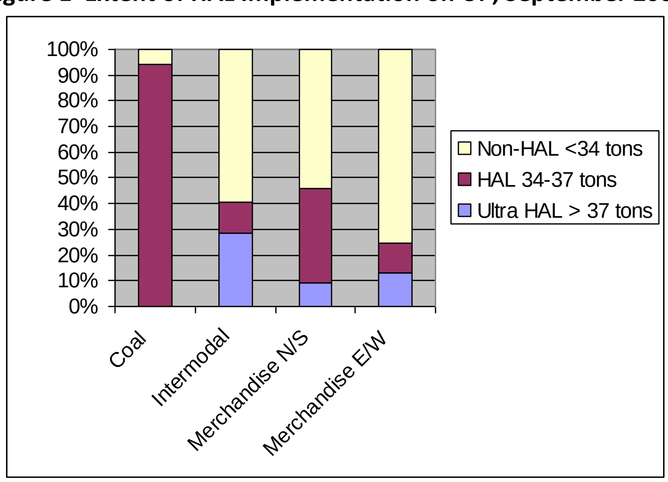
	1132 Corn	1137 Wheat	101 Iron Ore	11 Coal	142 Crushed Stone	144 Sand & Gravel	324 Hydraulic Cement
BNSF	106.1	107.3	105.6	119.2	106.7	101.5	106.5
CSX	105.0	104.6	106.2	113.9	101.3	99.0	108.5
GTW	100.8	103.8	78.3	117.5	84.9	103.0	111.5
KCS	103.0	102.4		120.2	110.1	110.2	104.0
NS	104.4	102.4	94.7	111.9	103.8	101.7	107.0
SOO	100.1	100.8		118.7		106.2	107.7
UP	106.9	104.4	97.4	118.3	104.6	104.3	107.2
Average	104.8	105.1	86.1	116.7	102.4	102.9	107.3
% Implemented	0-40%	0-40%	0-50%	90-100%	0-20%	0-25%	20-60%

Source of data: STB Quarterly Report of Freight Commodity Statistics, Third Quarter 2012.

Data in Table 1 are shown at the 2-, 3-, or 4-digit level of the STCC (Standard Transportation Commodity Code). The 2-digit level corresponds to the major commodity groups such as coal, which is the only 2-digit STCC averaging at least 104 tons per load. A finer level of detail is necessary to identify other commodities with significant amounts of HAL traffic. For example, although the average load for all farm products was under 100 tons in 2012, average loads exceeded 104 tons for corn and wheat handled by some of the railroads. Most grain shipments are expected to eventually move in 286k loads (Prater and Sparger, 2012). The full benefits of the 286k GVW limit cannot be achieved unless there is a match between the cubic capacity of the car and the density of the commodity; it is quite possible that a car rated for 286k GVW can be fully loaded without reaching the 286k limit. The extent of implementation therefore may be underestimated for some of the commodities listed in Table 1.

Another approach to estimating the extent of implementation is to use data from wheel impact load detectors (WILD data). For example, Figure 1 shows the distribution of axle loads for loaded traffic on representative UP routes in 2003. Traffic was separated into three categories based upon axle loads: non-HAL (6-34 tons), HAL (34-37 tons), and Ultra HAL (>37 tons). The chart shows that all but 6% of coal was HAL traffic – and none was Ultra HAL. The figure also shows that HAL loads and overloads were a quarter to nearly half of all axle loads on two primary merchandise corridors. Since these merchandise corridors may also have had some coal and intermodal traffic, these results should be interpreted as an upper limit for the extent of HAL implementation for general merchandise traffic in 2003.

Figure 1 Extent of HAL Implementation on UP, September 2003



Source of Data: Wimmer, 2003.

Figure 1 also shows that 29% of axle loads on this route were over 37 tons for intermodal traffic. It is well-known that loaded containers that are double-stacked on articulated intermodal cars may cause some of the axle loads to exceed 36-tons. This potential problem is exacerbated by the fact that many international containers may be overloaded (Ogard, 2012). However, excessive axle loads on articulated intermodal equipment were evident well before Phase I of HAL, and the average loads for intermodal traffic have been little if at all affected by the adoption of the 286k GVW limit. Therefore, the rest of this paper addresses the costs and benefits of HAL operations for coal and general freight, without consideration of intermodal traffic.

The AAR used WILD data to estimate the extent of HAL implementation on mainlines in 1999 (Kalay and LoPresti, 2000). Extrapolating from data collected at three sites, they estimated implementation to be 38.7% in the west and 27.1% in the east. At that time, the average load of coal was 107.8 tons, indicating a rate of implementation of 40 to 50% for coal using the methodology described above. Since coal accounted for less than 44% of the total tonnage moved that year, there must have been considerable HAL implementation for general freight in 1999, just as was the case for UP's two general merchandise lines in 2003 (Figure 1 above).

Factors Influencing the Rate of Implementation

Railroads initially implemented HAL by increasing the maximum load for existing bulk equipment (open top hoppers, covered hoppers, and gondolas). The ability to do so depended upon the cubic capacity of the cars and the average density of the commodities, and it was not always possible to load cars to 286k. Over time, cars designed for 286k GVW were added to the fleet, either to replace older cars or to expand the capacity of the fleet. By 2000, essentially all such equipment was designed for 286k loads.

Since the predicted benefits of HAL operations were insufficient to justify early retirement of 263k cars, the rate of implementation was quickest where the traffic growth was greatest. The role of traffic growth was most evident for coal. In the west, HAL loadings and average tons/load increased rapidly as coal production ramped up in the Powder River Basin; coal tonnage nearly doubled from1982 to 1986 and increased another 50% by 2008 (Table 2). The fleet had to be expanded to handle all of this new traffic, and once the GVW limit was increased, all of the new acquisitions were designed for 286k. Despite the drop in 2009, coal traffic was still more than 250% of the 1982 levels. By 2009, nearly all coal traffic moved in 286k loads. In the east, there was a completely different story. Between 1982 and 2008, there was essentially no increase in the tons of coal handled by eastern railroads. In 2009, coal tonnage dropped well below 1982 levels, because of the recession. The average tons/load therefore increased more slowly in the east than in the west.

Table 2 Coal Tonnage and Average Tons/Load, Selected Years

	Year	U.S.	East	West
Tons (Millions)	1982	523	337	187
	1986	705	344	361
	2008	879	340	539
	2009	787	292	495
Tons/load	1982	91.6	88.9	97.1
	1996	104.5	101.1	108.0
	2008	113.9	108.8	117.4
	2009	115.0	110.4	117.9

Source of Data: AAR, **Analysis of Class I Railroads**, various years.

BENEFITS FROM HAL OPERATIONS

Predicted Benefits, HAL Phases I and II

Benefits of 286k operations depend upon the extent of implementation, car characteristics, and unit costs. The generic case studies represented high density coal routes; the two railroad case studies in Phase I considered actual routes that had some general merchandise and intermodal traffic as well as high volumes of coal traffic. All of the case studies assumed steady state conditions, i.e. constant annual traffic volumes and constant rates of maintenance and renewal for the track structure. The most important benefits expected from HAL operations fall into the three key areas, which are discussed below.

Fewer freight cars and car-miles. HAL allows more freight to be moved in each car, thereby reducing the carloads and car-miles needed to move a given amount of freight. The HAL effects must be separated from the effects of the concurrent introduction of higher capacity aluminum cars. The benefits from these lighter cars were similar to the HAL benefits, because both changes allowed more freight to be carried per car. Therefore, the HAL effect on fleet size cannot be based upon a comparison of 286k aluminum cars with the 263k steel cars. Instead, the differences between steel 263k and aluminum 263k need to be attributed to the change in materials, while the HAL benefits need to be based upon a comparison between 286k aluminum cars and 263 aluminum cars. Table 3 shows the characteristics of typical steel and aluminum cars.

Table 3 Characteristics of Bulk Equipment

Equipment	Net Tons	Net-Tare	Gross-to-Net	Ratio to Base	Reduction in MGT
Steel 263	101.0	3.31	1.604	100.00%	
Steel 286	112.5	3.69	1.542	96.15%	-3.851%
Aluminum 263	110.0	5.12	1.391	100.00%	
Aluminum 286	121.5	5.65	1.354	97.37%	-2.635%

Higher net-to-tare and lower gross-to-net weight. The ratio of net tons to the tare weight of the equipment generally increases with GVW. The ratio of gross-to-net weight is a related measure that gives the gross tons to be moved to move a single net ton of freight. For unit trains with 100% empty return, this ratio is calculated as:

Gross-to-net = (Net Weight + 2* Tare Weight)/(Net Weight)

Gross-to-net is a key number, because many operating benefits are directly proportional to changes in gross tonnage. If tonnage is reduced, there will be a corresponding reduction in train-miles (i.e. crew miles), locomotives, locomotive miles, and fuel consumption. Table 3 shows differences in the ratios of net-to-tare and gross-to-net for steel and aluminum cars along with the reduction in MGT achieved by moving from 263k to 286k loads.

Fewer train crews. There will be a small reduction in train crews as a result of better gross-to-net ratios; there will be a larger benefit if trains are length-limited as opposed to weight-limited.

Table 4 summarizes the results from Phase II for the 80 MGT western coal route and the 30 MGT eastern coal route. The results from the HAL Economic Analyses were always presented in a format similar to that shown in Table 4 in order not to divulge sensitive data related to costs or benefits. For both routes, both 286k and 315k operations were predicted to reduce total costs, and the reductions were predicted to be greatest for 286k operations. The areas with the largest expected increases in costs were track maintenance and bridges. Although the percentage reduction in costs related to cars, locomotives, and train operations were predicted to be less than the percentage increases in infrastructure costs, the absolute savings were more than sufficient to cover the cost increases.

Table 4 Summary of Phase II Results

	West 263	West 286	West 315	East 263	East 286	East 315
Track						
- Maintenance	100%	111.3%	132.7%	100%	122.6%	147.5%
- Capital	100%	102.6%	108.6%	100%	106.5%	110.0%
Total Track	100%	105.0%	115.1%	100%	110.3%	118.8%
Bridges	100%	112.7%	156.9%	100%	114.0%	137.7%
Operations	100%	90.4%	93.8%	100%	91.1%	95.3%
Total	100%	92.6%	97.5%	100%	94%	99.6%

Source: Hargrove et al., 1996.

The published results for the HAL research were reported as percentage changes similar to those shown in Table 4. The unpublished results included much more detailed information concerning impacts on operating conditions, infrastructure deterioration rates, and unit costs.

There were also studies of the effects of HAL operations on capacity. Since fewer trains would be needed to move the same amount of freight, implementing HAL was expected to increase line capacity. Benefits associated with operating fewer trains were predicted to be more than enough to offset the added time needed for track maintenance on high density lines (Romps, 1993; Robert and Martland, 1997; Guins, Robert and Martland, 1997; Robert, Martland and Guins, 2003). Although line capacity was a minor issue for most railroads when Phase I was completed in 1990, it has since become a significant issue for the industry (Cambridge Systematics, 2007).

Actual HAL Benefits: Reductions in Equipment Acquisitions

The operating benefits resulting from increased axle loads began immediately once railroads allowed existing equipment to be loaded to 286,000 pound gross vehicle weight (286k GVW). The rate of implementation depended upon several factors: the timing of decisions by individual railroads to allow heavier loads, the cubic capacity of cars in the 1991 rail fleet, the rate of acquisition of new equipment, and the type of equipment acquired (steel or steel/aluminum). The widespread implementation of HAL traffic began in the mid-1990s, and the savings from buying cars with larger capacity began immediately. The first column in Table 5 shows the fleet size as of 1993 for three types of equipment used to haul bulk traffic; e second column shows the maximum fleet size for each of these types of equipment for the period 1994 to 2010. If the fleet size increased, as it did for covered hoppers and gondolas, then new cars must have been acquired, as shown in the third column. In addition, cars had to be acquired to replace cars that were retired because of age or condition. Assuming an average life of 40 years for freight cars, the average annual retirement rate would be 2.5%. Over the 17-year period from 1994 to 2010, 42.5% of the fleet would have been replaced. If the original fleet consisted entirely of 263k cars, then an equal number of 263k cars would have been needed to replace the retired cars. If that had been the case, then it would have been necessary to acquire 441 thousand new bulk cars. However, if the older cars could be replaced with 286k cars with a 10% boost in average loading capacity, then only 414 thousand cars would have been needed. Since the vast majority of all covered hoppers, gondolas, and hoppers acquired since 1993 have been designed to handle 286k GVW, the rail industry (consisting of railroads, car supply companies, and customers) has avoided purchasing 27 thousand bulk freight cars, an average of about 1,600 per year. At an average cost of about $67 thousand in 2010, the annual savings were approximately $100 million per year (Table 6).

Table 5 Estimating the Number of Bulk Freight Cars Acquired Between 1993 and 2010

Car Type	Fleet Size in 1993	Max after 1993	Min new after 1993	Annual Retirements	Total New Cars 263k GVW	Total New Cars 286k GVW
Covered Hopper	302,903	414,418	111,515	7,573	240,249	227,375
Gondola	148,541	220,238	71,697	3,714	134,827	128,514
Hopper	190,094	175,350	-14,744	4,752	66,046	57,967
Total	641,538	810,006	168,468	16,038	441,122	413,856

Source of Data: AAR, Railroad Facts, Various Editions

Table 6 Savings in Equipment Acquisition for Bulk Transportation
(Reduction in Purchases of Covered Hoppers, Hoppers, and Gondolas at $67,000/car)

	Total, 1993 to 2010	Average Annual,	Total Savings 1992 to 2010	Average Annual Savings
Estimated New 286 Cars Acquired (1000s)	414	24.3		
Estimated New Cars Required, if GVW were still 263k (1000s)	441	25.9		
Reduction in cars purchased, because of increase in HAL limit (1000s)	27	1.6	$1.7 Billion	$107 million

HAL Operating Benefits for Coal Traffic

Benefits are most evident for coal traffic, since essentially all coal now moves in 286k equipment. This section addresses coal; the next section uses the results for coal to estimate the extent of savings for general freight traffic. Estimating the operating benefits for coal required some additional assumptions concerning train length, locomotive consists, fuel consumption, and shipment characteristics (Table 7). With these assumptions, it was possible to estimate the changes in service units resulting from the shift to HAL operations. In all cases, the benefits were estimated by considering the differences in service units (car-miles, train-miles, etc.) resulting from the use of 286k cars rather than 263k cars. By using larger cars, railroads had to move fewer loads, which resulted in fewer car-miles. Since there were fewer car-miles, there were fewer train-miles and locomotive-miles. Since the gross-to-net tonnage ratio was lower, there were fewer gross ton-miles, provided additional savings related to locomotives and fuel consumption.

Table 7 Equipment and Operating Assumptions Used to Estimate Savings

Characteristics of 286k Operations	Parameter	Comments
Average cars/train	120	Typical unit train
Average locomotives/train	2.7	Average locomotive miles per train-mile in 2008
Average locomotive miles per day	174	Locomotive miles divided by total locomotives in 2008
Average car-miles per carload	1216	Average loaded car-miles per carload in 2008 plus 100% empty return
GTM/gallon	484	Average for Class Is, 2010

Unit costs were estimated using aggregate data provided by railroads to the STB. These costs are intended to support a reasonable estimate of the costs associated with operating unit trains. In any particular situation, costs could be significantly higher or lower than these industry averages. Moreover, there are other costs that are not considered at all; for example, yard costs are not considered because yards and terminals are a minor factor in bulk unit train operations.

Table 8 Unit Costs Used to Estimate Savings from 286k Operations

Cost Category	Unit Cost	Comments
Crew cost	$9.93 per mile	Total T&E wages divided by total train-miles, for 2010
Locomotive purchase	$1.17 million	Average cost of new or rebuilt locomotives in 2008
Locomotive ownership	$135 thousand per year	Assuming cost of capital 11% and 30-year life
Locomotive maintenance	$1.00 per locomotive-mile	Locomotive labor, fringe benefits, and materials & supplies divided by total locomotive miles in 2008
Car maintenance	$0.036 per car-mile	Freight car labor, fringe benefits, and materials & supplies divided by total car-miles in 2008
General Administration	$160 per load	General administrative expense divided by carload in 2008
Fuel	$2.24 per gallon	Average for 2010

Source of data: STB, *Analysis of Class I Railroads 2009*; AAR, *Railroad Facts 2011*

Because the cars each carry more freight, there are fewer cars to load and unload and fewer car-miles. Table 9 estimates the reduced costs for moving coal, on the assumption that all of the coal now moves in 286k cars.

At an estimated cost of $160 per load, the cumulative benefit of reducing the number of loads was $0.8 billion and the annual benefit in recent years was $110 million. For each load that is eliminated, an entire trip is eliminated, saving car-miles, both loaded and empty, for an estimated cumulative benefit of $220 million and an annual benefit of $30 million by 2010. If trains are length-limited, rather than weight-limited, then the reduction in loads will also result in a reduction in train-miles, with cost savings amounting to $70 million by 2010. The total savings related to reducing the number of carloads of coal is estimated to be $1.5 billion for 1994 to 2010 and $210 million per year by 2010. Since there were 7.06 million carloads of coal in 2010, the estimated operating benefits were approximately $30 per car.

The next category of savings results from the fact that the ratio of GTM to NTM is lower with HAL equipment. If half of the 286k cars are steel and half are aluminum, then there would be a 3.2% reduction in MGT if all traffic moved in HAL equipment (see Table 3 above). The number of locomotives, locomotive-miles, gallons of fuel, and train-miles needed to move a given quantity of coal can be estimated with the parameters given in Table 7 above. Table 10 summarizes the savings from a 3.3% (1/0.968 = 1.033) savings in the ratio of gross to net tons. These savings will lead to cost savings related to locomotives, locomotive-miles, train-miles (for weight-limited trains) and fuel. Together, the cumulative savings in these areas amount to $1.5 billion if trains are weight-limited and $1.26 billion if trains are length-limited (in which case the savings in crew costs would be greater, as estimated in Table 9). The $160 million savings estimated for coal in 2010 would be $23 per car. Summing the annual operating benefits for coal (Tables 9 and 10) results in estimated savings per car of $45 to $55 per car, depending upon whether trains are weight- or length-limited.

Table 9 Operating Savings Resulting From Fewer Carloads ($160/load, $0.0360 per car-mile and $9.93/train-mile)

	Total or Average 1994 to 2010 (millions)	Amount in 2010	Total Savings 1994 to 2010 (millions)	Average Annual Savings (millions)
Total Tons of Coal Shipped (millions)	13,000	814		
Total Loads (millions)	118	7.06		
Total Loads @ 105 tons/load (50% steel and 50% aluminum)	123	7.75		
Reduced loads (millions) and related savings (@ $160 per load)	5	0.69	$800	$110
Average Tons/load	110.0	115.0		
Average Tons/load at full implementation (50% steel and 50% aluminum)	117.0	117.0		
Average extent of implementation	59%	88%		
Car-mile savings (millions)	6,100	840	$220	$30
Train-miles Savings (crew costs for length-limited 120-car trains)	50	7	$500	$70
Total savings			$1,520	$210

Table 10 Operating Benefits for Coal Traffic Resulting from the Reductions in MGT and Car-Miles

	Total, 1994 to 2010 (millions)	Actual 2010	Increase in 2010 if GVW were 263k (1/.968=1.033)	Total Savings 1994 to 2010 (Average 59% implementation)	Savings in 2010
Coal loads	123 million	7.75 million			
Car-miles (@ 1216 per load)	150 billion	9.42 billion			
Train-miles @ 120 cars per train	1,250 million	78.5 million	2.6 million	$240 million	$26 million
Locomotive Miles @ 2.7 locomotives per train	3,750 million	212 million	7.0 million	$65 million	$7 million
Locomotive-years @ 174 miles/day	3500	3300	109	$140 million	15 million
Net Ton-miles @ 608 miles per ton	8 trillion	0.5 trillion	16.5 billion		
Gross ton-miles @ 1.5 gross tons per net ton	12 trillion	0.75 trillion	24.75 billion		
Fuel saved (@ 484 GTM/ gallon)	25 billion	1.55 billion	50 million	$1,080 million	$114 million
Total				$1.5 billion	$160 million

Actual Operating Benefits for Traffic Other than Coal

It is clear that substantial amounts of other bulk commodities are moving as 286k loads. The evidence from WILD data such as that obtained by UP (Figure 1 above) and the AAR indicates that a quarter or more of general freight was moving in HAL loads more than ten years ago. The percentage of HAL freight is certainly higher today, and there are several important bulk commodities with average loads of 105 to 111 tons in 2012 (Table 1 above). The percentage appears to be in excess of 50% for some types of ores, non-metallic minerals, and farm products. If 60% of the ores, non-metallic minerals and farm products are moving as 286k loads, that would amount to another 2.3 million loads per year in recent years. If 20% of the remaining 10.8 million non-intermodal traffic were also moving as HAL loads, that would be another 2.2 million HAL loads for a total of 4.5 million HAL loads other than coal. These estimates must be considered to be rough estimates, but they are roughly indicative of the current level of HAL implementation (Table 11).

Table 11 Estimated HAL Implementation as of 2012

Category	2010 Loads	Estimated HAL Loads	Estimated HAL %
Coal	7.1 million	7.1 million	100%
Ores, Non-Metallic Minerals and Farm Products	3.8 million	2.3 million	60%
Other General Freight	10.8 million	2.2 million	20%
Total	29.2 million	11.6 million	40%

The benefits associated with car acquisitions for these commodities was included in the savings estimated in Table 5 above. The operating benefits would likely be similar, on a per car basis, to the $45 to $55 per car estimated for coal in Tables 9 and 10 above. Thus, the benefits for these commodities could be estimated as being about $200 million per year. If cumulative benefits were similar to those for coal, they would be estimated to be on the order of $1.8 to $2 billion.

The total benefits from HAL therefore were on the order of $6 to $7 billion from 1994 to 2010 and $600 to $700 billion per year by 2010:

- Equipment acquisition: $1.7 billion ($107 million per year for all bulk equipment)
- Coal operations: $2.8 to $3 billion ($370 million per year)
- Other bulk operations: $1.8 to $2 billion ($200 million per year)
- Total: $6 to $7 billion ($600 to $700 million per year)

It must be emphasized that these benefits are spread among the car owners, customers, suppliers, and the railroads. The cost savings are certainly real. Car owners have benefited from being able to purchase capacity at a lower cost per ton. Railroads have saved fuel because they are moving less gross tonnage, and they are operating fewer trains with fewer locomotives and fewer car-miles than they would have if the GVW had not been increased. Who has profited from HAL is a question that is beyond the scoped of this paper, because such a question must delve into hitherto unexplored pricing issues.

INCREASES IN INFRASTRUCTURE COSTS RESULTING FROM HAL OPERATIONS

Predicted Increases, HAL Phase II

This section begins by looking at the Phase II estimates of the effect of HAL on infrastructure costs. The Phase II estimates were better than the Phase I estimates for three reasons (Kalay and LoPresti, 2000). First, better track deterioration models were available for the major track components. Second, Phase II included an extensive assessment of bridge costs. Third, the base case in Phase II assumed that premium components would be used on the coal routes, because the railroads were by that time installing premium rail, fasteners, and turnouts on their high density coal routes. The HAL Phase II analysis (Hargrove et al., 1996; Hargrove, Guins and Martland, 1996) predicted that track costs per net ton-mile would increase by 5.9% for 286k operations over a generic 80-MGT line in the west and by 11% for a generic 30-MGT coal route in the east (Table 5, above). Costs were expected to rise in each of six categories: rail, ties, ballast & subgrade, turnouts, bridges, and routine maintenance. Estimated cost increases included both capital and operating expenditures, based upon an assumption that the infrastructure had reached a steady state.

Table 12 shows the base case costs and the predicted increases in costs once HAL operations were fully implemented. The base case costs in Phase II were approximately $46,000/mile for the 80-MGT route and $21,000 for the 30-MGT route. TTCI estimated that 10,500 miles of mainline track were more similar to the 80-MGT route, while 46,200 miles were more similar to the eastern route. Hence, base case track costs for the total of 76,700 miles of high density mainlines were estimated to be $1.5 billion/year, and the HAL effect under 286k loads was estimated to be $124 million per year. The added costs for bridges increased the HAL effect for both routes.

Table 12 HAL Phase II Base Case Costs and Cost Increases Resulting from 286k operations (3)

	Annual MGT	Track-Miles	Annual Cost/Mile	Annual Cost (Millions)	% Increase	Increase (Millions)
Track						
• Western Route	80	10,500	$46,000	$480	5.0%	$24
• Eastern Route	30	46,200	$21,000	$970	10.3%	$100
• Total Track				$1,450	8.6%	$124
Bridges						
• Western Route	80	N.A.	N.A.	$30	12.7%	$4
• Eastern Route	30	N.A.	N.A.	$50	14.0%	$7
• Total Bridges				$80	13.8%	$11
Total				$1,530	8.8%	$135

Source of data: Hargrove et al. 1996. pp. 23-24.

The predicted increases in track costs were estimated on a yearly basis by considering the projected cost increase of approximately $0.08 per 1000 NTM together with the estimated extent of HAL implementation. Although HAL was essentially fully implemented for coal by 2010, only abut 40% of the total traffic moved in cars with 286k axle loads (see Table 11 above). Adjusting for the extent of implementation, the predicted annual increase in costs would have been approximately $50 to 60 million in recent years rather than the $135 million shown in the table. The adjusted prediction of cumulative cost increases for the entire period (from 1991 to 2011) would have been $0.7 billion, based upon the extent of HAL implementation.

The Phase II Economic Analysis included detailed estimates of costs for each major component of the track structure. Overall, the HAL effect was predicted to be much greater for maintenance expenditures than for capital expenditures. The areas with the highest increases in infrastructure costs for 286k operations over the 80-MGT western line were predicted to be spot surfacing, rail defects, and turnout installation. In the east, the three areas with the highest increases in infrastructure costs under 286k operations were predicted to be rail replacement, rail grinding, and spot surfacing. The differences between the east and the west largely reflected the fact that the western roads had, as of the mid- to late-1990s, already upgraded more of their rail and initiated intensive grinding and lubrication practices because of their much higher traffic densities. Costs related to ties and fasteners were not expected to increase significantly under heavy axle loads for either the western or the eastern routes.

Heavier axle loads increase the stresses on bridges and may reduce the fatigue life of bridge components. Because of the risks associated with bridge fatigue, railroads were careful to determine whether bridges would need to be strengthened or replaced before introduction of HAL traffic (Newman et al., 1990; Sweeney et al., 1996). In Phase II, the HAL Economic Analysis estimated increases in bridge costs based upon analysis of the effects of heavier loads on typical bridges. For timber structures, it was assumed that railroads would either replace the caps or replace the entire structure at some point during the next 20 years (i.e. by 2012). For steel structures, a thorough engineering analysis was conducted to determine the effect of higher axle loads on stresses on and fatigue life of critical bridge components. The shorter fatigue life was converted into an equivalent increase in annual costs for bridge maintenance. Analyses were completed for a representative sample of bridges provided by the Class I railroads; the results were used to estimate bridge costs by choosing sets of bridges to represent what might be found on typical eastern or western coal routes. For six generic case studies, steady state bridge costs were expected to rise 10-30% if all coal were to immediately to move in 286k cars. For 315k operations, costs were expected to go up 50-75% (Sharma, 1995).

Actual Effects of HAL on Infrastructure Costs

The actual effects of HAL on infrastructure costs were less than expected, primarily because costs related to rail, turnouts and bridges either declined or rose much less than predicted. For rail, which is the single most costly track component, costs actually declined; better rail metallurgies and more effective grinding techniques allowed railroads to increase rail life and reduce lifecycle costs (e.g. Clark et al. 1999; Martland and Massot, 1999. Following the widespread introduction of HAL traffic, rail life and lifecycle costs were better, not worse. Turnouts were another area where initial FAST/HAL results indicated that increasing axle loads could cause major increases in cost. As was the case with rail, new technologies and better maintenance practices extended turnout lives and reduced life-cycle costs despite the introduction of HAL traffic (Chapman and Martland, 1998). As expected, there were concerns with ballast and subgrade (Worth, 1993).

Research conducted as part of subsequent phases of the HAL and tests conducted by individual railroads led to a better understanding of bridge strength, efficient means of strengthening bridges and railroad-specific programs for upgrading and replacing weak structures (Unsworth, 2003). The actual expenses related to bridges were not as severe as anticipated, in part because the pace of implementation was slow enough to allow railroads time to prepare for the increase in axle loads within the context of their normal engineering budgets.

Analysis of aggregate expenditures on track and structures provides more evidence that HAL traffic did not lead to an increase in infrastructure costs. When capital and operating expenditures are combined, the average $/1000 revenue ton-miles (RTM) increased from $6.70 in 1990 to $9.41 in 2010. However, if total expenditures are expressed in constant 2010 dollars, the average expenditures per 1000 RTM declined from $10.25 in 1990 to $9.41 in 2010. The decline is more pronounced if the railroad cost recovery index is used to convert expenditures to constant dollars, as unit costs for rail labor, fuel, and materials and supplies increased more rapidly than general inflation over this 20-year period.

Table 13 Index of Constant Dollar Expenditures per Revenue Ton-Mile, 1990 to 2010

Expenditures on Way and Structures by Class I Railroads	1990	1995	2000	2005	2010
Operating Expense	$4.28 billion	$5.47 billion	$5.03 billion	$6.50 billion	$8.07 billion
Capital Expense	$2.64 billion	$3.65 billion	$4.55 billion	$5.36 billion	$7.85 billion
Total	$6.92 billion	$8.02 billion	$9.58 billion	$11.86 billion	$15.92 billion
Revenue Ton-Miles	1,033 billion	1,306	1,466 billion	1,696 billion	1,691 billion
$/1000 RTM	$6.70	$6.14	$6.53	$6.99	$9.41
Federal Reserve Implicit Price Deflator for GDP (2005 = 100)	72.593	81.710	88.903	100.461	111.045
$/1000 RTM (2010 $)	$10.25	$8.34	$8.16	$7.73	$9.41
Railroad Cost Recovery Index (RCR, 1981 = 100)	139.9	160.4	187.1	238.9	294.9
$/1000 RTM (using RCR)	$14.12	$11.29	$10.29	$8.62	$9.41

Source of Data: AAR, Railroad Facts, 2011 edition

It is impossible to use aggregate data to document changes in costs related to specific shifts in traffic mix or axle loads. However, the aggregate analysis does support two important conclusions. First, infrastructure expenses per revenue ton-mile declined from 1990 to 2010, despite the rise in 286k traffic. Second, the increase in traffic volume over this period had a much larger impact on infrastructure expense than the predicted increases resulting from HAL implementation. If there were no economies of density, a 50% increase in traffic volume would result in a 50% increase in infrastructure expense assuming no changes in traffic mix or axle load (3). The predicted HAL effect would only add another increase of 4.4% if all traffic were to move in 286k cars (and approximately half that if HAL loads were restricted to bulk traffic.)

Despite increasing proportions of HAL traffic, infrastructure expenditures per RTM declined. The rail industry's infrastructure of 2010 was better able to withstand the stresses of 286k operation than the infrastructure that was in place or assumed to be in place during the HAL economic analyses.

SUMMARY

Extent of Implementation. Nearly 100% of coal traffic and approximately 40% of all freight now moves in 286k loads.

Benefits from 286k Operations. If all bulk traffic had continued to move in 100-ton cars, many more cars would have been purchased, more trains would have been operated and more fuel would have been consumed. Cumulative benefits are estimated to be $6 to $7 billion, an amount that is now increasing at a rate in excess of $600 million per year.

Costs of 286k Operations. Implementing HAL traffic was predicted to increase expenditures for track and structures, but constant dollar infrastructure expenditures per 1000 RTM actually declined.

Benefits from better infrastructure technologies. Technologies that were essential for handling HAL traffic proved to be beneficial for other traffic as well. Upgrading rail, fasteners, turnouts and other elements of the track structure was estimated to provide savings of $100 million per year by 2000 (Kalay and LoPresti, 2000). Even greater benefits were achieved by subsequent research, which helped mitigate the effects of HAL traffic by reducing the stress state of the railroad (Byers, 2006 and 2007; Robert, 2011).

Total Net Benefits: The total of operating plus engineering benefits from the HAL research program and the introduction of HAL traffic exceed $1 billion per year, and cumulative benefits are greater than $13 billion.

Beyond 286k. Railroads, their customers and suppliers are already starting to introduce shorter cars that retain the 286k GVW limit, a strategy that was investigated as part of the HAL research (Robert, 1997; Guins et al., 1998; Chapman, 1998; Wile, 1998; Chapman, Martland, and Guins, 2003). Shorter 286k cars provide most of the cost and capacity benefits of heavier cars without increasing stresses on the track structure; their impacts on bridges are similar to the impacts that would be imposed by 315k cars. In North America, there has been little interest in operating with axle loads in excess of 36-tons, although such loads have been operated by mining railroads in Australia since the 1980s (Marich, 1986). More recently, FMG, a new iron ore railway in Australia, began to move iron ore 256 km from mine to port in the world's first cars designed for 44-ton (40 metric ton) axle loads (Shughart, 2012). Higher axle loads can clearly be justified in certain circumstances, especially when track and equipment can be designed or upgraded for an operation that is controlled by the shipper, as was the case with FMG.

The Next Steps: The industry is in a position to consider taking further steps to improve capacity, either by increasing axle loads or by continuing to invest in shorter 286k cars. Technological improvements have extended the life of track components, improved equipment, and enhanced inspection capabilities, while investments in bridges and track have strengthened the mainline infrastructure. Higher fuel costs and greater concerns with line capacity make it more important to pursue the most efficient means for transporting bulk commodities. Several options could be considered. Modest increases in GVW (e.g. an increase from 286k to 290k) would provide immediate operating benefits with minor impacts on track and structures. An increase in GVW to 315k, long considered the next logical step, may be justified now or in the not too distant future. Even heavier loads might be justifiable in special circumstances or restricted routes.

Whether or not higher loads or loading densities can be justified is a question that can be addressed using the results of FAST/HAL research and the models and evaluation techniques developed as part of that research. New research could address the technical issues associated with heavier axle loads and higher loading densities. For example, a new research phase at FAST could feature tests based upon operation of cars with axle loads above 39-tons. Phases I and II of the HAL Research Program provide an excellent model for investigating the engineering and economic impacts of the various options that are available. As documented in this paper, the benefits from implementing more efficient equipment can be very substantial. Even a small increase in axle loads or loading density, if the infrastructure is able to withstand that added stress, can result in very substantial savings for the railroads, their suppliers and their customers.

It makes sense to conclude this review of the decades-long process of implementing HAL traffic with the first sentence of the first paper describing the economic interpretation of the Phase I HAL research:

> *The history of freight railroad technology shows a pattern of increasing vehicle size with increasing axle loads as developments in materials and engineering knowledge have made their use technically feasible and economically desirable* (Hargrove, 1991, p. 227).

Is there any reason to believe that 286k is the ultimate limit?

END NOTES

1. The TRACS model (Martland and Auzmendi, 1989; Auzmendi, 1994; Hargrove and Martland, 1990 and 1991) was used to estimate deterioration rates and lifecycle costs related to rail, ties, ballast and routine maintenance. TRACS was calibrated based upon studies conducted in cooperation with individual railroads, including most recently studies of wear and fatigue on a high density coal route operated by Norfolk Southern (Clark, Bowman and Martland, 1999; Martland and Massot, 1999). A model developed by MIT and TTCI was used to estimate turnout maintenance requirements and lifecycle costs (Smith, E.W. et al., 1993). Results from TRACS and the turnout model were incorporated into HALTRACK, a spreadsheet model that was used repeatedly in the economic analyses conducted as part of Phases II to V of the HAL research. A sophisticated structural analysis supported the estimates of the effects of HAL on bridges (Sharma, 1993).

2. TTCI estimated the costs of operating a specific train consist over a particular route by using the Train Energy Model and the Rail Energy Cost Analysis Package, known collectively as TEM/RECAP (Stephens, 1989). This model had previously been used to assess various options for increasing fuel efficiency by reducing train resistance (Smith, M.E., 1987).

3. In fact there are economies of density, as suggested by the costs cited above in this paper: the cost per mile per annual MGT was predicted to be $575 in the west ($46,000 per mile/80MGT) vs. $700 in the east ($21,000 per mile/30MGT). A 267% increase in density therefore resulted in a predicted 18% decrease in costs per mile per MGT for these two routes. If density increased 50% on mainline track, the increase in costs per mile per MGT would only be about 3%. The traffic volume effect would vastly outweigh the traffic density or HAL effects.

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