Proceedings of the 2011 ASME/ASCE/IEEE Joint Rail Conference
JRC2011
March 16-18, 2011, Pueblo, Colorado, USA

JRC2011-56049

REVIEW OF INTERMODAL TRAIN LOADING METRICS FOR NORTH AMERICAN RAILROADS

Tristan G. Rickett
Graduate Research Assistant
rickett3@illinois.edu; (217) 244-6063
Railroad Engineering Program
University of Illinois at Urbana-Champaign

J. Riley Edwards
Lecturer
jedward2@illinois.edu; (217) 244-7417
Railroad Engineering Program
University of Illinois at Urbana-Champaign

Christopher P. L. Barkan
Professor
cbarkan@illinois.edu; (217) 244-6338
Railroad Engineering Program
University of Illinois at Urbana-Champaign

ABSTRACT

Intermodal freight transportation is one of the highest sources of revenue for North American freight railroads. However, intermodal trains are the least energy efficient in comparison to other types of trains and typically operate at higher speeds, thus creating significant aerodynamic resistance. The high resistance associated with intermodal trains results in significant fuel expenditures, and opportunities exist to reduce the aerodynamic drag through improved loading practices. An important step in the improvement of loading practices is gaining a greater understanding of how railroads load their intermodal trains and what metrics are used to evaluate loading configurations. Current North American railroad loading metrics consider equipment utilization, number of units, and/or total train length. However, these loading metrics do not account for the size of the well or platform and the size of the load placed in it. One proposed metric, slot efficiency, compares the difference between the ideal container/trailer size for the slot and the actual length of the load that is placed into the slot. Adopting this metric would enable railroads to better understand how their intermodal loading practices affect train energy efficiency. This paper reviews loading metrics used by North American railroads, identifies their strengths and weaknesses, and compares them to the slot efficiency metric using the AAR Aerodynamic Subroutine. The paper will also investigate potential challenges to improving slot efficiency of intermodal trains.

1. INTRODUCTION

One of the largest sources of revenue for North American railroads is the transport of intermodal freight. Intermodal traffic is continuing to grow as the United States' economy recovers (1). Economies of scale as well as the fuel efficiency of rail transportation make it a cost-effective option for intermodal freight movement. In comparison to truck transport, railway intermodal transport is more fuel efficient due to the low-friction steel-on-steel interface between the wheel and rail, closely coupled railcars, and rolling stock capable of transporting multiple trailers and/or containers with a single unit. To maximize the benefits of intermodal transportation by rail, railroads evaluate their terminals on how well they load intermodal trains. This promotes better utilization of intermodal railcar slots and maximizes the revenue for each intermodal train.

In addition to high revenues, intermodal rail freight has a higher fuel consumption rate in comparison to other freight types due to high aerodynamic drag and high speeds. In 2007, Class I railroads spent $12.2 billion on fuel, representing 25.8% of their total operating cost (2). Therefore, the adoption of a loading metric that incentivizes terminals to utilize all available slots as well as minimize gap lengths between loads may be of interest to railroads. This paper reviews loading metrics used by North American railroads, identifies their strengths and weaknesses, and compares them to the slot efficiency metric using loading scenarios and the AAR Aerodynamic Subroutine.

 Copyright © 2011 by ASME

It will also identify potential challenges to improving the slot efficiency of intermodal trains.

2. OVERVIEW OF INTERMODAL TERMINAL OPERATIONS

To evaluate the performance of intermodal train loading, it is necessary to understand how intermodal trains are loaded in a typical intermodal terminal. An understanding of terminal operations reveals container/trailer traffic flow, equipment constraints, switching operations, and other elements of terminal operations affect intermodal train loading.

A load, either a container or trailer, first arrives at a terminal either by truck or inbound train. For trucks, loads arrive through the terminal gate where they are checked in and inspected to assess its condition and ensure no damages were incurred while the load was in transit. After the check-in and inspection, the truck driver is instructed to park the load in a designated zone or to park beside the loading track for immediate loading onto an outbound train. When a load is checked into the gate, the load information is inputted into the terminal's computer system to notify the intermodal personnel that a load is available for loading. This information typically consists of the load's size, ID and number, and terminal destination. Using this load information, a clerk or programmer assigns the load to a specific platform or well. The loading assignment is typically done manually and computer software is used to check the clerk's assignment to ensure no loading violations occur.

During or before this time, the yardmaster arranges the available rolling stock to make up the blocks for the outbound train. The railcars used to make up blocks for an outbound train typically come from a recent inbound train, or from cars already in storage at the facility. When the clerk or programmer determines the specific location for a load, a work order is generated and sent to the loading crew. The loading crews are either railroad employees or contract employees who are compensated based on the number of primary lifts. Primary lifts include loading or unloading a trailer or container on or off a railcar. All other lifts occurring in the terminal, such as stacking the loads in storage or staging the load beside the track, are classified as secondary lifts. Hostlers transport the loads to and from the parking zone to the track. Lifting operators operate the machinery such as side loaders, reach stackers, or gantry cranes to load the containers and/or trailers onto the train. The clerk then verifies the completed work order to ensure that the load was correctly placed in the railcar slot specified. If it is in the incorrect location, then the loading crew moves the load to the correct location. When in the correct location, loads wait for the remaining loads to be added to the train. Once the cut-off time is reached, additional loads are no longer allowed to be loaded onto the train. The train is then released to the transportation personnel at the railroad, the train line and reservoirs are charged, and an initial terminal air brake test is conducted before the train is ready for departure.

Efficient terminal operation is critical in achieving productive and efficient rail network operation with minimal delay and a high percentage of on-time train departure and arrivals. Any improvements to terminal operations and efficiency must not compromise the safety of terminal personnel or network or customer service performance. Therefore, these must be taken into consideration when proposing a change in loading practices to maximize the train capacity and/or energy efficiency.

3. REVIEW OF LOADING METRICS

While each intermodal terminal is unique in terms of layout and design, lifting equipment, loading personnel, and inbound/outbound trains, many terminals use the same loading metric(s). Intermodal train loading performance metrics allow all trains to be compared using uniform and objective standards and it can be used to help railroad transportation management identify the number of blocks or trains serving specific origin-destination pairs.

3.1. Slot Utilization

The most common loading metric used by North American railroads is slot or platform utilization. Based on site visits and discussion with intermodal operations management, most Class I railroads evaluate train loading with this metric. Slot utilization is defined as the percentage of slots filled with either trailers or containers. Slot utilization promotes the utilization of all slots for all rolling stock within the train, including double-stacked containers in well cars. Mathematically, the metric is defined as follows:

$$(1) \quad Slot\ Utilization = \frac{\sum_{i=1}^{n} a_i}{\sum_{i=1}^{n} u_i}$$

Where

i = the ith railcar in the train
n = the total number of railcars in train
a_i = the number of slots loaded in railcar i
u_i = the total number of slots in railcar i

For example, a 5-unit articulated well car with a single stack in the middle well and the other four wells having double-stacked containers has a slot utilization of 90% as shown Figure 1a. If a container were added to the top of the middle well, the slot utilization would be 100% (Figure 1b).

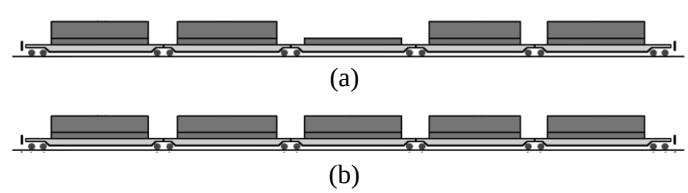

Figure 1. A five-unit well car with (a) 9 of the 10 slots filled and (b) 10 of 10 slots filled

 Copyright © 2011 by ASME

To determine a railcar's ideal number of units, the loading information for the railcar (i.e. the car's loading configuration) needs to be known. Terminals keep track of this information by generating reports that summarize and average outbound train slot utilization. Slot utilization's simplicity and ease of calculation makes it a useful tool for the determination of intermodal train capacity.

3.2. Train Feet Per Unit

One Class I railroad recently adopted a new loading metric called train feet per unit (TFPU). This metric provided them with an enhanced loading measure to replace slot utilization. Instead of summing the ideal number units per railcar, it sums the out-to-out length of all railcars in the train. An intermodal train's TFPU is calculated as follows:

$$(2) \quad TFPU = \frac{\sum_{i=1}^{n} L_i}{\sum_{i=1}^{n} U_i}$$

Where

i= the ith railcar in the train
n= the total number of railcars in the train
L_i= the outside length of railcar i
U_i= the number of units in railcar i

TFPU can also be measured as a percentage score by taking the ideal TFPU and dividing it by the train's actual TFPU. Typical ideal TFPU values are 60 ft/unit for spine cars, 70 ft/unit for single stack well cars used for domestic containers, and 35 ft/unit for double stack well cars for domestic containers, 53 ft/unit for single stack well cars and 26.5 ft/unit for double stack well cars for international containers (3). The ideal TFPU can be determined using the following equation:

$$(3) \quad Ideal\ TFPU = \frac{\sum_{i=1}^{n} L_i}{\sum_{i=1}^{n} P_i}$$

Where

i= the ith railcar in the train
n= the total number of railcars in the train
L_i= the outside length of railcar i
P_i= the ideal number of units for railcar i

The TFPU utilization is determined by dividing the ideal TFPU by the actual TFPU. The ideal number of units for a railcar and the railcar length can be retrieved from the AAR Loading Capabilities Guide or the Universal Machine Language Equipment Register (UMLER) database. This metric treats 20-foot containers and 28-foot trailers as individual units. Therefore, it is possible to achieve a TFPU utilization of over 100% if there are a sufficient number of 20-foot containers and/or 28-foot trailers on the train. The ideal TFPU does not consider these smaller units, thus the actual TFPU is smaller than the ideal TFPU in this case. Referring back to Figure 1, if the railcar's outside length is assumed to be 260 feet (5 cars with 48-foot wells), then the Actual TFPU for (a) is 260/9 = 28.89 ft/unit, giving a TFPU utilization of 26.00/28.99 = 90%. For Figure 1b, the ideal and actual TFPU values are equal so the TFPU utilization is 100%. For this scenario, both slot utilization and TFPU utilization scores were the same. Additional loading scenarios will be discussed in Section 6 to show how these two metrics will not always arrive at the same value.

3.3. Slot Efficiency

A third metric that can be used to evaluate the loading of intermodal trains is slot efficiency (4). Slot efficiency considers not only the length of wells or platforms but also the length of the units. The inclusion of the load lengths enables a more detailed comparison between the actual and ideal load configuration, while also identifying empty slots in the train. As was the case with TFPU calculations, the ideal load lengths for a railcar can be obtained by reviewing the AAR Loading Capabilities Guide or the UMLER database. Using this information, slot efficiency is calculated as follows:

$$(4) \quad Slot\ Efficiency = \frac{\sum_{j=1}^{m} l_j}{\sum_{j=1}^{m} t_j}$$

Where

j= the jth slot in the train
m= the total number of slots in the train
l_j= the actual load length(s) in slot j
t_j= the ideal load length in slot j

For example, 40-foot containers double-stacked in a 53-foot slot well car would have a slot efficiency of 75%. Placing 53-foot containers instead of 40-foot containers would make the slot efficiency equal 100%. The inclusion of slot length and load length make slot efficiency an excellent tool to evaluate how well loads and platform/well sizes are matched as well as achieving an objective determination of the energy efficiency of intermodal trains.

4. INTERMODAL TRAIN AERODYNAMICS' IMPACT ON TRAIN ENERGY EFFICIENCY

North American intermodal rolling stock consists of flat cars, spine cars, and well cars (Figure 1). These cars have a variety of designs and loading capabilities, which result in varying gap lengths between loads on adjacent railcars or platforms/wells. If gaps between loads exceed 6 feet in length, the loads are aerodynamically separate and the aerodynamic drag increases significantly due to the change in the boundary layer (5). In addition to equipment variety, intermodal freight trains are among the fastest trains operated by North American

 Copyright © 2011 by ASME

freight railroads. Intermodal trains are often operated at speeds of up to 70 miles-per-hour (mph), to remain competitive with highway trucks that have traditionally offered more reliable and flexible service.

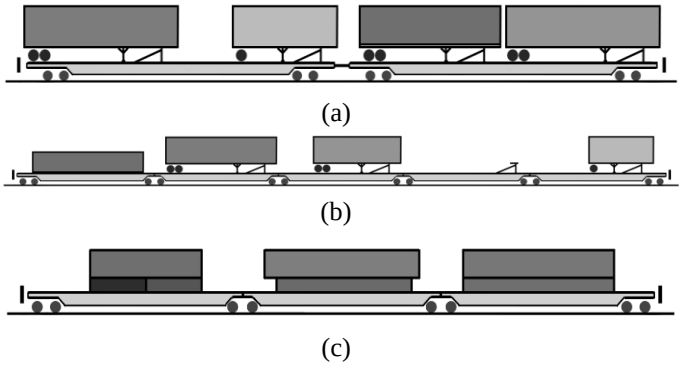

Figure 2. Typical North American intermodal rolling stock: (a) two-unit flat car with trailers (b) five-unit articulated spine car with a container trailers, and (c) three-unit articulated well car with containers.

4.1. Train Resistance and Fuel Consumption

Train resistance is the summation of frictional and other forces that a train must overcome in order to move (6). The general equation for train resistance is $R = AW + BV + CV^2$, where A is the bearing resistance, B is the flange resistance, and C is the aerodynamic resistance (6). The A term varies with the weight (W) of the railcar or train, the B term varies linearly with train speed (V), and the C term increases exponentially as train speed increases. To relate a train's aerodynamic resistance to fuel consumption, Paul et al. (7) referenced an equation used to estimate fuel consumption based on the train's weight, speed, and aerodynamic drag:

$$FC = K(0.0015W + 0.00256S_d V^2 + CW) \quad (5)$$

Where

FC= the fuel consumption in gal/mi
K= the fuel consumed per distance traveled per unit of tractive resistance = 0.2038
W= the train's total weight (lb)
S_d= the consist drag area (ft^2)
V= the train's speed (miles/hr)
C= Hill Factor = 0.0 for level routes and 0.0007 for hilly routes

Due to the exponential nature of train aerodynamic resistance, any methods of reducing the aerodynamic coefficient significantly reduce train resistance and warrant further study. Using fuel consumption equation from Paul et al., a train of 3 locomotives with 53-foot double stack containers in thirty 3-unit railcars traveling at 70 mph can have its fuel consumption reduced 0.1 gallons of fuel per mile per percent reduction in the train's drag area. This savings over thousands of miles can result in a significant savings in operating costs due to fuel consumption. Aerodynamic drag reduction can take on several forms including redesign of intermodal rolling stock and/or installing aerodynamic reduction attachments (7), container/trailer design improvements (7), and improved terminal loading practices (4). Improved loading practices could provide an economical alternative to redesigning railcars or containers/trailers, which requires significant capital investment and design considerations regarding compatibility with existing container and trailer types.

4.2. Optimizing Intermodal Train Loading

The University of Illinois at Urbana-Champaign (UIUC) is investigating methods for optimizing intermodal loading to reduce gap lengths between containers/trailers. In 2005, Lai and Barkan compared the benefits of slot efficiency and slot utilization (4). The potential savings from switching from slot utilization to slot efficiency can be as much as 1 gallon of fuel per mile, depending on the specific rolling stock and loads available (4). Additionally, Lai, Barkan, and Ö nal developed an optimization model that minimized a train's gap lengths given specified loads (8). Lai, Barkan, and Ouyang expanded the earlier optimization model to account for loading multiple trains simultaneously and the uncertainty of incoming loads (9). In addition to modeling, the BNSF Railway is funding UIUC to develop a machine vision system that will be used as a diagnostic tool to evaluate current train loading practices and future loading improvements (10).

5. CRITIQUE OF LOADING METRICS

A juxtaposition of loading metrics and train aerodynamics shows how loading affects aerodynamics and energy efficiency and how improved aerodynamics can come from improved loading. A more detailed critique reveals the limits of each loading metric's ability to holistically describe loading changes that would be beneficial from an aerodynamic drag reduction standpoint.

5.1. Slot Utilization

Slot utilization is the most basic and the least specific of the three metrics described because it only identifies empty slots in the train. It cannot determine the loading capability of the railcars within the train and whether or not the terminal manager minimized the gap length between loads (i.e. improved its aerodynamic performance). In comparison to TFPU, slot utilization does not reward terminal managers for loading more than one unit (such as 20-foot containers in a size 40-foot or larger well car) in a slot. However, it may not be advantageous for railroads that are limited in double stack capability due to clearance restrictions to adopt slot utilization because the scores will not reflect the operational constraint of the corridor. Also, if railroad transportation management is looking to identify which destinations' blocks are underutilized, the metric does not discriminate between different blocks on the train unless is a unit train where all of the loads bound for a single destination (11).

 Copyright © 2011 by ASME

5.2. TFPU

TFPU provides a more detailed analysis of intermodal train loading because it considers the equipment used to make up the train's consist. This metric promotes the reduction in train length while still maintaining a high number of units. TFPU can also help reduce operating costs and maximize revenue generation for each train by reducing its length (12). However, like slot utilization, it cannot be used to determine how well loads were matched with the appropriate well or platform size. Also, the TFPU utilization score is the same as the slot utilization score except that it considers the number of units used rather than whether or not the slot was utilized or not. The TFPU metric is biased towards trains that have 20-foot containers and/or 28-foot trailers because they can achieve higher scores than trains that have larger load sizes. However, this bias could help compensate terminals that are limited in double stack capability by giving their trains higher scores for using smaller units. The TFPU metric would not penalize this scenario where the top of a well car could not be utilized because of weight restrictions or incompatibilities between certain load designs. The use of the ideal TFPU can be adopted to reflect the context of the operational limits of the train such as clearance restrictions.

5.3. Slot Efficiency

In comparison to the other two loading metrics, slot efficiency is the most specific because it considers the length of the wells and/or platforms and its loads. However, the specificity of this metric makes difficult to decipher whether a train has empty slots or if the loads do not match their assigned slots. From an aerodynamic point of view, this metric does not account for location of the minimized gaps so the loading could be very good in the middle and in the back of train but poor in the front of the train where the aerodynamic penalties are highest. The following scenarios and variations show that slot efficiency is generally the best estimate for improvements in energy efficiency from improved loading.

6. ANALYSIS OF LOADING METRICS

To provide a further comparison of loading metrics, two loading scenarios are introduced. These scenarios capture many of the deficiencies in loading performance metrics. Also, an analysis of the scenarios will be conducted to see how incremental changes in train loading will affect the loading score and the train's aerodynamic performance. The aerodynamic coefficient for each train was determined using the AAR Aerodynamic Subroutine (13). The first scenario, Scenario A, is a train pulled by three Electromotive Division (EMD) locomotives with the short hoods facing forward. There are thirty 3-unit well cars modeled after a TTX railcar having 53-foot wells. These wells can hold two 20-foot containers or one 40, 45, 48, or 53-foot container in the bottom slot and a 40, 45, 48, or 53-foot container on top (14). Well A has two 20-foot containers in the bottom slot and a 40-foot container on top. Well C has a 53-foot container in the bottom slot and no load on top. Well B has a 48-foot container in the bottom slot and a 53-foot container above it. This loading configuration is shown in Figure 3a. The second scenario, Scenario B, is a train with three EMD locomotives just like in Scenario A and thirty 3-unit articulated spine cars with 57-foot platforms. Platform A has two 28-foot trailers, Platform B has one 28-foot trailer, and Platform C has a 48-foot trailer as shown in Figure 3b.

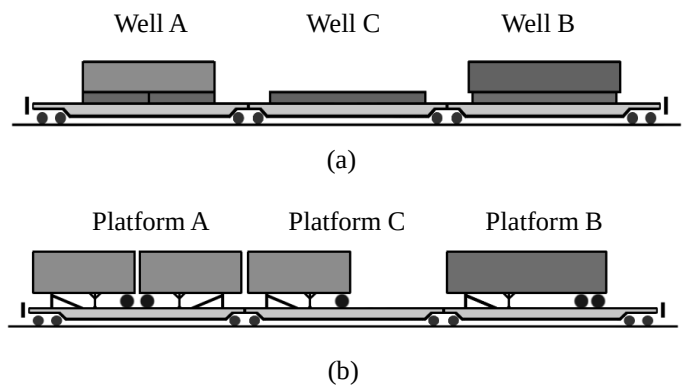

Figure 3. (a) Loading Scenario A (well cars with 53-foot wells) and (b) Scenario B (spine cars with 57-foot platforms)

6.1. Analysis of Scenario A: Containers in Well Car

For this scenario, 5 slots are utilized out of 6 possible slots, thus the unit's slot utilization is 83%. For TFPU, assume that the railcar's length is 203 feet (67.67 ft per well). The train's actual TFPU is the following:

$$(6)\quad Actual\ TFPU = \frac{30 \times 203\,ft}{30 \times (2+1+0+1+1+1)\,units}$$

$$Actual\ TFPU = 33.83\ ft/unit$$

If the ideal TFPU is 33.83 ft/unit, which represents a well having two units, then the TFPU utilization is 100%. If the ideal TFPU was 67.67 ft/unit, then the score would double. If the ideal TFPU was 22.56 ft/unit assuming 3 units per well, then the TFPU utilization would be 66.7%. In this scenario, the two 20-foot containers average out the TFPU utilization and make it appear as if the train has 2 units per well when every one of three wells has 3 units. This scenario shows how terminals could use 20-foot containers to achieve a perfect loading score and have empty slots within a train. Slot efficiency is able deduce the empty slots as well as consider the improper matching of cars with units:

$$(7)\quad Slot\ Efficiency = \frac{30(2 \times 20\,ft + 40\,ft + 53\,ft + 48\,ft + 53\,ft)}{30(6 \times 53\,ft)}$$

$$Slot\ Efficiency = 73.6\%$$

The empty top position in the middle well and the international containers in the 53-foot well contribute to a lower score. The missing container in the middle as well as the larger gaps

Copyright © 2011 by ASME

between the loads cause the train's aerodynamic coefficient to be 12.82 lb/mph^2, which is an incredibly high coefficient. The following sections will describe variations of this scenario where the train's loading is incrementally altered to exploit changes to drag coefficient as well as loading performance scores.

6.2. Variations of Scenario A

6.2.1. Adding 53' Containers to Empty Slots

For the first scenario, the empty slot in the top middle well is filled with a 53-foot container. Figure 4 shows incremental improvement in all metric's scores as well as the aerodynamic improvement when the empty slots are replaced from the front to the back of the train. Notice the improvement is the same for slot utilization, slot efficiency, and TFPU. Looking at Figure 5, the loading metrics have differing y-intercepts but their improvement is indeed the same. The lines in all of the figures for are regression lines and the relationships are linear. The improvement in the aerodynamic coefficient was determined using the following equation:

$$(8) \quad \textit{Improvement in Aerodynamic Coefficient} = \frac{C_o - C_i}{C_o}$$

Where

C_o = the aerodynamic coefficient for the base case with no empty slots replaced with 53-foot containers

C_i = the aerodynamic coefficient for i empty slots replaced with 53-foot containers

This method of determining the improvement in the aerodynamic coefficient will be used for all scenario variations with i representing the slot or loads being changed as shown in the horizontal axis of the figure describing the scenario variation.

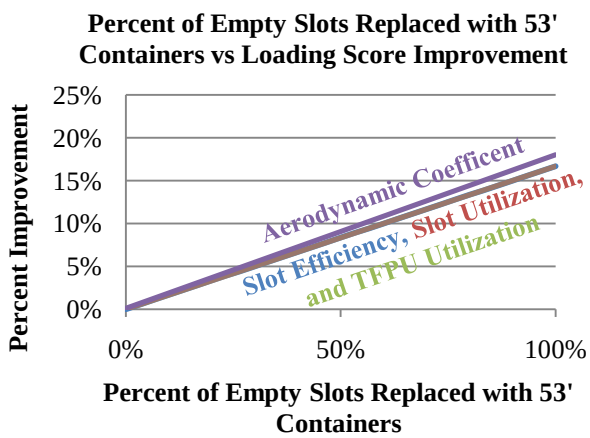

Figure 4. Improvement in loading performance and aerodynamics by replacing empty slots with 53-foot containers in the train

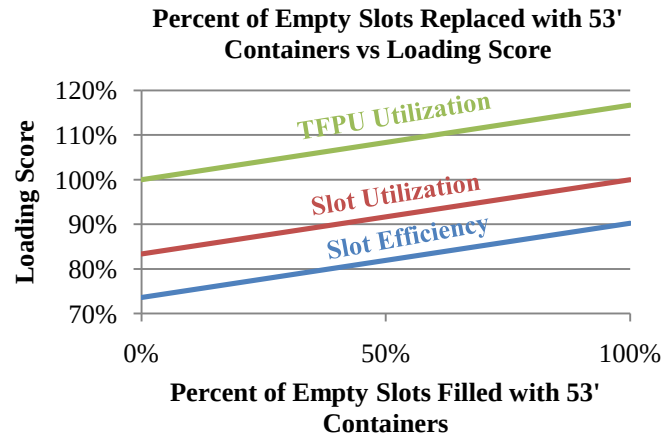

Figure 5. Improvement in loading score starting with the base score as empty slots are replaced with 53-foot containers

The incremental addition of a 53-foot container to the train results in all loading performance scores having the same incremental improvement of 0.56% to the scores, per 53-foot container added. However, if the size of the added load changes, the slot efficiency improvement will not be as great. For instance, if a 40-foot container was added to empty slots instead of a 53-foot container, the improvement in the slot efficiency score would be 0.42% per unit added while the other loading metrics improvements would not change in comparison to the 53-foot case. Another interesting case is adding two 20-foot containers to the middle well and the 53-foot container originally in the bottom slot was placed on top. In comparison to the addition of 40-foot containers, the only metric that would behave differently is TFPU utilization where its score would be improved 1.1% for each pair of 20-foot containers added to the train. This would however affect train resistance because the increased weights of two 20-foot containers rather than one 53-foot or 40-foot container. From this analysis, each loading metric as well as the aerodynamic coefficient improves as more empty slots are filled with loads.

6.2.2. Replacing Loads in Well A with 53' Containers

The next variation was developed to observe how the loading metrics adapt to increasing the load lengths to 53-foot containers. Specifically, we answer the question: "how does the loading performance change when the 40-foot containers and the pair of 20-foot containers are switched to 53-foot containers?" The results are shown in Figure 6. This incremental improvement is as follows:

1. Exchange a 40-foot container on the top of Well A for a 53-foot container
2. Exchange the two 20-foot containers on the bottom of Well A to a 53-foot container
3. Repeat steps 1 and 2 for the other 29 railcars in the train, from front to rear

Copyright © 2011 by ASME

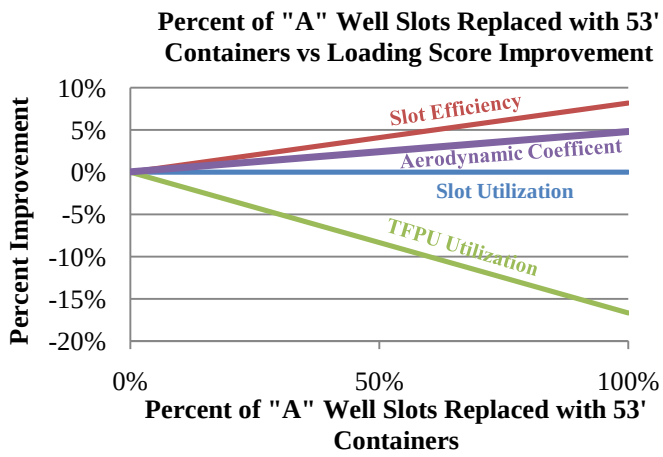

Figure 6. Improvement in loading score as international units in Well A are switched to 53-foot containers

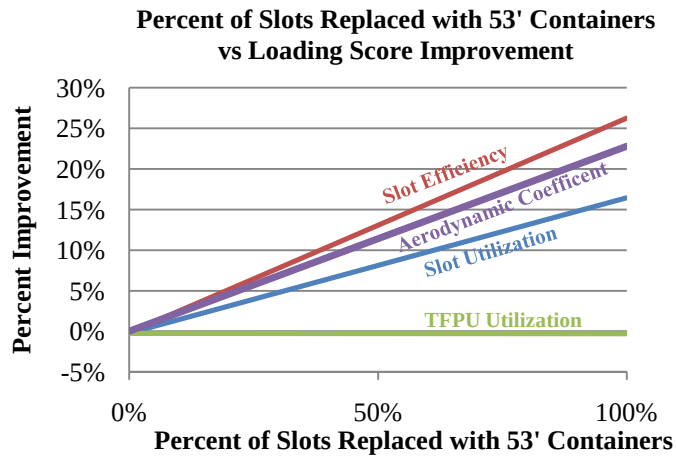

Figure 7. Improvement in loading score as all loads are switched to 53-foot containers

Replacing 20-foot and 40-foot containers with 53-foot containers did not affect slot utilization and had a negative change in the TFPU utilization score. The aerodynamic improvement is smaller in comparison to adding containers in the middle car's empty slot but can it can still be useful in improving an intermodal train's energy efficiency. Therefore, an increase in load size was detrimental to TFPU utilization, yet it also provided a positive improvement in slot efficiency and the aerodynamic coefficient and no improvement in slot utilization.

6.2.3. Replacing All Loads to 53' Containers

The final variation is combining the two previous variations to include the replacement of empty slots and increase the size of all loads to 53-foot containers. The order in which the railcars are replaced is as follows:

1. Exchange a 40-foot container on the top slot of Well A for a 53-foot container
2. Exchange two 20-foot containers on the bottom slot of Well A for a 53-foot container
3. Add a 53-foot container in the top slot in Unit C
4. Exchange a 48-foot container on the bottom slot of Well B for a 53-foot container
5. Repeat steps 1 to 4 for the other 29 cars, from front to rear

The results are shown in Figure 7. The combination of filling empty slots and exchanging smaller loads for 53-foot containers results in increased slot utilization and slot efficiency, and a reduction in the train's aerodynamic coefficient. The TFPU utilization remains unchanged at 100%, while slot efficiency and slot utilization reach 100% as all 120 slots are filled and/or replaced with 53-foot containers. This final scenario variation had a final aerodynamic coefficient of 9.91 lb/mph^2 while only replacing empty slots had an aerodynamic coefficient of 10.51 lb/mph^2 and increasing load size had a final coefficient of 12.22 lb/mph^2. Therefore, from an aerodynamics standpoint, it is better to fill empty slots than try to increase the size of loads within the train consist.

6.3. Analysis of Scenario B: Trailers on Spine Car

For the spine car scenario, all three slots have at least one load, thus the slot utilization of the units is 100%. For TFPU, assume the railcar length is 189.5 feet (4 units at 189.5 feet) so the actual TFPU would be the following:

$$(9)\quad ActualTFPU = \frac{189.5\,ft}{(2\,units + 1\,unit + 1\,unit)}$$

$$ActualTFPU = 47.38\,ft/unit$$

If the ideal TFPU is assumed to be 63.17 ft/unit, one third of the railcar length, the TFPU utilization is 133%. The score is greater than 100% because of the 28-foot trailers in Platform A. Assuming the ideal load length for each platform is 57 feet, the train's slot efficiency is the following:

$$(10)\quad Slot\ Efficiency = \frac{30(2\times 28\,ft + 28\,ft + 48\,ft)}{30(3\times 57\,ft)}$$

$$Slot\ Efficiency = 77.19\%$$

The aerodynamic coefficient for the train is 9.09 lb/mph^2 and it will be the base value for three variations of Scenario B which consider adding a 28-foot trailer to Platform C, exchanging the 28-foot trailer in Platform C for a 53-foot trailer, and converting all platform loads to 53-foot trailers.

6.4. Variations of Scenario B

6.4.1. Adding a 28' trailer to Platform C

For the first iteration, a 28-foot trailer is added to Platform C and the results are shown in Figure 8. Each 28-foot trailer adds 1.11% to the TFPU utilization score and a 0.55% improvement to the slot efficiency. However, the slot utilization does not change because all slots in the train remain filled. Looking at the reduction in the aerodynamic coefficient, there is a 0.65% reduction in the coefficient as 28-foot trailers are added to the train. In this case, the

Copyright © 2011 by ASME

aerodynamic improvement best follows the improvement in the slot efficiency.

6.4.2. Switching the 28' trailer in Platform C to a 53' trailer

The second variation of Scenario B is switching the 28-foot container in Platform C to a 53-foot trailer. This improvement causes the utilization and TFPU utilization to remain fixed at 100% and the only score that changed is slot efficiency, which improves by 0.43% per 28-foot trailer switched (Figure 9). The aerodynamic coefficient has a higher improvement compared to the improvement in slot efficiency. Compared to the previous variation, the addition of a 28-foot trailer results in a slightly higher improvement in aerodynamics than switching it to a 53-foot trailer.

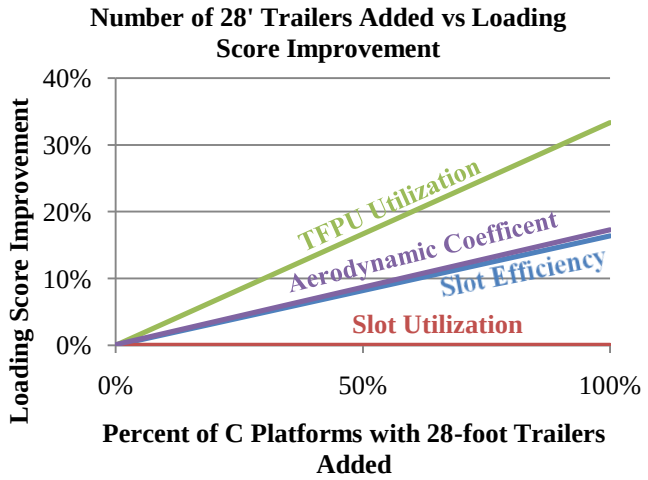

Figure 8. Improvement in loading score as 28-foot trailers are added to the train

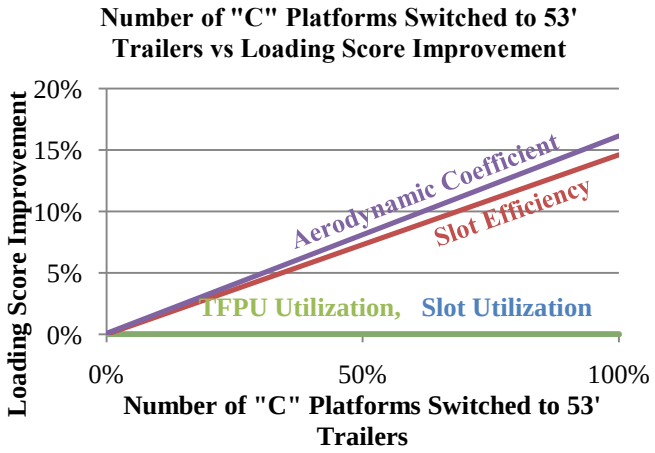

Figure 9. Improvement in loading score as the middle platform is switched to a 53-foot trailer

6.4.3. Switching all platform loads to 53' trailers

Similar to the last variation of Scenario A, all loads on the platforms will be incrementally switched to 53-foot trailers. The replacement order is as follows:

1. Exchange two 28-foot trailers on Platform A for a 53-foot trailer
2. Exchange a 28-foot trailer on Platform C for a 53-foot trailer
3. Exchange a 48-foot trailer on Platform B for a 53-foot trailer
4. Repeat steps 1 to 3 for the other 29 cars in the train, from front to rear

Figure 10 shows how the metrics and aerodynamics change as loads in the train change from the front to rear. Exchanging all loads for 53-foot trailers on the train provided a 16.6% reduction in the train's aerodynamic coefficient or 0.18% reduction per platform. This exchange also improved the slot efficiency score by 15.79% or 0.17% reduction per platform. TFPU utilization decreases because the 28-foot trailers are replaced with one trailer. The lowest aerodynamic coefficient attained from adding 28-foot trailers was 7.52 lb/mph^2 and is almost equivalent to the aerodynamic coefficient of 7.58 lb/mph^2 when all platforms have 53-foot trailers. Like Scenario A, filling large empty spaces in the train with loads are more beneficial than changing load sizes in terms of train aerodynamics and slot efficiency.

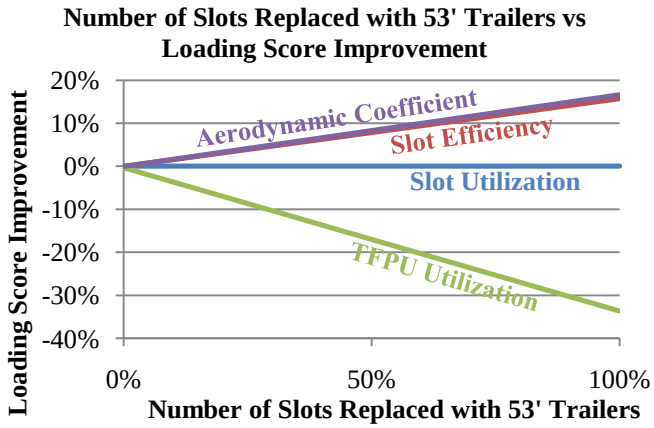

Figure 10. Improvement in loading score as all platforms are switched to 53-foot trailers

6.5. Analysis of Case Study Results

Both the well car and spine car scenarios show that slot efficiency is a better indicator of the aerodynamic efficiency of intermodal trains in comparison with TFPU and slot utilization. In addition to failing to distinguish between empty slots and larger load sizes, another weakness of slot efficiency is that it does not discriminate against location of where the improvements are made. From the literature and wind tunnel tests, the first ten gaps of the train are the most critical in the reduction of aerodynamic drag. Therefore, if the loads were added in the back of train and moved forward, the aerodynamic

Copyright © 2011 by ASME

drag reduction would not be as significant but the slot efficiency would improve at the same rate as when the loading was improved from front to back. A way to ensure that loading improvements first occur at the front of the train would be assigning coefficients to each position in the train where the coefficient would be numerically larger in front in comparison to the back of the train. A possible model to assign coefficients based on a railcar's position would be the following:

$$\sum_{j=1}^{m} c_j = 1 = \sum_{j=1}^{m} \frac{1}{j+q} \quad (11)$$

Where

q = a positive value that we solve for to determine the position coefficient

c_j = the position coefficient for the jth slot

Note that the q-value is dependent on j and is independent of the position in the train. Adding this coefficient to the slot efficiency equation would result in the following modified equation:

$$\textit{Modified Slot Efficiency} = \sum_{j=1}^{m} c_j \frac{\left(l_j + l_j^* d_j\right)}{\left(t_j + t_j^* d_j\right)}$$

Where

c_j = the position coefficient for slot j.

d_i = a binary variable that is equal to one when the slot has double stack capability and zero when the slot only has single stack capability

l_i = the actual load length for slot j

l_j^* = the actual load length for the top load in slot j

t_j = the ideal load length for slot j

t_j^* = the ideal load length for slot j's top position

The results from the case studies reveal loading improvements do indeed improve train aerodynamics, especially filling empty slots within the train. Improvements include increasing the trailer/container size, filling empty slots, and matching loads. However, the loading improvements may be limited by several factors at the terminal, which are often out of the terminal manager's control.

7. POTENTIAL IMPACT ON TERMINAL OPERATIONS

From a terminal operations perspective, there are many limitations to consistently achieving high slot efficiency and reduced aerodynamic resistance. These include load availability, railcar availability, time constraints, terminal parking availability, and maintaining a high customer satisfaction rating by ensuring on-time arrivals. Some of these constraints are interrelated, thus the problem is not trivial. Additionally, some constraints are equipment resource related and/or demand induced.

7.1. Load and Equipment Availability

A train made up of several blocks bound for different destinations may have blocks that are more highly utilized than others. The utilization of each block is dependent on the customer demand for the destination location. Some destinations may require larger blocks or more frequent service than others. The block size can be estimated by looking at historical data to predict the number of loads for that destination and the block size needed. To prevent empty slots, the number of railcars in the block or the frequency of service could be reduced. However, this could lead to other negative impacts on terminal performance especially customer service quality if loads are held to improve train loading. Loads are held back in this case because there is not enough space in the blocks for additional loads or there is little demand for the destination and the costs are higher for a few customers.

Terminal managers often have to use the railcars from inbound trains to make up the blocks for their outbound trains even if the slots or platforms are too large for the outbound loads. Also, outbound trains may include more poorly loaded railcars because its destination terminal is short on railcars so more railcars are added to meet the destination terminal's need. Railcars with larger platform or well sizes, such as 53-foot well cars or the 57-foot spine cars, have more utility for terminals because they can hold all possible standard trailer and container sizes rather than cars with smaller platforms or well lengths. Having larger-sized well and platforms also require less switching because all load sizes could fit and terminal operating efficiency would be improved.

7.2. Dwell Time and Traffic Flow

A terminal cannot accurately predict the loads that will arrive through the gate. To maximize the train's loading efficiency, loads may be held and loaded closer to the cut-off time to provide more time for clerks to place loads in an optimal location within the train. However, waiting to load trailers/containers to maximize the efficiency of the train loading may increase the container dwell time and limit the terminal's parking space capacity if many loads are also held. Some terminals have limited or no parking space for arriving loads so this results in quick decisions about load placement on the train. Often the load arrival rate is not constant, but peaks on certain days of the week and some of the days have little inbound loads. Trying to optimize loading on peak traffic days in the week may prove infeasible if a queue builds up.

7.3. Customer Service Performance

If the loading employees wait too long to place loads onto a train, they may not have enough time to load all the containers/trailers bound for that destination before the cut-off time, thus this scenario must be avoided. Having a load miss the cut-off time when there was space and opportunity to load it onto the train is unacceptable from customer satisfaction

Copyright © 2011 by ASME

standpoint. However, because fuel is the highest operating cost for railroads, a reduction in fuel consumption through improved loading practices may be worth a marginal increase in time spent in the terminal. The fuel savings would reduce costs and this would benefit customers who need to pay for operating costs such as fuel.

8. FUTURE WORK

Minimal changes in loading practices could result in substantial savings due to reduced fuel consumption. UIUC is continuing to investigate how improved intermodal train loading practices can have minimal impact on terminal operations, yet provide the aforementioned fuel savings. Using radio frequency timestamp data from several intermodal terminals, we are studying the motion of containers and trailers through terminals. The investigation will help determine if there is a significant difference in terminal dwell time for a poorly loaded train compared to a well-loaded train. This study could also help identify sources of unnecessary and avoidable waste in terminal operations and loading for lean improvements. It will also provide a better understanding for why poor loading from an aerodynamic standpoint occurs at terminals.

9. CONCLUSION

Loading metrics can help terminals make up more energy-efficient train consists and facilitate loading improvements by using a stricter loading metric like slot efficiency. The slot efficiency metric identifies the improvements associated with matching loads to the right well/platform size. If the negative impacts to terminal operations due to changing loading practices are minimized and other energy efficiency improvements, such as more fuel-efficient locomotives, improved train handling, and improved railcar design, are considered, railroads can significantly reduce operating costs by reducing fuel consumption.

ACKNOWLEDGMENTS

The authors would like to thank the BNSF Railway and BNSF's Technical Research and Development group for sponsoring this research, as well as research aimed at developing machine vision inspection systems for evaluating intermodal train loading. Special thanks to Lex White, Terry Hart, and Doug Daun at CSX Intermodal, Deron Amans at BNSF, and Mike Smeltzer at Canadian Pacific. J. Riley Edwards has been supported in part by grants to the UIUC Railroad Engineering Program from CN, CSX, Hanson Professional Services, Norfolk Southern, and the George Krambles Transportation Scholarship Fund.

REFERENCES

(1) Association of American Railroads. Class I Railroad Statistics. Washington, D.C., May 24, 2010.

(2) Association of American Railroads. Railroad Facts 2009. Washington, D.C., 2009.

(3) White, Lex. Personal Communication. CSX Intermodal.

(4) Lai, Y.C., and C.P.L. Barkan. Options for Improving the Energy Efficiency of Intermodal Freight Trains. *Transportation Research Record*, No. 1916, Transportation Research Board of the National Academies, Washington, D.C., 2005, pp. 47-55.

(5) Engdahl, R., R.L. Gielow, and J.C. Paul. Train Resistance—Aero- dynamics Volume I, Intermodal Car Application. *Proc., Railroad Energy Technology Conference II*, Atlanta, Ga., Association of American Railroads, 1986, pp. 225-242.

(6) Hay, W.W. *Railroad Engineering*, 2nd ed. John Wiley and Sons, New York, 1982.

(7) Paul, J.C., R.W. Johnson, R.G. Yates. Application of CFD to Rail Car and Locomotive Aerodynamics. *The Aerodynamics of Heavy Vehicles II: Trucks, Buses, and Trains*, pp. 259-297, 2009.

(8) Lai, Y.C., C.P.L. Barkan, and H. Önal. Optimizing the energy efficiency of intermodal freight trains. Transportation Research, Part E 44, 2007, pp. 820-834.

(9) Lai, Y.C., C.P.L. Barkan, and Y. Ouyang. A Rolling Horizon Model to Optimize the Aerodynamic Efficiency of Intermodal Freight Trains with Uncertainty. Transportation Research, Part E 44, 2007, pp. 820-834.

(10) Rickett, T.G., J.M. Hart, J.R. Edwards, A. Kumar, C.P.L. Barkan, and N. Ahuja. Monitoring the Aerodynamic Efficiency of Intermodal Train Loading Using Machine Vision. Proceedings of the TRB 90th Annual Meeting, Washington, DC, January 2011 (In Press).

(11) Quoram Corporation. Container Use in Western Canada: Inland Terminals, Container Utilization, Service and Regulatory Issues and the Optimization of Use in Western Canada. Accessed from http://www.tc.gc.ca/eng/policy/report-acg-containerusewesterncanada2007-html-menu-224.htm. November 2007.

(12) Doug Daun. Personal Communication. CSX Intermodal.

(13) Furlong, C.F., Aerodynamic Subroutine Users Guide, Publication R-683. Association of American Railroads, Washington, D.C., 1988.

(14) Association of American Railroads, Loading Capabilities Guide, Washington D.C., May 19, 2009.

Copyright © 2011 by ASME