Options for Improving the Energy Efficiency of Intermodal Freight Trains

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Intermodal trains are typically the fastest trains operated by North American freight railroads. Ironically, these trains tend to have the poorest aerodynamic characteristics. Because of constraints imposed by equipment design and diversity, intermodal trains incur greater aerodynamic penalties and increased fuel consumption than other trains. Improving the loading patterns of intermodal trains has the potential to improve aerodynamic characteristics and thus fuel efficiency. Train aerodynamics and resistance analyses were conducted on several alternative intermodal train-loading configurations. Matching intermodal loads with cars of an appropriate length reduces the gap length between loads and thereby improves airflow. Filling empty slots with empty containers or trailers also reduces aerodynamic resistance and improves energy efficiency, despite the additional weight penalty and consequent increase in bearing and rolling resistance. Depending on the particular train configuration, train resistance can be lowered by as much as 27% and fuel savings by 1 gal/mi per train.

Intermodal freight is the second-largest source of U.S. railroad revenue and is the fastest-growing segment of freight traffic. This traffic has grown more than threefold from 3 million trailers and containers in 1980 to 9.9 million in 2003 (*1*).

Because of the constraints imposed by equipment design and diversity, intermodal trains incur greater aerodynamic penalties and increased fuel consumption than do their general freight counterparts. This is particularly ironic given that these trains are typically the fastest freight trains operated. Class I railroads spent over $3 billion on fuel in 2003, making fuel their second-largest operating expense. Furthermore, fuel cost has increased by more than 60% since 1998, making fuel efficiency more important than ever (*2*). Intermodal train fuel efficiency is affected by both equipment and loading patterns; thus investigating options and the effects of those options is worthwhile.

At intermodal terminals, containers or trailers are assigned to available well, spine, or flat cars (*3, 4*). Although terminal managers often use computer software to help with this task, it is still a largely manual process (*5*). The principal metric used to measure the efficiency of loading is slot utilization (*6*). Although the details vary depending on the particular combination of intermodal load and car being considered, slot utilization is basically a metric used to measure the percentage of the spaces (i.e., slots) on intermodal cars that are used for loads. Slot utilization does not take into account the size of the space compared to the size of the load. Although perfect slot utilization indicates the maximal use of spaces available, it is not intended to ensure, nor does it ensure, that intermodal cars are loaded to maximize energy-efficient operation. Two trains may have identical slot utilization, but different loading patterns and, consequently, different aerodynamic resistances.

During the 1980s, a number of studies focused on technologies to reduce train resistance and therefore fuel costs (*7, 8*). Aerodynamic drag was known to be a major component of total tractive resistance, particularly at higher speeds, so the Association of American Railroads (AAR) supported research on wind tunnel testing of rail equipment, including large-scale intermodal car models (*9, 10*). The results were used to develop the aerodynamic subroutine of the AAR's train energy model (TEM) (*11*).

From these wind tunnel tests, it was found that the lead locomotive experienced the highest drag and that drag decreased until about the 10th unit or car in the train, after which drag remained roughly constant per unit. It was also found that closely spaced containers or trailers behave as one long load. Conversely, loads spaced at equal to or greater than 6 feet behave as distinct objects on whose surfaces boundary layers are reinitialized (*12*). Consequently, Engdahl et al. suggested that filling empty slots with empty containers might have potential advantages; however, this suggestion did not consider the effect of the increased weight of the additional loads (*13*).

Improving the loading patterns of intermodal trains has the potential to improve railroad fuel efficiency and reduce emissions. Maximizing slot utilization does enhance energy efficiency, but matching intermodal loads with appropriate-length intermodal car slots can further reduce gap length between loads and thus improve airflow. Filling empty slots with empty containers or trailers also reduces aerodynamic resistance; however, the additional weight penalty generates more bearing and rolling resistance. A series of analyses was conducted to compare both the relative and absolute effects of different loading patterns and operating practices on train make-up and energy efficiency.

METHODOLOGY

Several approaches to maximizing intermodal train energy efficiency were considered: slot utilization, improved equipment matching, and use of empty intermodal loads to improve train aerodynamics. Train resistance and the aerodynamic coefficient were computed for a series of different train scenarios using TEM (*11*) and the aerodynamic subroutine (*14*). Train resistance is the sum of the forces opposing the movement of a train (*15*). The greater the resistance, the more energy is required to move the train. Therefore, it is a major factor affecting fuel economy.

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The general expression for calculating train resistance is as follows (*15*):

$$R = A + BV + CV^2$$ 53I79 Tw653 s1 611A4nce9areass y2oe811A4n94n8.s7dshe 5nm-l0313e aer7y,Fo5 1 er7y,

where

R = train resistance (lb),
V = train speed (mph),
A = bearing and rolling resistance independent of train speed (lb),
B = coefficient used to define train resistance dependent on train speed (lb/mph), and
C = aerodynamic coefficient (lb/mph/mph).

The B term is generally small and is sometimes ignored (*9, 16*). The C term can be computed from the aerodynamic subroutine by specifying a train consist. For bearing and rolling resistance, the equations in TEM were used. TEM requires input regarding bearing type and condition and truck design and condition. On the basis of information from railroads and intermodal equipment engineering personnel (J. M. Hettinger, TTX Engineering Department, personal communication, 2004), the following assumptions were used in the analyses:

- 50% of the bearings are manufactured by Timken, and the other 50% by Brenco;
- 50% of the bearings are worn, and the other 50% are new;
- 50% of the trucks are three-piece worn, and the other 50% are three-piece new;
- Ambient temperature is 60°F; and
- No side wind effect exists (i.e., yaw angle = 0°).

According to these assumptions, the bearing resistance is calculated as follows (*11*):

$$R_{Bk} = n_k C_{Bk}$$

$$C_{Bk} = 6.2334 \times W_k^{0.20194}$$

where

k = ordinal number of vehicle in consist,
R_{Bk} = bearing resistance acting on vehicle k (lb),
n_k = number of axles on vehicle k,
C_{Bk} = bearing resistance coefficient for vehicle k (lb/axle), and
W_k = total weight for vehicle k (tons).

Rolling resistance is computed as follows (*11*):

$$R_{Rk} = 0.0005 w_k C_{Rk}$$

where

R_{Rk} = rolling resistance acting on vehicle k (lb),
C_{Rk} = rolling resistance coefficient for vehicle k (lb/ton), and
w_k = total weight for vehicle k (lb).

If $w_k < \gamma_k$,

$$C_{Rk} = 2.25 - [2.25 - \lambda]\left[\frac{w_k - \tau_k}{\gamma_k - \tau_k}\right]$$

Otherwise, if ($w_k \geq \gamma_k$)

$$C_{Rk} = \lambda$$

where

γ_k = gross rail load for vehicle k (lb),
τ_k = vehicle k tare weight (lb), and
λ = loaded rolling resistance coefficient for vehicle k (lb/ton) (λ is 2.13 lb/ton for a three-piece worn truck and 1.57 lb/ton for a three-piece new truck).

As a result, the resistance equation in this study can be represented as follows:

MATCHING INTERMODAL LOADS WITH CARS

A typical intermodal train has three locomotives and 80 to 120 units. Therefore, a train of three locomotives and 100 units (20 five-unit cars) was chosen as suitably representative for these analyses. The capacity of well and spine cars is usually constrained by the length of the loads. For example, a five-unit articulated double-stack well car with a 40-ft well cannot handle containers greater than 40 ft long in the bottom position, whereas a five-unit car with a 48-ft well can handle containers up to 48 ft in length. Similarly, a five-unit articulated spine car with 48-ft slots cannot handle containers or trailers greater than 48 ft, whereas a five-unit car with 53-ft slots can handle trailers of any length up to 53 ft (*3, 4, 17, 18*). Consequently, cars with longer slots are more flexible; however, if loaded with trailers or containers less than the maximum they allow, then the gaps between loads are correspondingly larger and are less aerodynamically efficient. The following analyses were conducted to illustrate the potential differences in resistance for different train-loading configurations.

In the case of the well car, a 40-ft container can be assigned to a car with either 40-ft or 48-ft wells; however, only use of a car with 40-ft wells would result in the shortest gap and the best aerodynamics. In this example, the gap between two double-stack 40-ft containers would increase by 8 ft if 48-ft-well cars were used (Figures 1*a*, 1*b*).

For a train of 20 cars with 40-ft double-stack containers, the aerodynamic coefficient increases from 4.82 to 5.05 lb/mph/mph when

48-ft-well cars are used instead of 40-ft-well cars. The resistance was calculated for these two train configurations for speeds up to 70 mph. As expected, the train with 40-ft-well cars had lower resistance at all speeds (Figure 2*a*). The difference in resistance for the 40-ft-well car with 40-ft containers, compared to the 48-ft-well car with 40-ft containers (Figure 2*b*), increases from 1.03% to 2.96% as speed increases to 70 mph.

Similarly, a 48-ft trailer can be placed on a spine car with either 48-ft or 53-ft slots. The gaps between trailers are shortest when using cars with 48-ft slots (Figures 1*c*, 1*d*). For a train made up of 20 spine cars with 48-ft trailers, the aerodynamic coefficient increases from 5.90 to 9.12 lb/mph/mph when 53-ft-slot cars are used instead of 48-ft-slot cars. The difference in resistance ranges from 0.07% to 26.72% depending on speed (Figures 3*a*, 3*b*).

Fuel Consumption Computation

In the analyses above, each datum represents the effect on train resistance at a specific speed; however, a train's speed will actually vary as it traverses a route. In addition to resistance, the power-to-ton ratio, route characteristics, and train schedule will all affect fuel consumption. Therefore, the distribution of speed profiles and throttle setting is needed to more accurately estimate fuel saving. TEM was used to compute and compare the fuel consumption for each case using a representative rail line. A typical intermodal route in the Midwest was chosen for this analysis. It is 103 mi in length with gently rolling topography, grades generally under 0.6%, and curves less than 3°.

In the first case, placing 40-ft double-stack containers on cars with 40-ft wells would save 13 gal of fuel per train on this route compared to cars with 48-ft wells. In the second case, placing 48-ft trailers in spine cars with 48-ft slots would save over 100 gal of fuel per train. The resultant fuel savings in the first case is 0.13 gal/mi; in the second, over 1 gal/mi. The reason for the difference is that in the first case, the gaps are reduced in length, whereas in the latter case, the gaps are almost completely eliminated.

Slot Utilization Versus Equipment Matching

Maximizing slot utilization has a positive effect on train energy efficiency because it eliminates empty slots and the consequent large gaps that would otherwise occur. However, as should be evident from the

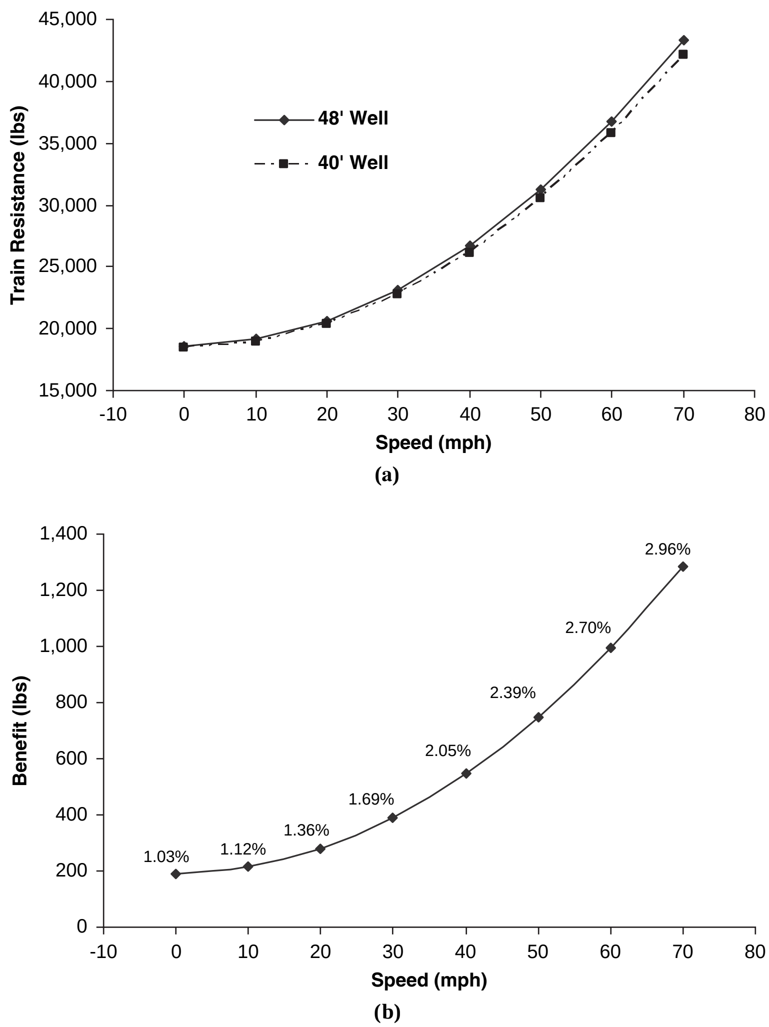


FIGURE 2 Train with 20 cars: (*a*) resistance of 40-ft containers on 48-ft-well cars or 40-ft-well cars and (*b*) benefit of using 40-ft-well cars.

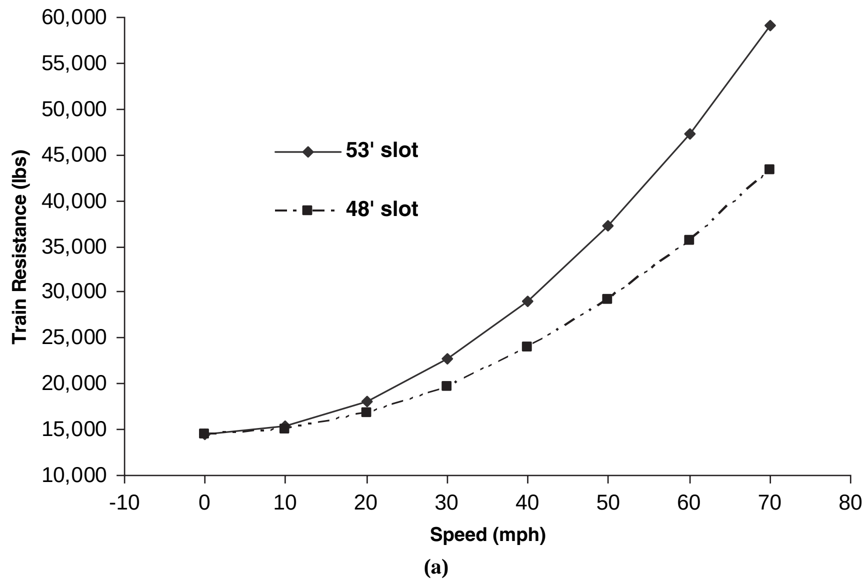


FIGURE 3 Difference in resistance: (*a*) resistance of 48-ft trailers on 53-ft-slot spine cars or 48-ft-slot spine cars and (*b*) benefit of using 48-ft-slot spine cars.

prior example in which all the trains considered had 100% slot utilization, efficiency can still be substantially improved depending on the specific load-and-car combinations that are used. Maximizing slot utilization alone does not ensure that the lowest aerodynamic resistance is achieved; proper matching of intermodal loads with cars does. Consequently, matching is a better metric for energy efficiency than slot utilization.

For example, the aerodynamic coefficient for a train of twenty 48-ft-well cars loaded with 40-ft containers will be reduced by 23% if slot utilization is improved from 90% to 100% (Figure 4). However, if the 48-ft-well cars are replaced with 40-ft-well cars, the aerodynamic coefficient would be reduced by another 5%. Note that in both cases, slot utilization is 100%.

Similarly, the aerodynamic coefficient decreases by 3% if slot utilization is increased from 90% to 100% for a train of twenty 53-ft-slot spine cars with 48-ft trailers (Figure 4). Replacing 53-ft-slot spine cars with 48-ft-slot spine cars reduces the aerodynamic coefficient by another 36%.

Accordingly, a train can be more efficiently operated if loads are assigned based not only on slot utilization, but also on better matching of intermodal loads with cars. This process is termed slot efficiency (L. R. Milhon, Burlington Northern Santa Fe Railway Company, personal communication, 2004). This effect will be especially pronounced for the units in the front of the train, where the aerodynamic effect is greater.

FILLING EMPTY SLOTS WITH EMPTY LOADS

The load configurations of more than 30 intermodal trains on a high-density intermodal route of a Class 1 railroad were recorded. It was observed that empty slots usually occur as a single container on a well car or as an empty slot on a spine car. Therefore, three different loading combinations were analyzed in three scenarios to evaluate the effect of placing empty loads in empty slots (Figure 5): double-stack containers on well cars, trailers on spine cars, and containers on

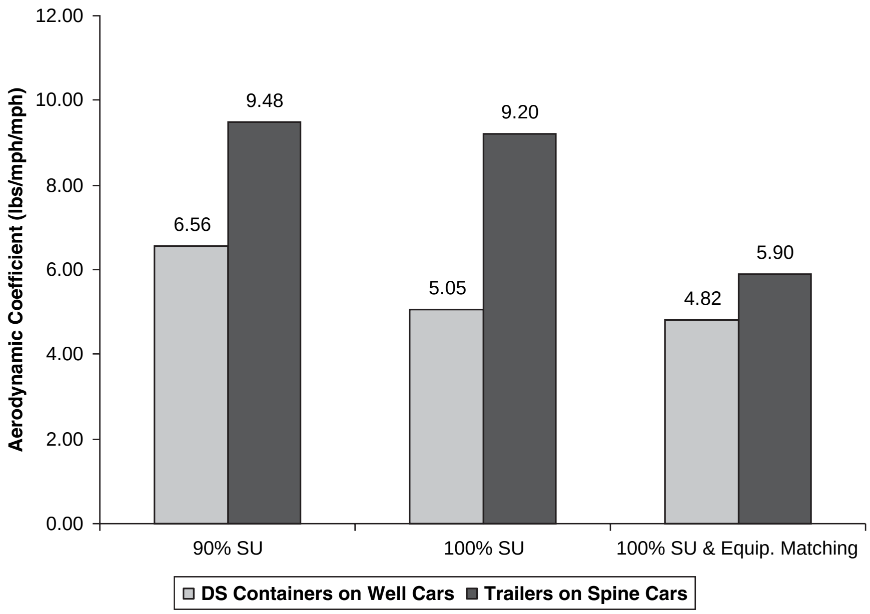


FIGURE 4 Aerodynamic coefficient of 90% slot utilization, 100% slot utilization, or equipment matching for double-stack containers on well cars and trailers on spine cars.

spine cars. For each scenario, the "baseline" case represents empty slots, and the "alternative" case represents the filling of empty slots with empty intermodal loads.

Both the number of empty slots and the train speed affect the train resistance computation. In the following analysis of three scenarios, train speed was held constant at 50 mph. Resistance values were computed for each case by changing the number of discrete empty slots. These changes were restricted to the last 90 units of the train to avoid the complicating effects of factoring in the different aerodynamic effects characteristic of the front of the train (*9*). In this respect, the results here understate the potential benefits to a small extent because the aerodynamic benefit of improvements in the front of the train is slightly higher (*9*).

Scenario 1: Double-Stack Containers on Well Cars

In Scenario 1, the train consists of 20 five-unit articulated 48-ft-well cars with 48-ft double-stack containers and from one to 10 empty slots. A single empty slot in a five-unit well car is shown in Figure 5*a*. The baseline condition with empty slots was compared to the alternative condition, in which empty containers are placed in the previously empty slots (Figure 6*a*). In the baseline case, the greater the number of empty slots, the higher the train resistance despite the reduction in train weight. The higher resistance is caused by the increased number of large gaps and the consequent greater turbulence. In the alternative case, empty containers are placed in the open slots. The extra weight generates a small increase in bearing and rolling resistance, but this resistance is more than offset by the reduction in aerodynamic resistance. This results in an inverse relationship between resistance and the number of empty slots filled with empty containers because of both the lighter train and improved aerodynamics. The benefit is the difference between the baseline and alternative cases, and it increases with the number of empty slots filled with empty containers. For all the conditions, the alternative method results in a reduction in resistance (Figure 7).

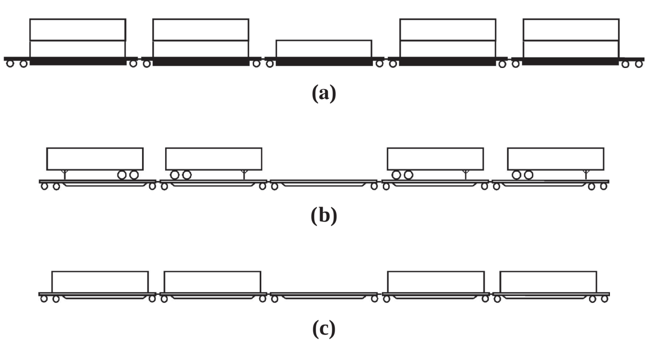


FIGURE 5 Loading combinations: (*a*) containers on five-unit articulated well car (Scenario 1), (*b*) trailers on five-unit articulated spine car (Scenario 2), and (*c*) containers on five-unit articulated spine car (Scenario 3).

Scenario 2: Trailers on Spine Cars

In Scenario 2, the train consists of 20 five-unit articulated 48-ft-slot spine cars with 48-ft trailers. As in Scenario 1, the number of cars with empty slots was varied from one to 10 (an example of a car with a single empty slot is shown in Figure 5*b*). The resistance of the baseline condition is compared to the alternative in which empty trailers are placed on empty slots on spine cars (Figure 6*b*). The resistance of the baseline case increases and that of the alternative declines with the greater number of empty slots, and the overall benefit increases with the number of empty slots filled with empty trailers. As in Scenario 1, the alternative method reduced resistance for all the conditions (Figure 7). The values are consistently higher than for comparable numbers of empty slots in Scenario 1. As discussed above, this is because the spacing between trailers on spine cars is closer than the spacing between containers on well cars; consequently, the difference in aerodynamics is greater between the baseline and alternative conditions. In fact, it is possible to space trailers so closely that they appear to be one continuous body.

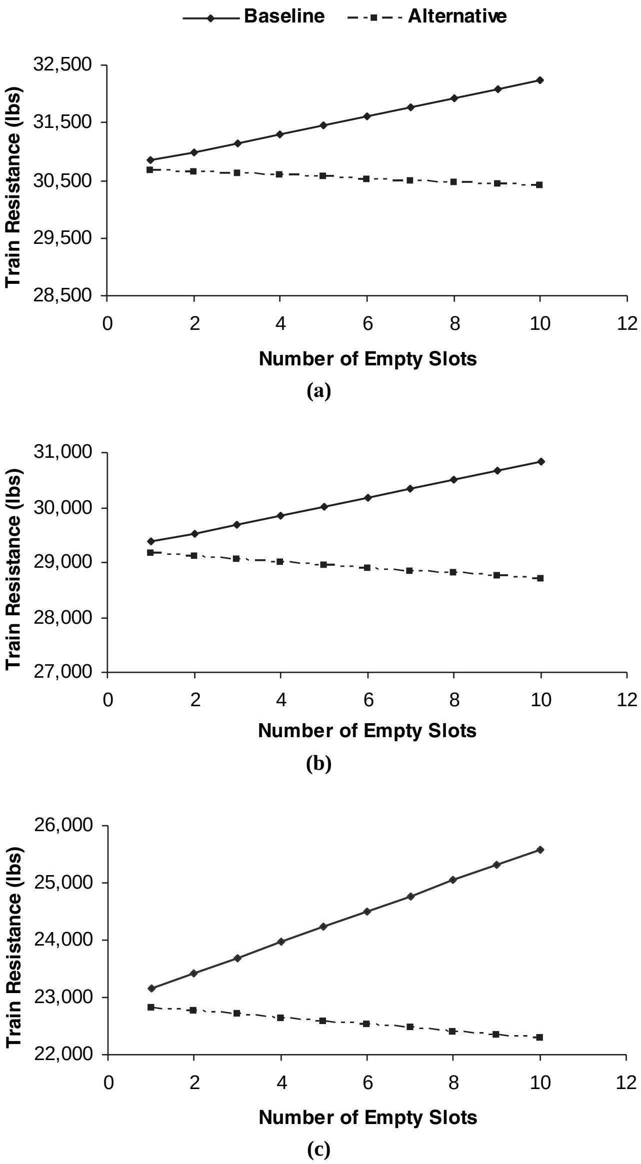


FIGURE 6 Resistance of placing or not placing (*a*) empty containers on empty slots in well cars, (*b*) empty trailers on empty slots in spine cars, and (*c*) empty containers on empty slots in spine cars.

Scenario 3: Containers on Spine Cars

In Scenario 3, the train consists of 20 five-unit articulated 48-ft-slot spine cars with 48-ft containers. The number of empty slots is varied as in the previous scenarios (Figure 5*c*). Again, the resistance of the baseline case increases and that of the alternative case decreases as the number of empty slots goes up (Figure 6*c*). In this scenario, the corresponding benefits are even higher than in Scenarios 1 and 2 (Figure 7). More benefit is derived from filling empty slots with empty containers on spine cars compared to the other two train configurations. This is not only because the spacing between containers on spine cars is closer to that on well cars, but also because closely spaced containers can be regarded as a single long box. Closely spaced trailers cannot; they create drag because of the presence of the hitch, trailer landing gear, and wheels below the floor of the trailer.

Effect of Speed

The scenario analyses demonstrated the effect of the number of empty slots at a single speed (50 mph). The aerodynamic term in the train resistance model is a squared function of speed. Consequently, a greater aerodynamic benefit at higher speeds is expected. Conversely, at lower speeds the relative benefit is expected to be smaller. Sensitivity analyses were conducted on the effect of train speed on resistance while holding the number of empty slots constant (Figure 8*a*).

A train configured as in Scenario 1 with 20 double-stack well cars and five empty slots in the train is first considered. Figure 8*a* compares the resistance of the train in the baseline and alternative conditions as a function of speed. The resistance in both increases exponentially with speed, and the difference between them also increases. If the number of empty slots in the train is increased to 10, the resistance and corresponding benefit are also greater (Figures 8*b*, 9*a*, 9*d*). There is no benefit when the speed is less than 10 mph because the reduction in aerodynamic resistance is not enough to offset the increase in bearing and rolling resistance caused by the extra weight of the empty intermodal loads. Above this speed, however, there is a net benefit that increases with speed so that at 70 mph, filling five empty slots with containers reduces train resistance by 4%, and filling 10 empty slots reduces it by 8%.

Similar analyses were conducted on trains configured as in Scenarios 2 and 3, with similar results. Figures 9*b* and 9*e* show the effect of placing empty trailers on five empty slots and 10 empty slots, respectively. For the spine cars with trailers, the trend is the same as for containers on the well cars, but the benefit is greater. At 70 mph, filling five empty slots with trailers reduced train resistance by 5%, and filling 10 empty slots reduced it by 9%. The greatest benefit comes from placing empty containers on empty slots in spine cars, with a benefit for filling five empty slots at 70 mph of 10%, and a benefit for filling 10 empty slots of 18% (Figures 9*c*, 9*f*).

In conclusion, the practice of loading empty intermodal equipment in empty slots will generally have a beneficial effect on train resistance. Use of this practice benefits containers on spine cars the most; trailers on spine cars next; and then containers on well cars after that.

Fuel Consumption Computation

Four trains were analyzed for each of the three scenarios representing the baseline and alternative cases with five or 10 empty slots each (Table 1). Simulations using TEM were conducted for each train configuration over the same 103-mi route described previously. Filling five empty slots with loads resulted in a savings of about 22 gal of fuel per train in Scenario 1 (double-stack containers on well cars), 24 gal of fuel in Scenario 2 (trailers on spine cars), and 68 gal of fuel in Scenario 3 (containers on spine cars) (Table 1). Filling 10 empty slots with loads would save 47 gal of fuel in Scenario 1, 53 gal of fuel in Scenario 2, and 104 gal of fuel in Scenario 3. The fuel savings ranged from 0.21 gal/mi to 1.01 gal/mi.

Extra Costs of Filling Empty Slots

Maximizing slot efficiency involves better matching of equipment and loads but does not require transportation of extra equipment; filling empty slots, however, does. Consequently, the extra costs associated with this activity should be accounted for. These costs include the extra grade resistance and the opportunity cost of the equipment.

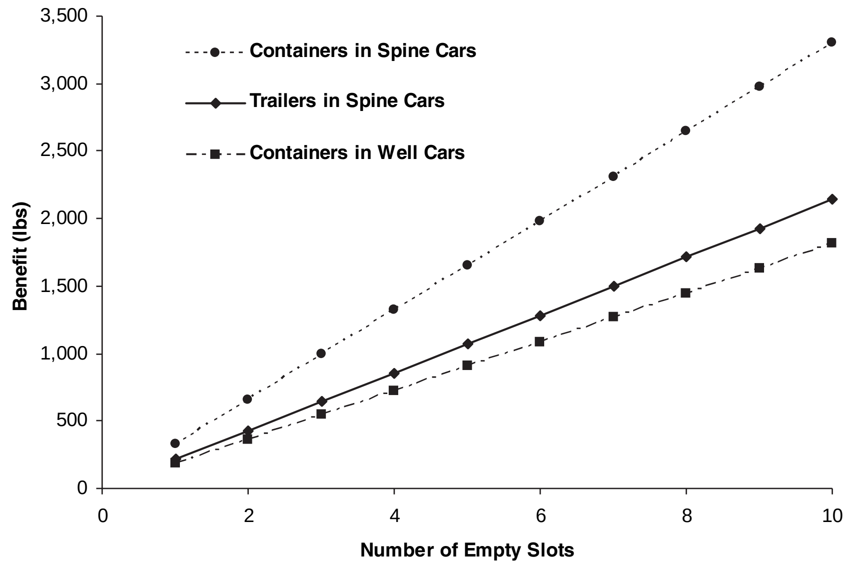
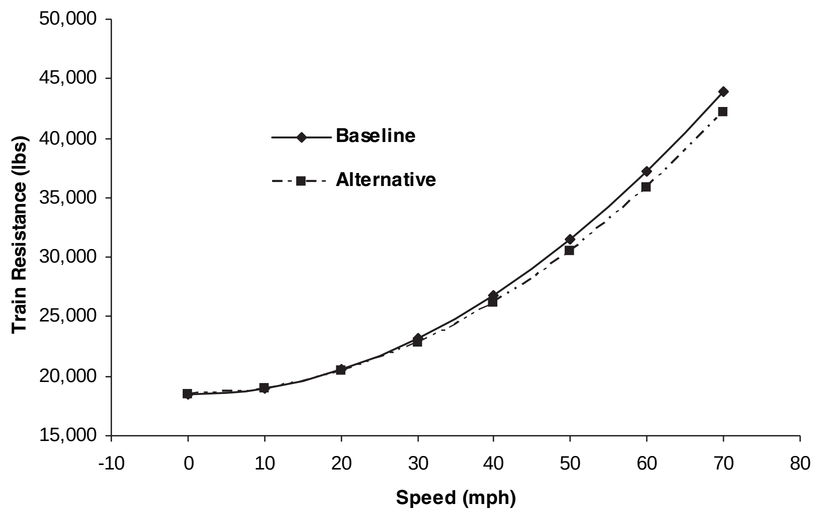


FIGURE 7 Benefit of placing empty containers on empty slots in well cars, placing empty trailers on empty slots in spine cars, and placing empty containers on empty slots in spine cars.



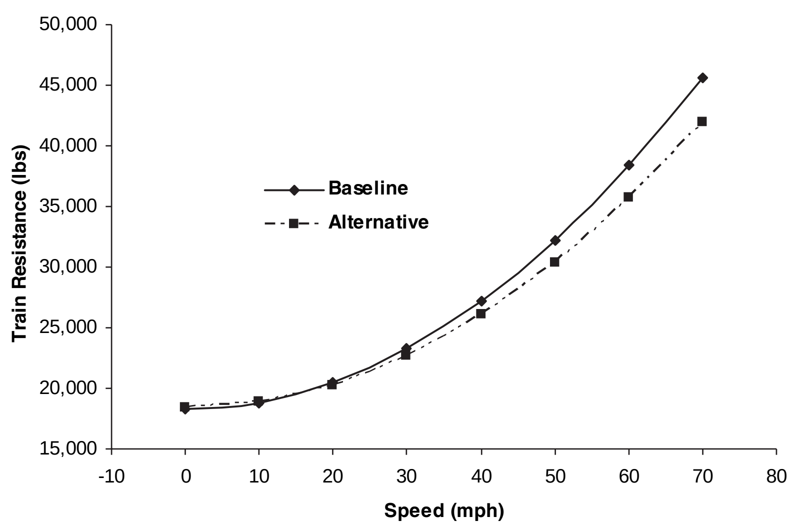


FIGURE 8 Sensitivity analysis of speed in resistance of placing or not placing empty containers on (*a*) five empty slots in well cars and (*b*) 10 empty slots in well cars.

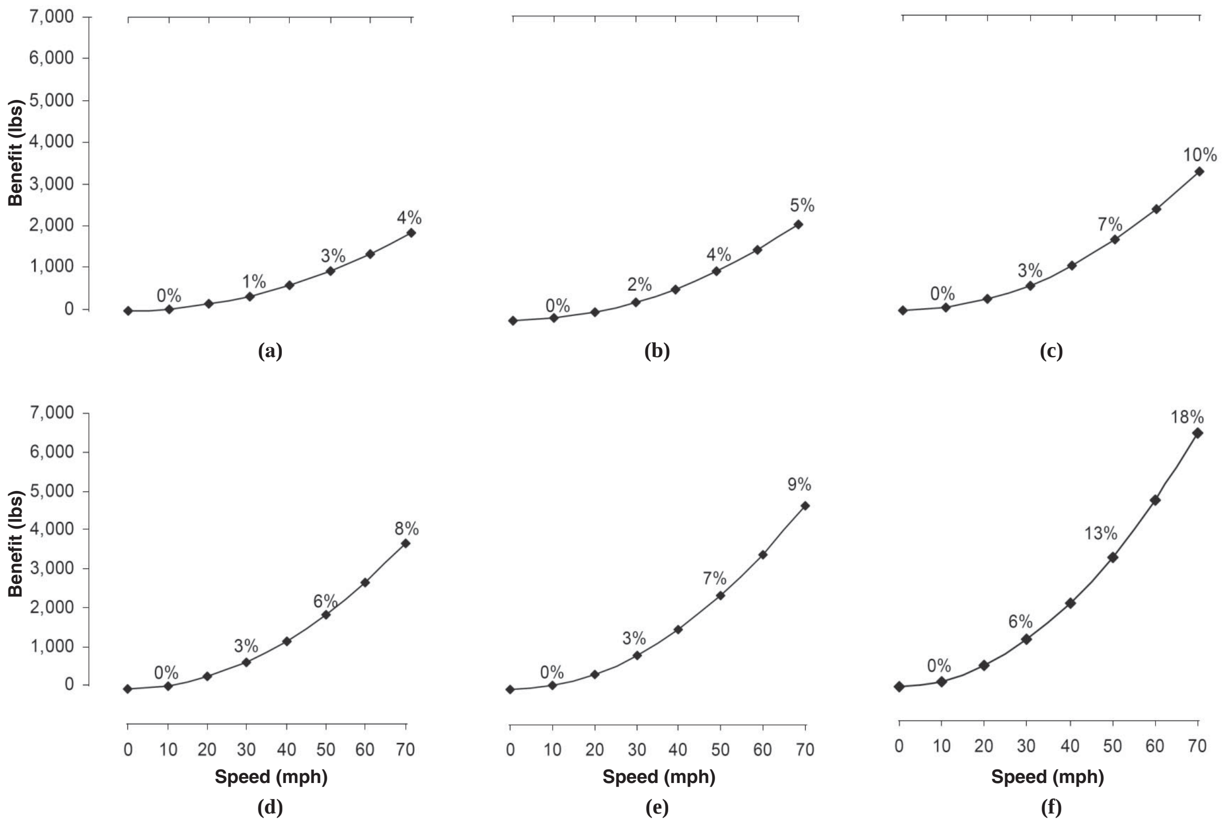


FIGURE 9 Benefit of placing (*a*) empty containers on five empty slots in well cars, (*b*) empty trailers on five empty slots in spine cars, (*c*) empty containers on five empty slots in spine cars, (*d*) empty containers on 10 empty slots in well cars, (*e*) empty trailers on 10 empty slots in spine cars, and (*f*) empty containers on 10 empty slots in spine cars.

Over the 103-mi route analyzed, grade resistance was not a significant factor. However, many intermodal routes feature substantial elevation changes. Empty 40-ft containers weigh approximately 8,500 lb, and the added grade resistance should be accounted for in calculating the savings generated from the improved aerodynamics. TEM and Poole's fuel consumption formula (*16, 19*) were used to evaluate the importance of this effect over a typical western transcontinental route with approximately 15,000 ft of total elevation rise. Lifting the weight of 10 empty containers was found to require approximately 38.5 additional gallons of fuel. Using the figures in Table 1, the estimated fuel savings generated by the improved aerodynamics over a 2,000-mi route range from about 400 to 2,000 gal per train, which is considerably more than the fuel penalty caused by the extra weight.

Regarding the opportunity cost of empty intermodal loads, empty containers were assumed to be worth about $2,000 each, and the time value of 10 empty containers assumed to be about $5.50 per day. Thus, for a 3-day trip, the total cost would be about $16.50, less than 1% of the value of the fuel that would be saved.

DISCUSSION OF RESULTS

The current practice of measuring intermodal loading efficiency uses the metric of slot utilization. For example, improving slot utilization from 90% to 100% on some typical intermodal trains reduced the aerodynamic coefficient by 3% to 23%, depending on train type.

TABLE 1 Fuel Consumption of Baseline and Alternative Cases

	5 Empty Slots				10 Empty Slots			
			Fuel Savings				Fuel Savings	
	Baseline (Gallons)	Alternative (Gallons)	(Gallons)	(Gal/mile)	Baseline (Gallons)	Alternative (Gallons)	(Gallons)	(Gal/mile)
Scenario 1	765	743	22	0.21	787	740	47	0.46
Scenario 2	786	762	24	0.23	811	758	53	0.51
Scenario 3	635	567	68	0.66	669	565	104	1.01

NOTE: Scenario 1 is double-stack containers on well cars; Scenario 2 is trailers on spine cars; and Scenario 3 is containers on spine cars.

Beyond this, matching intermodal loads with cars of an appropriate length to maximize slot efficiency results in further improvement in train aerodynamics and can provide greater energy efficiency than slot utilization alone. If the loads and cars are matched, the additional aerodynamic benefit ranged from 5% to 36%. Over the 103-mi route considered, this benefit was estimated to reduce fuel consumption by 0.13 to 1.0 gal/mi, depending on the load-and-car combinations analyzed. When these amounts are extrapolated to the 800-to-2,000 mi distances typical of many intermodal routes, the potential for fuel savings is substantial. Intermodal trains can be more efficiently operated if loads are assigned based not only on slot utilization, but also on better matching of intermodal loads with cars. Although not considered in this paper, the effect will be even greater for the units in the front of the train where the aerodynamic effect is greater.

Filling empty slots with empty loads also reduces aerodynamic resistance and improves energy efficiency, despite the additional weight penalty and consequent increase in bearing, rolling, and grade resistance. A series of analyses for double-stack containers on well cars (Scenario 1), trailers on spine cars (Scenario 2), and containers on spine cars (Scenario 3) were conducted. These scenario analyses show that filling empty slots with empty loads is beneficial and that the magnitude of this benefit increases with the number of empty slots to be filled.

Based on sensitivity analyses of speed, filling empty slots with empty intermodal loads will generally reduce train resistance at the speeds typical of intermodal trains. The scenario involving containers on spine cars received the most benefit, followed by the scenario involving trailers on spine cars and then that involving containers on well cars. The fuel savings generally ranged from 0.21 to 1.01 gal/mi over the route considered.

Although these loading options appear to offer potential benefit in terms of energy efficiency, they also introduce logistical challenges regarding rail car use, positioning and availability, terminal operations and design, and placement of empty containers or trailers. The cost-effectiveness of implementing new practices based on the results presented here would have to consider all of these factors.

In view of the potential savings from more efficient loading of intermodal trains, an automated wayside machine-vision system is being developed to monitor loading efficiency (*20*). The system uses an advanced camera that images each container or trailer as trains pass by. Machine-vision algorithms are used to analyze these images, detect and measure gaps between loads, and develop a quantitative index of the loading efficiency of the train.

CONCLUSION

Three approaches for improving intermodal train energy efficiency were evaluated: slot utilization, slot efficiency, and filling empty slots. All have a beneficial effect. Maximizing slot utilization does increase energy efficiency. Maximizing slot efficiency, i.e., matching intermodal loads with cars of an appropriate length, reduces the gap length between loads, thereby improving airflow and reducing drag, which in turn reduces fuel consumption and operating costs. Filling empty slots with empty containers or trailers also reduces aerodynamic resistance, further improving energy efficiency. Although an additional weight penalty and consequent increase in bearing and rolling resistance does accrue, the reduction in aerodynamic resistance more than offsets this at speeds typical of intermodal trains.

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