

Emerging Freight Truck Technologies: Effects on Relative Freight Costs

Final Report
May 2018

Sponsored by

Midwest Transportation Center
U.S. Department of Transportation
Office of the Assistant Secretary for
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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Emerging Freight Truck Technologies: Effects on Relative Freight Costs		5. Report Date May 2018	
		6. Performing Organization Code	
7. Author(s) Ken Bao and Ray A. Mundy		8. Performing Organization Report No.	
9. Performing Organization Name and Address Center for Transportation Studies University of Missouri—St. Louis 240 JC Penny North, One University Boulevard St. Louis, MO 63121-4400		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. DTRT13-G-UTC37	
12. Sponsoring Organization Name and Address Midwest Transportation Center U.S. Department of Transportation 2711 S. Loop Drive, Suite 4700 Office of the Assistant Secretary for Ames, IA 50010-8664 Research and Technology University of Missouri—St. Louis 1200 New Jersey Avenue, SE One University Boulevard Washington, DC 20590 St. Louis, MO 63121-4400		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes Visit www.intrans.iastate.edu for color pdfs of this and other research reports.			
16. Abstract This research sought to evaluate the broad impacts that automated and connected vehicle technologies can have on both the motor carrier and rail industries. Since the development and adoption of these technologies are likely to be gradual, three phases were posited and analyzed. Depending on the degree of autonomy that is available, the motor carrier industry could achieve up to a 42.1% reduction in average cost per mile. And if fully autonomous technology was made available for use in the motor carrier industry, it is estimated that the American rail freight industry could see a 19% to 45% drop in demand.			
17. Key Words autonomous vehicle—connected vehicle—cost impacts—platoon—rail impact		18. Distribution Statement No restrictions.	
19. Security Classification (of this report) Unclassified.	20. Security Classification (of this page) Unclassified.	21. No. of Pages 26	22. Price NA

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**Final Report
May 2018**

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Sponsored by
University of Missouri–St. Louis,
Midwest Transportation Center, and
U.S. Department of Transportation
Office of the Assistant Secretary for Research and Technology

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ACKNOWLEDGMENTS

The authors would like to thank the University of Missouri-St. Louis, the Midwest Transportation Center, and the U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology for sponsoring this research.

INTRODUCTION

The United States has taken great measures to successfully develop its extensive transportation networks among all modes. There were the railroad subsidies of the late 19th and early 20th centuries, massive highway projects funded by the Federal government in the mid-1900s, as well as the airport development grants at about the same time. More recently, there was the Intermodal Surface Transportation Efficiency Act of 1991, which sought to improve highway and rail corridors that were deemed critical for facilitating intermodal transportation. Governments all around the world are looking toward intermodalism to address the problem of increasing transportation demands per capita, which has been on an upward trend for decades (Fagnant and Kockelman 2015). Given the fact that an expansion of the existing transportation infrastructure for any given mode comes at a high cost, intermodal transport has become the answer for many companies and thus for the government as well.

However, new and emerging technology has the potential to be a disruptive force in these efforts. For instance, further government assistance in the intermodal transportation industry may prove to be a frivolous endeavor in the face of driverless vehicles. Driverless vehicles can drastically reduce the private cost of truck freight shipments by an amount equal to the cost of labor. Furthermore, if these vehicles are operated in a “platoon,” then there are potential fuel savings that can further reduce the cost of truck freight. Higher fuel prices lead to higher marginal fuel cost savings, and with possible total cost savings of over one third, it seems reasonable to question whether further subsidies towards intermodal transportation is as necessary as before.

Truck platooning involves at least two trucks driving in a perfectly synchronized fashion aided by computer technology. Platooning requires trucks to drive in tandem such that they maintain a small distance apart for the air flow around both trucks to work synergistically to reduce drag for both the end vehicle(s) and the front vehicle; thus, it saves fuel for all those involved. According to recent studies, platooning can have anywhere from 2% to 15% fuel savings depending on the gap between trucks, with the fuel savings to be negatively related to the distance gap (Dávila and Nombela 2011). The basic idea is to have one driver at the head of the platoon or convoy, and the vehicles that are following closely behind are completely controlled by software that mimics the lead vehicle to maintain a specific distance from one another in a synchronized fashion. Whether the following vehicles will have drivers depends entirely on the response of legislative authorities and technological development.

Emerging automated driving technology can provide real and significant benefits to society, especially the trucking industry. However, there are many who fear the implications of widespread use of such technology in the private sector and, in particular, the commercial sector. These fears are not unreasonable nor without basis. New technology, such as autonomous driving software, leaves itself open to many vulnerabilities as it tries to mimic the complex decision-making process that occurs in humans despite having the advantageous 360 degree sensor range and a seemingly eternal attention span.

Most of these technologies employ programs that are capable of “self-learning,” otherwise known as machine learning or artificial intelligence. However, as promising as these

technologies sound, they are only able to achieve functioning status after a certain amount of “experience.” These programs require a massive amount of training data from which the program is supposed to learn and thus appropriately respond to a whole host of potential traffic situations. Furthermore, this kind of technology often requires continuous global positioning system (GPS) tracking that is open to software attacks or hacks. If an autonomous vehicle (AV) were involved in an accident, there would be serious issues regarding accountability. These are the primary issues that concern lawmakers and provide justification for postulating multiple phases to characterize the legal progression associated with the employment of such technologies.

Both autonomous vehicle and connected vehicle (CV) technologies have direct benefits to the motor carrier industry because their implementation would translate into significant levels of cost reduction. But to evaluate the cost impacts, it is important to understand that these effects will vary with the technology and how it is permeated and regulated. Therefore, three phases were posited to characterize a possible progression in how AV will be deployed if CV capabilities are available throughout all stages.

The focus of these analyses is the potential effects of the technology (at each stage of adoption) on the cost of truck freight relative to that of rail intermodal services. The first chapter introduces the three phases as well as their effects on truck costs and breakeven points between trucks and rail. The next chapter explores the potential effects on the rail freight market. The third and final chapter lays out some of the study limitations and policy implications.

COST IMPACTS

The three phases presented here differ by available AV and CV technology, as reflected by the legislative climate. AV technological advancements have a standard characterization provided by the Society of Automotive Engineers (SAE), but CV technology does not. Therefore, it was necessary to be explicit about how CV technology differs between the posited phases. The only CV application considered in this report is platooning, which is arguably the most relevant CV application within the motor carrier industry. Since platooning can have any number of trucks greater than one, then, for simplicity, only platoons of two trucks were examined.

Phase One

This initial stage is characterized by the existence of regulation that prevents any truck in a platoon to operate without a human driver, which means that SAE Level 3 is the highest available level of autonomy. Though it is correct to point out that the highest level of autonomy that would be on the road also depends on technological advancements, it is useful to view legislative developments as a function of technological capabilities. Thus, it is sufficient to consider legislation as the only determinant in the allowable degree of autonomy.

In this phase, AV technology above SAE Level 3 was not yet viable, and CV technology exists such that the following trucks within a platoon mirrored the leading truck in real time. Here, the ability for a motor carrier to reduce its labor force existed in so far as there were more employees than there were trucks. Typically, motor carriers want to utilize their trucks as much as possible and avoid any idle time to maximize returns on capital investments. Due to the maximum consecutive work hours imposed by the Federal Motor Carrier Safety Administration (FMCSA), as well as biological limitations, carriers are forced to have a labor force larger than the stock of vehicles. Drivers take turns throughout the week, but the same vehicle is utilized.

A platoon scheme can reduce the need for a large labor force since the “drivers” in the following vehicles do not have to do any driving while the vehicle is in transit. This allows for carriers to decrease their labor force since one driver could effectively utilize a vehicle for much longer. However, carriers will still not be able to substitute away from the labor required per unit of “output,” since there are limits to how long drivers can be “on duty,” which includes time spent not operating a vehicle. That means that the benefit from logging off-duty hours while in the following vehicle maxes out at 3 hours due to hours of service (HOS) regulations, thus enforcing a maximum of 14 consecutive “on-duty” hours.

Furthermore, drivers are generally paid on a per mile basis, which means that if a carrier can reduce the size of its labor force, it would not matter since it will still drive the same number of miles (i.e., the man-hours per unit of output will be the same). Therefore, the most important issue that is addressed in this section is whether companies will still find it profitable to invest in the technology even if they cannot substitute away from labor.

The average cost per mile in the motor carrier industry during 2015 was \$1.593, with fuel making up 25% of that cost and driver wages and benefits accounting for about 39.5% (Torrey and Murray 2016). Given that fuel is the second highest variable cost that trucking firms face, platooning technology could still offer substantial savings. However, there is a significant caveat to this. Since a platoon requires at least two trucks, then any cost savings that would result from the implementation of a platoon would also require that there be at least two shipments going in the same direction at the same time. Thus, it is assumed that third party logistics (3PLs) and freight forwarding companies can match shipment demands so that they can capture the benefits of platooning technology. Likewise, the technology could also make it possible for trucks to match with one another in real time in a decentralized fashion, since they often drive alongside one another. Therefore, it is assumed that platooning technology can be utilized for every long-haul shipment for simplicity and because the focus of this study was to analyze the potential effects of platoons.

The first step included graphing the relative cost curves and breakeven point between the two modes under consideration. Per Boardman et al. (1999), the estimated cost per container mile for rail was \$0.35 per container mile with a loading fee of about \$250. The Producer Price Index (PPI) from Research and Innovative Technology Administration (RITA) was used to put these cost estimates into 2015 dollars, which gave rise to Figure 1.

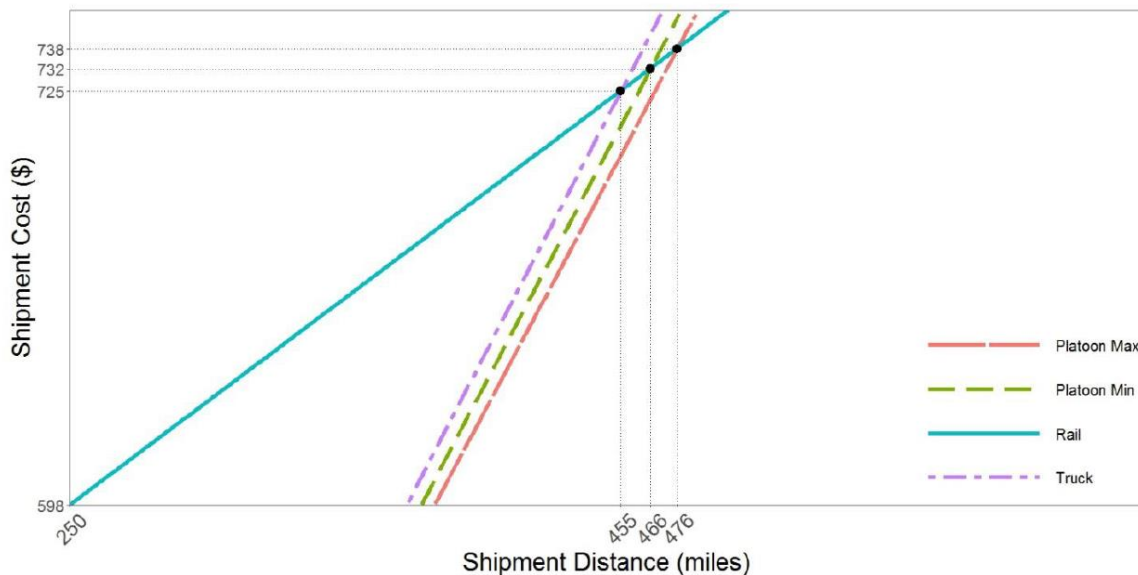


Figure 1. Estimated costs for Phase One

The truck and rail curve shows that the 2015 estimated breakeven point was somewhere in the ballpark of 455 miles. This meant that if there were no other preferences outside of price, then a consumer would be indifferent between using rail and truck for any shipment with a distance around the 455 mile mark, and rail would have a price advantage above the 455 mile mark.

The cost per mile and fuel cost per mile for trucks used in these calculations was \$1.593 and \$0.403, respectively (Torrey and Murray 2016). The platoon maximum and minimum curves

correspond to the cost per mile at the maximum and minimum possible fuel savings that would result from platooning. As Figure 1 indicates, platooning increases the breakeven distance between truck and rail by a small amount (somewhere between 11 to 21 miles). This is a result of the fact that a platoon at this phase has the potential to reduce the average fuel cost per mile from anywhere between 5 to 12%, which translates to a reduction in the total cost per mile by about 1% to 3%.

Phase Two

A reasonable next step in legislation regarding automated driving technology and platoons would be the allowance of an effective driver-to-truck ratio of less than one but more than zero. This phase does not necessarily require higher AV capabilities but rather higher CV capabilities, since the following vehicles that lack drivers are not acting independently of human control. Thus, this phase requires CV technology to be advanced enough to not only mirror the lead vehicle but to perfectly time the mirroring so that making turns and lane changes is safe. Under a two-truck platoon scheme, this means that the only allowable configurations are two trucks/two drivers or two trucks/one driver. The following equation details the calculation that describes the labor cost savings of shipping n truck containers from A to B:

$$SAB = DAB \times nAB \times [CAB - (1-R) \times CABL] \quad (1)$$

SAB = Cost savings of labor reduction in dollars for a shipment between point A to B

nAB = Number of containers going from A to B with similar time schedule

CAB = Cost per container going from A to B

$CABL$ = Cost per unit of labor going from A to B

DAB = Distance between AB in miles

R = Legally allowed driver to truck ratio

For simplicity and without loss of generality, the framework presented here will focus on a two-truck platoon schematic, i.e., $nAB=2$ is assumed.

Further, it is easy to see that this assumption restricts the value for R to 0.5. A wage per mile of \$0.499 is added together with the driver benefits per mile of \$0.131 to obtain a total labor cost per mile of \$0.63. Using Equation 1 and normalizing DAB to equal 1, then the labor cost savings per mile per container is about \$0.32. This translates to a new reduced cost per mile of about \$1.28, and, after including the fuel savings, which ranges from 2.97 to 1.25%, a final estimated reduced cost per mile is obtained that is between \$1.24 and \$1.26. Thus, depending on the gap distance between trucks, a platoon could result in a reduction in the cost per mile between 21% and 22.3% (see Figure 2).

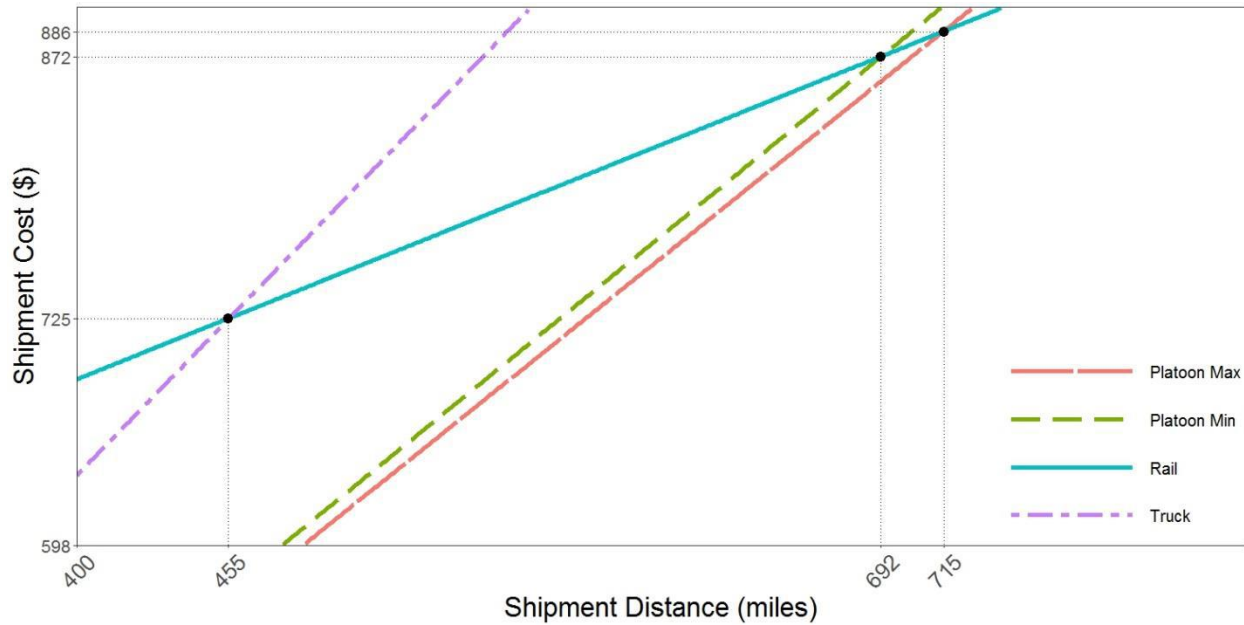


Figure 2. Estimated costs for Phase Two

Phase Three

This phase is characterized by legislation that allows for an autonomous platoon (i.e., $R = 0$ is allowed). For this legislation to materialize, SAE Level 4 or higher is necessary. The analysis in this section is like that of Phase Two but is greatly simplified. Using the \$1.593 cost per truck mile figure and subtracting the total labor cost per mile of \$0.63 gives \$0.963 as the new total cost per mile. Applying the fuel cost savings gives an estimated cost per mile for trucks ranging from \$0.923 to \$0.943.

Figure 3 illustrates the enormous increase in the breakeven point that would result from an autonomous platoon operation. In all, a full reduction in driver cost and a partial reduction in fuel cost amounts to about a 40% decrease in the cost per mile.

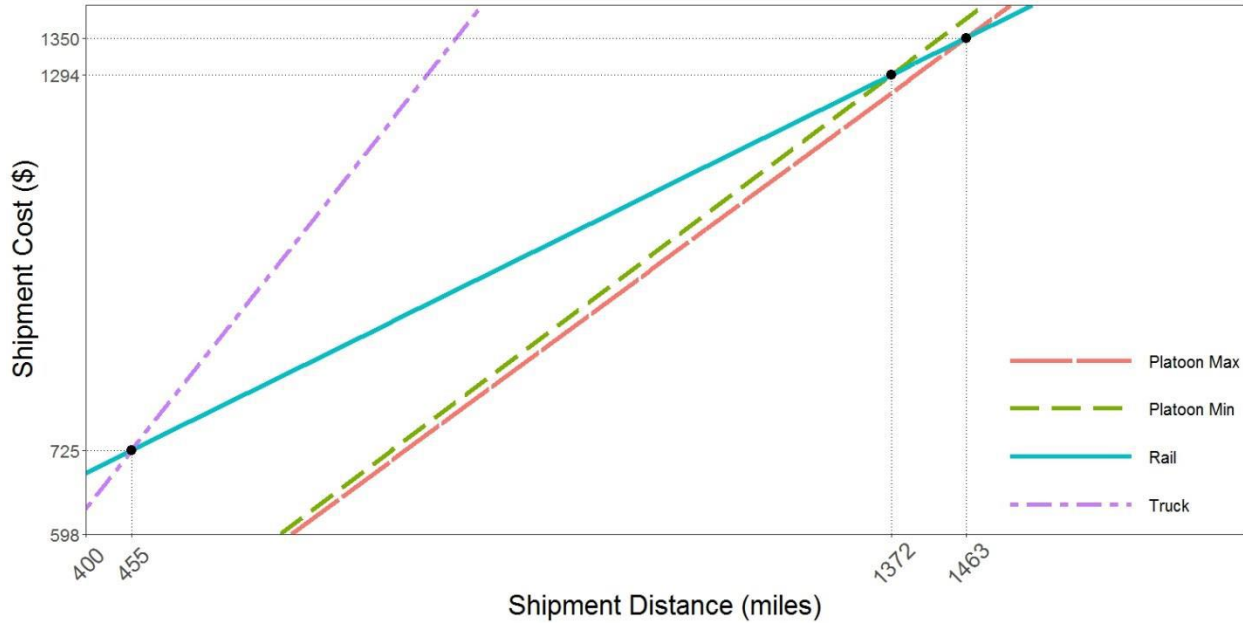


Figure 3. Estimated costs for Phase Three

The first two columns of Table 1 include the estimated new cost per mile if a platoon were implemented with an SAE Level 4 or higher system.

Table 1. Summary of effects on truck cost per mile

Phases	Maximum Fuel Savings	Minimum Fuel Savings	Percent Decrease Max. Fuel Savings	Percent Decrease Min. Fuel Savings
Phase One	\$1.55	\$1.57	2.7%	1.4%
Phase Two	\$1.24	\$1.26	22.1%	20.9%
Phase Three	\$0.923	\$0.943	42.1%	40.8%

The third and fourth columns of Table 1 include the percent decrease in cost per mile associated with the values in the first two columns. It is also easy to envision a motor carrier industry that primarily uses autonomous vehicle technology rather than platooning. Without the added benefits of platooning, the industry could still enjoy a substantial potential reduction in costs per mile of about 39.6%.

IMPACT ON RAIL FREIGHT DEMAND

AV and CV (platooning) technologies can essentially be viewed as cost-lowering technologies for long-haul truck freight services. Furthermore, long haul truck freight services are often seen as a direct substitute to rail freight services, whereas short-haul truck freight can be viewed as a compliment to rail. Since platooning is only economical over long distances and AV technology is likely to be first used on Interstates and highways, this research treated the two modes (truck and rail) as substitutes. As such, the typical way of evaluating the impact of a price drop of one service on the demand of a separate service requires the use of an estimated cross-price elasticity of demand.

Abdelwahab (1998) estimated modal elasticities for freight demand using a three-equation simultaneous discrete choice modelling technique with a disaggregated dataset. The study estimated the same model separately for different commodity types, and thus each commodity had different estimated cross-price elasticities. The findings were aggregated in this study to evaluate the total effect on the rail industry. Data from the 2012 Commodity Flow Survey Public Use Microdata was used, which contained data on shipment characteristics (U.S. Census Bureau 2015). First, observations of rail-only modes were selected and assigned a value for the estimated cross-price elasticity, the value of which depended on commodity type. If the specific commodity type in the dataset could not be categorized as any of those from Abdelwahab (1998), then it was assigned a value equal to the arithmetic mean of all commodity types. Since the cross-price elasticity of demand for rail with respect to truck is given by

$$\varepsilon_i^{R,T} = \frac{\% \Delta q_i^R}{\% \Delta P^T} \quad (2)$$

where q_i^R = ton-miles for rail and shipment i , rearranging the terms then gives the estimated market response for a given shipment by

$$\% \Delta P^T \times \varepsilon_i^{R,T} = \% \Delta q_i^R \quad (3)$$

This equation is then applied to the dataset using the percent change in truck costs from Table 1 as the percent change in truck prices. After calculating $\% \Delta q_i^R$ for each row in the data, it is then multiplied by the shipment tabulation weighting factor, which is an estimate of the number of shipments that are represented by a unique row:

$$\% \Delta Q^R = \frac{\Delta Q^R}{Q^R} = \frac{\sum_i \% \Delta q_i^R \times wf_i \times d_i \times wght_i}{\sum_i wf_i \times d_i \times wght_i} \quad (4)$$

$$QR = \sum wfi \times di \times wghti$$

wghti = shipment weight for shipment *i*

wfi = weighting factor for shipment *i*

di = route distance for shipment *i*

Table 2 presents the estimated impacts on the total rail freight market based on the results from Abdelwahab (1998) and Equations (3) and (4).

Table 2. Percent decrease in rail demand

Phases	Percent Decrease in Q (Max. Fuel Savings)	Percent Decrease in Q (Min. Fuel Savings)
Phase One	2.91%	1.56%
Phase Two	23.89%	22.54%
Phase Three	45.34%	43.99%

Note: “Q” represents the quantity demanded for rail freight transportation services

A potential limitation of these results is that they are based on data from 1981, which is almost 40 years ago. It is also entirely possible that the underlying structure of the freight transportation industry has changed sufficiently to hinder the usefulness of these elasticity estimates. Thus, it is useful to cross-validate these results with a more current data set. However, instead of using the methods presented in Abdelwahab (1998), an alternative ad hoc method of estimating the rail market response is presented, which avoids the need of running simultaneous discrete choice models.

This alternative method of estimating the percent decrease in rail demand relies on the accuracy of the cost curves and strict distributional assumptions about shippers’ value functions. It is assumed that the breakeven point given by the intersection of the two curves is correct, or at least sufficiently close.

Figure 4 clearly shows that there exist rail shipments that lie below (to the left of) the projected breakeven point (illustrated by the black vertical line) between rail and truck (without platoon) (as shown in Figure 1).

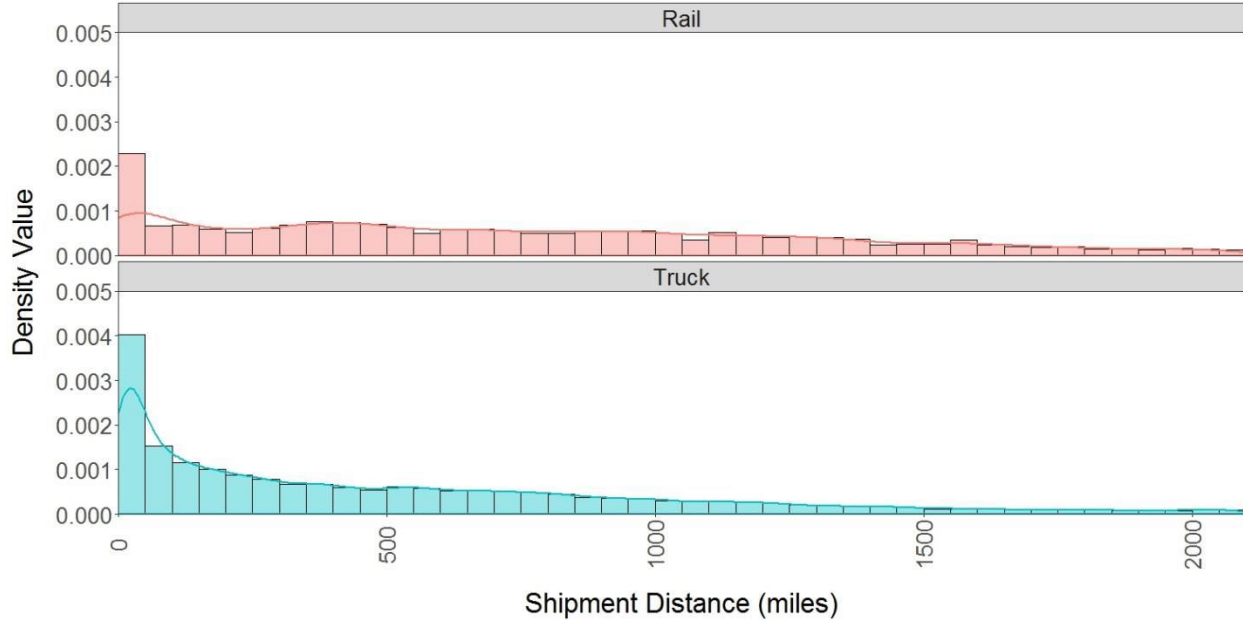


Figure 4. Histogram and density plot of shipment distances by mode

This is easily explained by introducing other factors that affect the decision of modal choice, such as time (t), consistency (c), flexibility (f), reliability (r), and accessibility (a) of service. Therefore, if a shipment with a distance value that is to the left of the breakeven point, B , is made over rail, then the following must be true:

$$V_T^A(c, f, r, a) - C_T - [C^t \times t_T] \leq V_R^A(c, f, r, a) - C_R - [C^t \times t_R] \quad (5)$$

$$C_R - C_T \leq (V_R^A - V_T^A) - C^t (t_R - t_T) \quad (6)$$

$V_T^A(c, f, r, a)$ = A function that gives the dollar value of all the nonpecuniary attributes for truck freight services; is a function of consistency (c), flexibility (f), reliability (r), and accessibility of service (a)

$V_R^A(c, f, r, a)$ = A function that gives dollar value of all nonpecuniary attributes for rail freight

C^t = Dollar cost of a unit of travel time

t_T = Time required for truck to complete service

t_R = Time required for rail to complete service

C_T = Cost of truck service, calculated as the cost per mile multiplied by distance

C_R = Cost of rail service, calculated as the cost per mile multiplied by distance plus the loading fees

Thus, the difference in values of nonpecuniary service attributes minus the cost of additional travel time has a lower bound given by the vertical distance between the curves Truck_0 and Rail in Figure 5 (e.g., the value labelled as pd_2).

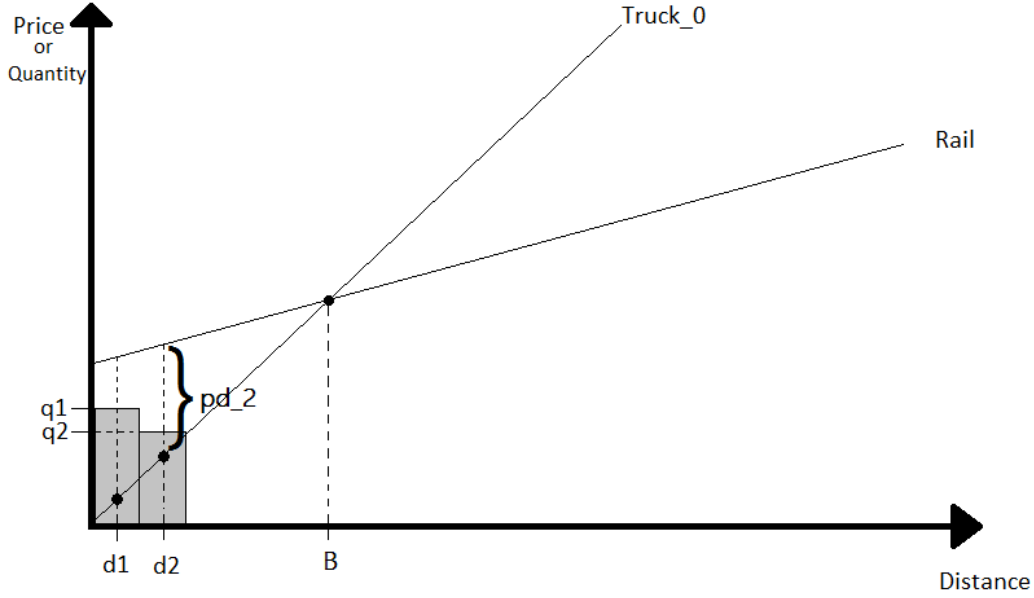


Figure 5. Graphical illustrations of equations

Intuitively, what this says is that if the estimated cost curves for truck and rail are accurately represented, then the only way that a consumer would choose rail over truck for a shipment distance that lies below B is if the value of the nonpecuniary service attributes of rail is sufficiently greater than that of truck, such that it more than compensates for the dollar difference in cost.

To get an upper bound for the implicit value difference, however, it is assumed that if the pecuniary cost of truck were zero everywhere, then consumers would choose truck over rail regardless of the implicit value difference of attributes. Thus, the final inequality is given:

$$C_R - C_T \leq (V_R^A - V_T^A) - C^t (t_R - t_T) \leq C_R \quad (7)$$

Then, by comparing the net change in price differences for each unique distance that would result from platooning, it is possible to see whether the cost savings are enough to compensate for the implicit value difference. Applying this to each unique distance value, it is possible to estimate the proportion of demand that lies below B that would switch to truck.

Let $f(di)$ be the cost curve for truck services, $g(di)$ be the cost curve for platoon services, and di be the unique distance value for shipments that is observed in the CFS data with $di \in (0, B)$. Only the data for rail shipments are used here, and the following is calculated:

$$(di) - g(di) \quad (8)$$

The observations (with observations each being di), which satisfies the inequality, are kept as

$$C_R - C_T \leq (d_i) - g(d_i) \quad (9)$$

For each d_i , there are wfi numbers of shipments, and we assume that these shipments can have varying levels of implicit value differences of service attributes that are uniformly distributed throughout the range defined by Equation (7). This then allows for the estimation of the proportion of shipments, for a given d_i , that would switch from rail to truck, and is given by

$$\frac{[f(d_i) - g(d_i)] - [C_R - C_T]}{[C_R] - [C_R - C_T]} = \frac{[f(d_i) - g(d_i)] - [C_R - C_T]}{C_T} \quad (10)$$

Adding these all up gives the total demand measured as ton-miles, which lies below B , and will switch over to truck after the price change.

$$\sum_{i=1}^B \frac{[f(d_i) - g(d_i)] - [C_R - C_T]}{C_T} * \theta_i \quad (11)$$

where $\theta_i = di * wfi * wghti$ and $wghti$ denotes the weight in pounds of a shipment. For those rail shipments that lie to the right of B , Equation (5) must also hold. However, being to the right of B means that $C_T > C_R$, which gives

$$V_T^A(c, f, r, a) - V_R^A(c, f, r, a) + C^t[t_R - t_T] \leq C_T - C_R \quad (12)$$

Here, it is assumed that $V_T^A(c, f, r, a) > V_R^A(c, f, r, a)$, because if the opposite were analyzed, then it would be uninformative since the cost of rail is also lower than that of truck for distances beyond B . The fact that consumers choose rail would tell us nothing about how the implicit value differences are bounded.

$$0 \leq V_T^A(c, f, r, a) - V_R^A(c, f, r, a) + C^t[t_R - t_T] \leq C_T - C_R \quad (13)$$

Similarly, the following gives the number of ton-miles to the right of B that will switch over to truck after the price change, where $h(di)$ is the cost curve for rail and D denotes the highest distance value observed in the data.

$$\sum_{i=B}^D \frac{[h(d_i) - g(d_i)]}{C_T - C_R} * \theta_i \quad (14)$$

D is the distance at which $h(D) = g(D)$.

Adding the two summation equations together gives the total demand that will switch to trucks after a price change. Then, dividing the total demand that will switch by the total number of ton-miles on both sides of B gives the estimated percent change total rail demand. These estimates are presented in Table 3 for all three phases.

Table 3. Ad hoc method: Percent change in rail demand (Q)

Phases	Percent Decrease in Q Max. Fuel Savings	Percent Decrease in Q Min. Fuel Savings
Phase One	0.51%	0.2%
Phase Two	5.93%	5.44%
Phase Three	20.4%	18.59%

PUBLIC POLICY ISSUES

The cross-price elasticity estimates that result from the ad hoc approach is much less than unity, and those that are used by Abdelwahab (1998) are just a bit above unity. Abstracting from technical considerations for a moment, it is possible to conceive a story that can explain why rail freight demand is either responsive or unresponsive to truck prices. On the one hand, it is generally believed that the attributes associated with truck freight services are valued more than those of rail on almost every dimension other than accessibility, which probably depends on the nearby infrastructure and is idiosyncratic to any given shipping scenario. So, if shippers are choosing rail over truck even though truck costs are lower and service attributes are better than rail, then it must be due to accessibility reasons. Thus, it can be argued that rail freight demand is highly responsive to truck freight prices because, up to a certain distance, truck outcompetes rail so much so that consumers of rail services are only marginally attached.

The flipside of this is that, for similar reasons, it can also be argued that the value associated with rail service accessibility must be extremely high to compensate for the many disadvantages of rail and results in a very unresponsive rail demand with respect to truck prices. The stark differences between the estimates from the two methods highlight the need for a more up-to-date estimation of the cross-price elasticity of rail freight demand relative to truck prices.

One of the downsides to the ad hoc method that was used in the previous section is that it relies on several convenient and strict assumptions about preferences. This limits the usefulness for policy decisions. However, the results from Abdelwahab (1998) are also limited in its usefulness considering that the cost structures of the two modes have changed significantly. Over the last 20 years or so, the producer price index for line-haul rail operations increased much faster than that of long-haul trucking, which suggests that the elasticities from Abdelwahab (1998) may not necessarily hold (Bureau of Transportation Statistics 2018). Therefore, there are no obvious ways of determining which of the two methods dominate.

With the rapid pace of AV/CV technological development, it is likely that fully automated trucks will be in use in half this time. Therefore, a portion of the rail intermodal funds would be vastly underutilized, as well as the associated costs from the decision-making process used to allocate these funds.

In many cases, the process of applying for and receiving federal funds for local transportation infrastructure projects are costly, in both time and money, for all those involved. This type of undertaking has varying rates of success as well, because a project requires unanimous agreement from all stakeholders that would be affected by the completion of the proposed project. In contrast, Interstate projects are controlled by the federal government, and any decision to improve Interstate infrastructure to accommodate new motor carrier technologies would not have as high of an administrative cost.

In evaluating whether any given infrastructure project is worth funding, it is useful to assess the payback period of the project in relation to the development and adoption stages of platooning and driverless truck technologies. It is also important to understand the implications that these

stages would have on the overall freight network. The previous sections have shown that the implications of Phase One on the rail freight demand are small but grow larger as the phase progresses. In response to this, the rail industry could conceivably bring down the fixed loading costs (intercept of the rail cost curve) of rail and make the cost of rail at least as competitive as that of truck after platoon adoption.

Moreover, if the National Freight Strategic Plan sets the goal of having more long-distance freight be moved by rail, using primarily intermodal services, then the only way that the researchers can suggest this be done is for the federal government to purchase and maintain the rail infrastructure to help lower the fixed cost of rail operations. Railroads would still pay a variable fee per ton-mile of track utilized, similar to the fuel fees paid by the trucking industry for the use of public highways. However, their operating costs could then compete with those of the motor carrier industry.

Despite this, there are still a multitude of factors that work against the rail industry and subsequently the demand for intermodal freight service. The proliferation of just-in-time delivery as an inventory strategy creates a market that favors a delivery service with high scheduling flexibility and time consistency. Both of these are advantages that trucks have over rail, and this discrepancy will only increase with the advent of the new trucking technologies considered in this report.

It is ironic that our nation's first railroads were run on public right-of-ways. Anyone could run on these primitive wooden rails, staying out of the mud, for a fee. Perhaps this may be the only way for public policy to lessen congestion on our highways of the future.

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