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Would weight parity on interstate highways improve safety and efficiency of timber transportation in the US South?

Joseph L. Conrad, IV

Harley Langdale Jr. Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA, USA

ABSTRACT

In the US, weight limits on interstate highways are established by the federal government while weight limits on other roadways are established by state or local governments. State weight limits for log trucks exceed federal interstate highway weight limits in all major timber-producing states. This disparity discourages log trucks from traveling loaded on interstate highways. This study compared the safety and efficiency of log truck transportation on current routes to routes utilizing interstate highways in eight wood baskets in the US South. Timber harvest and delivery locations were collected from logging businesses, log truck owners, and forest landowners. GPS truck tracking software and ArcGIS were used to estimate travel distance and travel time on optimal interstate routes and current routes that avoided interstate highways. The sample included 907 unique routes from 257 harvest sites. An average of 39% of routes would benefit from interstate highway access and 66% of harvest sites had at least one load that would benefit from interstate access. Evidence suggests that interstate routes would be safer than current routes because log trucks would encounter 41% fewer intersections, 33% fewer stop signals, and approximately one fewer school zone per route. Despite no significant change in average haul distance, interstate highway access would result in estimated cumulative annual travel cost savings of $7.4 million (USD) in the wood baskets analyzed. Findings suggest that allowing state-legal, loaded log trucks to operate on interstate highways would improve the safety and efficiency of timber transportation in the US South.

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Wood supply chain; logging costs; log truck crashes; log truck accidents

Introduction

More than 200 million tonnes of timber are harvested annually in the US South (Oswalt et al. 2019), nearly all of which is delivered to forest products mills by log trucks.[1] Timber transportation accounted for nearly 25% of the delivered cost of pine (*Pinus spp.*) pulpwood in the region during the first quarter of 2020 (TimberMart-South 2020a, 2020b). Logging business owners in the region identified timber transportation as one of their top challenges in 2017 (Conrad et al. 2018). Logging business owners in the US South and Northeast have reported difficulties hiring qualified drivers, rising insurance premiums, rising overall costs, and long transportation distances as major challenges (Koirala et al. 2017a, 2017b; Conrad 2018).

Timber transportation safety is critical to the southern wood supply chain. The US South had the highest rate of fatal log truck crashes of any US region between 2011 and 2015 (Cole et al. 2019). Improving timber transportation safety would not only save lives but also reduce costs associated with crashes, which can exceed 1 million (USD) per incident when injuries or fatalities are involved (Zaloshnja and Miller 2007).

Many mills in the US South are located in heavily populated areas. Log trucks often encounter heavy traffic en route from harvest sites to mills. This raises the risk of log truck crashes, which contribute to rising liability insurance costs and exposes companies to lawsuits (Conrad 2018). Crash risk for log trucks and other vehicles varies considerably by roadway type and location. Overall crash rates are generally highest on urban roads, whereas the rates of fatal crashes are highest on rural roads (Abdel-Aty and Radwan 2000; Khorashadi et al. 2005; Zwerling et al. 2005; Yan et al. 2012). In the US, fatal crash rates are highest on rural primary roads and lowest on interstate highways (Figure 1). Primary roads, such as state and US highways, but excluding interstate highways in this context, connect major population centers. Approximately 27% of fatal heavy truck crashes occur at intersections even though more than half of truck miles are driven on interstate highways without intersections (FMCSA 2019; FHWA 2019b). For all vehicles, including passenger vehicles, approximately 40% of accidents are intersection-related (NHTSA 2015).

The US Interstate Highway System was first described in a Bureau of Public Roads report to Congress in 1939. The Interstate System was established and funded as a result of the *Federal-Aid Highway Act of 1956* (FHWA 2019b). The Interstate System currently includes 75,440 km (46,876 miles) of highways. Design standards for the system were developed by state highway agencies via the Association of State Highway and Transportation Officials (AASHTO), which were then adopted by the Federal Highway Administration (FHWA). Interstate highways were designed to higher standards than most other roads in the US and include full control access, at

CONTACT Joseph L. Conrad, IV jlconrad@uga.edu Harley Langdale Jr. Center for Forest Business, Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA, USA

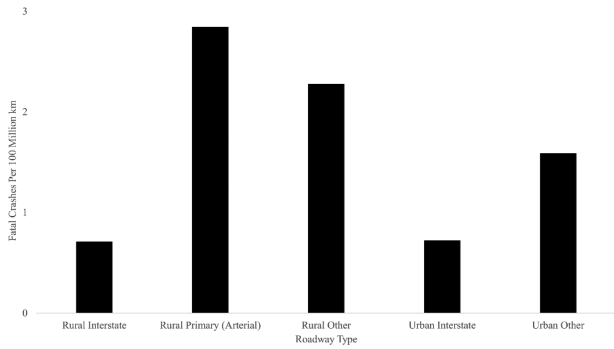

Figure 1. Fatal crash rates for large trucks by road classification in 2016, the most recent year for which data was available. Sources: FHWA (2019a), FMCSA (2019).

least two travel lanes in each direction, and paved shoulders, among other standards.

US states, not the federal government, own and operate interstate highways (FHWA 2019b). However, federal law governs weight limits for heavy trucks operating on interstate highways. Since 1974, gross vehicle weight (GVW) has been limited to 36,287 kg (80,000 pounds) and tandem axle weight has been limited to 15,422 kg (34,000 pounds) on interstate highways (FHWA 2017A). Truck weight is also governed by the Federal Bridge Formula (Equation 1). These weight rules apply nationwide, but the federal government allows numerous exceptions to these rules. States with weight limits higher than current federal limits at the time the interstate highway system was established were allowed to retain those higher weight limits through grandfather clauses, many dating back to the 1950s. All states may issue overweight permits for nondivisible loads that weigh up to 45,359kg (100,000 pounds) on five-axle tractor-trailers. In addition, the US Congress has provided specific exemptions. For example, in Minnesota log trucks with six axles and GVW up to 44,906 kg (99,000 pounds) may operate on Interstate Highway 35 (I-35) from mile marker 235.4 to mile marker 259.552 and in Wisconsin log trucks with six axles and GVW up to 44,452 kg (98,000 pounds) are allowed to operate on I-39 between mile markers 175.8 and 189 (Public Law 114–94, §1410).

$$W = 500\left[\frac{LN}{N-1} + 12N + 36\right] \tag{1}$$

Where:

W = Overall gross weight on any group of two or more consecutive axles to the nearest 500 pounds (227 kg)

L = The distance in feet (0.3 m) between the outer axles of any group of two or more consecutive axles

N = The number of axles in the group under consideration

All states in the US South have GVW limits and tandem axle weight limits for state and US highways, including enforcement tolerances or variances, that exceed federal interstate weight limits (Table 1). State weight regulations are described in state statutes and are summarized by FHWA (2017a). North Carolina and Virginia allow five-axle log tractor-trailers to weigh up to 40,823 kg (90,000 pounds) GVW. Alabama, Florida, Kentucky, and Tennessee allow GVW up to 39,916 kg (88,000 pounds) while Georgia, Mississippi, and South Carolina allow GVW of approximately 38,102 kg (84,000 pounds) without penalty. States in other US regions have even higher GVW limits. For example, several states in the US Northeast, Lake States, and West allow GVW of approximately 45,359kg (100,000 pounds) on 6–8 axle tractor-trailers and Michigan allows GVW up to 74,389 kg (164,000 pounds) on eleven axles.

Table 1. Gross vehicle weight (GVW) for all five-axle tractor-trailers and GVW, single axle, and tandem axle weight limits (including tolerances, permits, etc.) for five-axle log tractor-trailers in the US South. These values are based on the author's reading of state statutes, confirmed by secondary sources (e.g. FHWA 2017a). State tolerances and permits may have specific stipulations not described here.

Region/State/ Country	GVW (kg)	Timber GVW (kg)	Timber Single Axle (kg)	Timber Tandem Axle (kg)
Interstate Highways	36,287	36,287	9,072	15,422
Alabama	36,287	39,916	9,979	16,964
Arkansas	36,287	38,555	9,072	16,556
Florida[a]	36,287	39,916	9,979	19,958
Georgia	36,287	38,102	10,954	21,909
Kentucky	36,287	39,916	Unlimited[b]	Unlimited[b]
Louisiana	36,287	39,916	Unlimited[b]	Unlimited[b]
Mississippi	36,287	38,102	9,979	16,964
North Carolina	36,287	40,823	9,979	19,051
South Carolina[c]	33,239	38,225	10,433	18,779
Tennessee	36,287	39,916	9,979	16,964
Texas	36,287	38,102	–	19,958
Virginia	36,287	40,823	10,886	18,144

[a]Florida's GVW limit is published including a 10% tolerance. An overweight permit for timber allows an additional 10% tolerance.
[b]Log tractor-trailers not cited for axle weight violations as long as they are under GVW limits, including tolerances.
[c]All tractor-trailers are allowed a 10% tolerance. Timber is allowed a 15% tolerance.

Loads of timber that abide by state weight laws, but exceed federal weight limits, are not allowed on interstate highways. Most log trucks in the US South have a tare weight of approximately 12,383 kg (27,300 pounds) (Conrad 2018). Therefore, log trucks can legally haul up to 25.9 t (28.4 tons) of payload on state and US highways in Georgia and South Carolina, 27.7 t (30.4 tons) in Alabama and Florida, and 28.6 t (31.4 tons) in North Carolina and Virginia. On interstate highways, maximum payload would be 24.0 t (26.5 tons) to comply with GVW limits, but probably closer to 22 t (24 tons) to comply with tandem axle limits. Losing 3–6 t (3–7 tons) of payload for the privilege of hauling timber on interstate highways is, in most cases, cost-prohibitive.

Most log trucks avoid traveling loaded on interstate highways. Log trucks are not restricted from traveling on interstate highways when they are unloaded. However, despite unloaded log truck traffic on interstate highways, log truck crashes on interstate highways are relatively rare. Cole et al. (2019) found that only 3.7% of fatal log truck crashes occurred on interstate highways between 2011 and 2015. Most fatal crashes occurred on state (46%) and US highways (34%). Likewise, in Georgia, fewer than 5% of crashes occurred on interstate highways but 41% occurred within 8 km (5 miles) of an interstate highway (Conrad 2019).

Higher engineering standards and lower fatal crash rates (Figure 1) on interstate highways combined with findings from previous log truck crash research (Cole et al. 2019; Conrad 2019) suggest allowing state-legal, loaded log trucks to operate on interstate highways would improve timber transportation safety. Therefore, the objectives of the study were to 1) estimate the percent of routes, loads, and harvest sites that would benefit from interstate access and 2) compare the safety, cost, and infrastructure impacts of routes that avoid interstate highways to those that utilize interstate highways.

Materials and methods

Timber harvest and delivery information was collected from landowners, logging businesses, and log truck owners in eight wood baskets in the US South (Figure 2). Collectively, more than 60 million t of timber are harvested annually within the study area (Table 2), approximately 25% of the total harvest in the US South (Oswalt et al. 2019). Five of the wood baskets are centered in areas with relatively large populations (>100,000 residents) and Brunswick, GA's population grows during the summer because of tourism. Brewton, AL and Roanoke Rapids, NC are relatively rural wood baskets. These eight wood baskets were selected because they contain at least one large mill near one or more interstate highways. These wood baskets should not be considered representative of all areas in the region; rather, they should be considered representative of areas with large mills near interstate highways.

Participants were identified through contacts with state loggers' associations, state forestry associations, and other forest industry contacts. Participants were contacted by phone or e-mail and asked to provide information on harvest locations, mill locations, and number of loads delivered to each mill from each harvest site. Participants were asked to provide

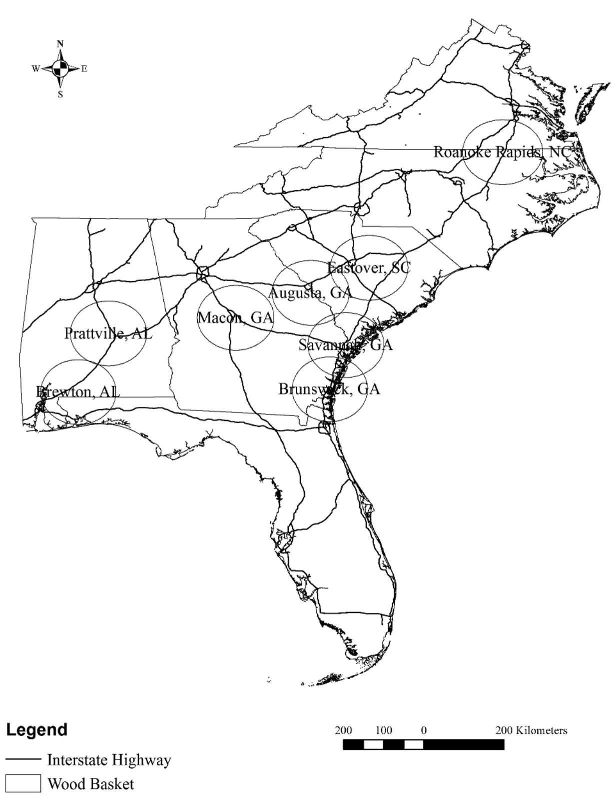

Figure 2. Study area and 80-km (50-mile) radius around the center of each wood basket.

Table 2. Description of eight wood baskets analyzed during this study.

Wood Basket	Population[a]	Interstate Highways	Large Mills	Annual Harvest[b] (million t)
Brewton, AL	40,000	10, 65	Georgia-Pacific, WestRock	5.7
Prattville, AL	250,000	65, 85	International Paper	7.5
Augusta, GA	200,000	20, 520	Graphic Packing International, West Fraser	11.6
Brunswick, GA	90,000	95	Georgia-Pacific, Rayonier, WestRock	7.6
Macon, GA	150,000	16, 75	Graphic Packaging International, Interfor	9.8
Savannah, GA	290,000	16, 75	International Paper, Interfor	7.6
Roanoke Rapids, NC	50,000	85, 95	WestRock, West Fraser, Enviva	8.9
Eastover, SC	415,000	20, 26, 77, 95	International Paper, Canfor	8.4

[a]Estimated population of the city and surrounding metropolitan area or county (US Census Bureau 2019).
[b]Tonnes harvested annually within an 80-km radius (USDA Forest Service 2019).

approximately 3 months of data. Participants ranged in size from single crew logging firms to companies that subcontract with hundreds of logging contractors for timber harvest and delivery. Data came from harvests conducted during 2019 or early 2020, with most data coming from the third quarter of 2019.

Two companies with combined 25 trucks provided access to their GPS truck tracking systems. In these cases, travel time and travel distance were recorded from the GPS tracking system's website. Approximately 12% of the haul routes were analyzed from GPS tracking data. The remaining eleven participants provided spreadsheets listing the GPS coordinates of harvest sites, the name, and location of the mills to which timber was delivered, and the number of loads delivered to each mill from each harvest site. Participants that were clients of TRACT™; a company that provides load tracking, settlement, and accounting, and job management services, provided the author with access to their records on the TRACT™ website. When only harvest site location and mill locations were provided (i.e. no GPS tracking), ArcGIS Online (Esri 2020) was used to estimate travel time and travel distance for the quickest legal route for heavy trucks.

ArcGIS Online's settings were configured to minimize trucking time. If the quickest route included use of an interstate highway for part of the trip, interstate access was deemed beneficial. In a small number of cases, interstate highway access was deemed beneficial when estimated travel time was up to 5 minutes longer using an interstate highway if interstate access allowed the log truck to bypass a large urban area. In these cases, travel time would likely be lower on the interstate route during periods of heavy traffic.

When interstate access was beneficial, a detailed route analysis was conducted on an *interstate* route and the *current* route. The interstate route included travel on at least one interstate highway for part of the route whereas the current route intentionally avoided all interstate highways. On both interstate and current routes, travel time, travel distance by roadway type, fuel consumption, intersections, school zones, towns/cities, vehicle turns, fatal crash risk, emissions, and pavement damage costs were estimated. From a random sample of routes benefiting from interstate access (approximately 25 routes per wood basket), the number of stop signs and/or stop lights was recorded. Travel time, travel distance, intersections, school zones, and towns/cities were estimated by analyzing maps on ArcGIS Online. Travel within urban areas was quantified using ArcGIS Online with urban area boundaries defined by US Census Bureau topologically integrated geographic encoding references (TIGER) files from the USDA Natural Resources Conservation Service (2019).

Fuel consumption was estimated using fuel economy values of 1.59 km l^{-1} (3.75 miles per gallon [mpg]) on non-interstate urban roads, 2.08 km l^{-1} (4.90 mpg) on non-interstate rural roads, and 2.38 km l^{-1} (5.60 mpg) on interstate highways. Non-interstate urban fuel economy was estimated using values from Rizet et al. (2012) and conversations with log truck owners. Non-interstate rural fuel economy was estimated from values provided by Hooper and Murray (2018) for trucks with operating weights exceeding 36,287 kg (80,000 lbs). The estimate from Hooper and Murray (2018) was verified as applicable to log trucks by analyzing the fuel economy achieved by a Georgia log truck fleet of approximately 20 trucks that drove over 2.4 million km (1.5 million miles) during 2018. Interstate highway fuel economy was estimated from previous studies (Tunnell 2009; Rizet et al. 2012; FHWA 2019b). Fuel economy improved by 15% on interstate highways compared to an alternative route with heavier weight limits (Tunnell 2009). Rizet et al. (2012) estimated that fuel economy was approximately 18% higher on highways compared to rural roads in the United Kingdom. FHWA (2019a) estimated that nationwide fuel economy for all combination trucks (i.e. tractor-trailers) was 2.51 km l^{-1} (5.90 mpg) in 2016. Carbon dioxide emissions were estimated assuming 2.68 kg of CO_2 l^{-1} of diesel consumed (22.40 lbs per gallon) (EIA 2016).

Travel costs were estimated on interstate and current routes. Fuel costs were estimated from trip mileage by roadway type from ArcGIS or GPS tracking, fuel economy values listed above, and a diesel price of \$0.77 USD l^{-1} (\$2.92 gallon^{-1}) (EIA 2019). All monetary values described here are reported in US dollars. All other costs were calculated using travel time from ArcGIS or GPS tracking combined with the hourly cost of owning and operating heavy trucks (\$52.59 hr^{-1}) from the American Transportation Research Institute's 2019 trucking cost survey, excluding fuel, permits and licenses, and toll costs (Murray and Glidewell 2019). Travel costs include only the cost of owning and operating the log truck from the time it left a harvest site until it reached a mill. They do not include the costs of loading, unloading, or traveling empty because these costs are not affected by interstate access and were not of interest to this study.

Fatal crash risk was estimated using a weighted average based on the distance traveled between harvest sites and mills on each type of road and nationwide crash rates by roadway type (Figure 1). This estimate is imprecise; nonetheless, it does give a general indication of which routes have higher or lower crash risk.

Pavement damage costs were estimated assuming costs of- \$0.06, \$0.13, \$0.16, and \$1.92km^{-1} (\$0.09, \$0.21, \$0.25, and \$3.09 mile^{-1}) on interstate highways, non-interstate urban roads, rural primary roads, and rural secondary roads, respectively. Secondary roads, such as county roads, often have very thin pavement and insufficient road bases to support heavy truck traffic and can suffer severe damage from heavy truck traffic. These estimates were based on previous estimates from the literature (FHWA 2000; Luskin et al. 2002; Carson 2011; Dey et al. 2014; Ahmed et al. 2015; Zhao and Wang 2015) adjusted for inflation using the National Highway Construction Cost Index (FHWA 2019c).

Annual travel cost savings and emissions reductions were calculated for each wood basket using Equation 2. Savings per logging business were calculated assuming the average logging business produces approximately 1,524 t wk^{-1} (1,680 tons) and operates approximately 50 weeks per year (Conrad et al. 2018).

$$A_i = L_i \times I_i \times S_i \quad (2)$$

Where:

A_i = total annual savings in wood basket i

L_i = number of loads of timber per year delivered in wood basket i

I_i = percent of loads benefiting from interstate access in wood basket i

S_i = savings per trip resulting from interstate access in wood basket i

Total savings within each wood basket were calculated using equation 2 combined with the number of tonnes of timber harvested annually in each wood basket from USDA Forest Service (2019) Forest Inventory and Analysis data. The number of dry tonnes harvested per year from trees ≥12.7 cm (5 inches) in diameter at breast height was calculated within 80 km (50 miles) of the center of each wood basket. An 80-km radius was selected because it is the average haul distance in the region (TimberMart-South 2020b) and almost all mills will purchase timber from at least this distance. Dry tonnes were converted to green tonnes assuming 50% moisture content on a wet basis (Baker et al. 2012; Cutshall et al. 2013; Jernigan et al. 2013). Green tonnes were converted to loads by assuming 25.4 t (28 tons) per load in Georgia and South Carolina and 27.2 t (30 tons) per load in Alabama, North Carolina, and Virginia. There was some overlap between wood baskets (Figure 2); consequently, some savings were double-counted. However, this should be more than offset by savings on loads hauled from outside the 80-km radius that were not considered in the calculation.

Data were analyzed using Microsoft Excel and JMP Pro 14.3.0 (2018). Within each wood basket, differences between interstate and current routes were compared using matched pairs t-tests at $\alpha = 0.05$.

Results

The sample included 36,023 loads hauled on 907 unique routes from 257 harvest sites (Table 3). Timber deliveries were made to an average of 3.5 mills per site. Loggers in the Prattville wood

Table 3. Summary statistics for all routes analyzed in eight wood baskets in the US South. Average haul distance and total route km were calculated assuming interstate highways were not used.

Wood Basket	Harvest Sites	Routes Analyzed	Loads	Average Haul Distance (km)	Total Loaded Distance (km)
Brewton	32	146	5,892	97	575,030
Prattville	34	42	2,764	79	217,424
Augusta	30	96	1,111	85	93,958
Brunswick	58	244	10,526	84	888,094
Macon	33	98	1,865	85	158,797
Savannah	23	75	2,704	68	181,312
Roanoke Rapids	21	102	7,027	55	383,016
Eastover	26	104	4,134	64	268,614

basket often delivered timber to only one or two mills and consequently fewer routes were analyzed there.

The average haul distance was 77 km (48 miles), which is consistent with reports from logging business owners and timber price reporting services (Conrad et al. 2018; TimberMart-South 2020b). Average haul distance ranged from 55 km (34 miles) in Roanoke Rapids to 97 km (60 miles) in Brewton. Interstate access tended to be most beneficial on long hauls. The average haul distance on routes that benefited from interstate access was 97 km (60 miles) while the average haul distance on other routes averaged 71 km (44 miles).

Across all eight wood baskets, an average of 39% of routes, 40% of loads, and 66% of harvest sites benefited from interstate access (Figure 3). Augusta had the highest percentage of routes benefiting from interstate access, while Brunswick had the lowest. Brewton had the highest percentage of loads benefiting from interstate access, while Savannah had the lowest. The percentage of sites benefiting from interstate access ranged from 32% in Prattville to 82% in Roanoke Rapids. In the Prattville wood basket, loggers typically delivered timber to only one or two mills per site, which meant a smaller percentage of sites benefited from interstate access compared to other wood baskets where loggers commonly delivered timber to four or more mills per site.

Safety comparison

The remainder of the results focuses on routes that benefited from interstate access. Comparisons are made between interstate routes that utilize interstate highways for a portion of each

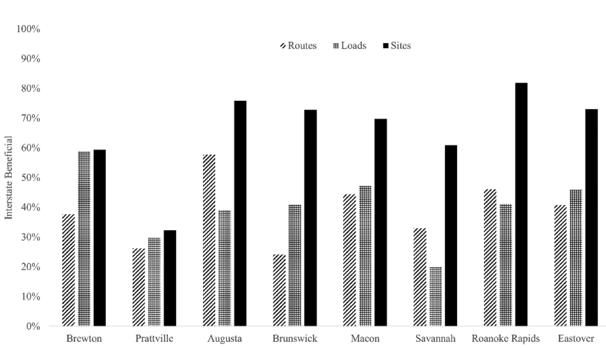

Figure 3. Percent of routes, loads, and sites benefiting from interstate highway access in eight wood baskets.

Table 4. Distribution of km driven on interstate and current routes avoiding interstate highways in eight wood baskets in the US South.

	Average Distance (km)				
Wood Basket and Route Type	Rural Secondary[1]	Rural Primary[1]	Urban Non-Interstate	Interstate	Total[2]
Brewton					
Interstate	5.5[a]	60.2[a]	4.0[a]	40.1	109.6[a]
Current	8.9[b]	94.1[b]	7.6[b]	–	110.7[a]
Prattville					
Interstate	5.0[a]	32.7[a]	15.0[a]	19.8	72.4[a]
Current	5.0[a]	46.0[b]	20.3[b]	–	71.1[a]
Augusta					
Interstate	2.3[a]	46.0[a]	10.8[a]	49.6	108.5[a]
Current	2.4[a]	78.5[b]	27.2[b]	–	107.8[a]
Brunswick					
Interstate	4.3[a]	58.3[a]	20.9[a]	28.8	112.5[a]
Current	4.5[a]	77.9[b]	23.8[b]	–	106.4[b]
Macon					
Interstate	5.1[a]	49.1[a]	10.5[a]	32.7	100.3[a]
Current	5.3[a]	75.8[b]	17.7[b]	–	99.1[a]
Savannah					
Interstate	3.4[a]	45.7[a]	3.5[a]	82.2	135.0[a]
Current	2.7[a]	102.7[b]	22.0[b]	–	127.3[b]
Roanoke Rapids					
Interstate	9.2[a]	29.1[a]	4.2[a]	26.6	69.0[a]
Current	16.3[b]	43.0[b]	8.0[b]		67.3[a]
Eastover					
Interstate	3.2[a]	40.9[a]	6.3[a]	38.1	88.5[a]
Current	3.5[a]	71.1[a]	8.2[b]	–	82.9[b]

[1]Primary roads refer to state and US highways. Secondary roads are analogous to county roads in many states.
[2]May differ slightly from the sum of the previous columns because of rounding.
[a, b]Within each wood basket, values in columns not connected by the same letter are statistically different ($p < 0.05$).

route and current routes that avoid interstate highways entirely.

Interstate access resulted in a statistically significant ($p < 0.05$) reduction in distance traveled on rural primary and non-interstate urban roads (Table 4). A typical route from a harvest site to a mill originated on a secondary road for between two and ten km (1–6 miles) followed by travel on primary roads. In many wood baskets, especially in Georgia, log trucks traveled through urban areas for 15 km (~10 miles) or more on the way to a mill. On interstate routes, log trucks traveled approximately the same number of km on secondary roads as they do on current routes; however, km traveled on primary roads and within urban areas shifted to interstate highways. The shift from primary roads and non-interstate urban roads to interstate highways resulted in lower weighted-average crash risk per km traveled in every wood basket (Table 5).

Log trucks encountered an average of 41% fewer intersections and 33% fewer stop signals on interstate routes compared to current routes (Table 5). There were statistically significant ($p < 0.05$) reductions in intersections on interstate routes in every wood basket and the same was true of stop signals in every wood basket except for Brunswick. In Augusta and Savannah, intersections were reduced by 50% or more on interstate routes. Brunswick was the only wood basket in

Table 5. Average crash risk and average number of intersections, stop signals, cities/towns, school zones, and turns per route on interstate and current routes in eight wood baskets in the US South.

Wood Basket and Route	Fatal Crash Risk (crashes km^{-1} x 10^8)	Intersections	Stop Signals	Cities and Towns	School Zones	Turns
Brewton						
Interstate	1.98^a	89^a	7.7^a	2.3^a	1.3^a	6.2^a
Current	2.72^b	149^b	11.4^b	3.6^b	2.7^b	6.3^a
Prattville						
Interstate	1.95^a	72^a	13.3^a	2.2^a	0.9^a	6.5^a
Current	2.42^b	103^b	18.6^b	2.3^a	2.4^b	5.3^b
Augusta						
Interstate	1.70^a	93^a	10.7^a	2.2^a	1.3^a	6.4^a
Current	2.50^b	186^b	28.2^b	4.3^b	1.6^b	6.5^a
Brunswick						
Interstate	1.96^a	147^a	20.9^a	4.5^a	3.1^a	7.9^a
Current	2.53^b	178^b	19.4^b	5.2^b	3.4^b	7.4^b
Macon						
Interstate	1.99^a	90^a	15.2^a	2.0^a	1.0^a	7.9^a
Current	2.60^b	154^b	23.2^b	3.3^b	1.3^a	7.4^a
Savannah						
Interstate	1.53^a	79^a	7.9^a	2.9^a	0.6^a	6.7^a
Current	2.58^b	212^b	23.2^b	7.1^b	2.5^b	6.0^a
Roanoke Rapids						
Interstate	1.95^a	61^a	6.3^a	2.0^a	1.3^a	5.6^a
Current	2.42^b	101^b	8.6^a	2.7^b	2.1^b	6.0^a
Eastover						
Interstate	1.81^a	81^a	10.3^a	1.6^a	0.9^a	7.4^a
Current	2.69^b	136^b	11.4^b	2.7^b	1.4^b	7.0^a

[a,b]Within each wood basket, values in columns not connected by the same letter are statistically different ($p < 0.05$).

which log trucks encountered more stop signals on interstate routes. In this wood basket, log trucks encountered clusters of stop signals within 5 km of entrance/exit ramps to an interstate highway.

Log trucks avoided approximately one school zone per trip on interstate routes (Table 5). There were significantly ($p < 0.05$) fewer school zones encountered in every wood basket except for Macon. Likewise, log trucks encountered significantly fewer ($p < 0.05$) cities and towns on interstate routes in every wood basket except for Prattville. The same number of turns were required oninterstate and current routes except in Prattville and Brunswick where more turns were required on interstate routes.

Transportation efficiency and cost comparison

Interstate access did not reduce average haul distance (Table 4). The average haul distance on interstate and current routes was within 2 km (~1 mile) of each other in five of eight wood baskets. In the three other areas, interstate routes were 6–8 km (4–5 miles) longer.

Average travel time was an average of 8 minutes per trip shorter on interstate routes (Table 6). The difference in travel time between interstate and current routes averaged less than 5 min in Prattville, Brunswick, and Eastover. In contrast, travel time savings in excess of 10 min per trip were observed in Brewton, Augusta, and Savannah. Travel time differences on individual trips ranged from 5 min longer to 56 min shorter on interstate routes. It is important to remember that interstate access was judged beneficial if travel time was equal or shorter on the interstate route, or up to 5 min longer if a large urban area could be bypassed.

Table 6. Comparison of travel time and travel speed on interstate routes and current routes in eight wood baskets in the US South.

Wood Basket	Average Travel Time Interstate Route (min)	Interstate Travel Time Savings (min)			Average Travel Speed Interstate Routes ($km\ h^{-1}$)	Average Travel Speed Current Routes ($km\ h^{-1}$)
		Average	Minimum	Maximum		
Brewton	75	12*	0	26	89^a	76^b
Prattville	50	3	0	19	87^a	79^b
Augusta	76	15*	−1	56	85^a	71^b
Brunswick	83	1	−5	20	82^a	76^b
Macon	71	9*	−3	41	82^a	74^b
Savannah	86	14*	−2	36	93^a	76^b
Roanoke Rapids	52	9*	−2	36	77^a	66^b
Eastover	64	4*	−3	21	84^a	79^b

*Within each wood basket, an asterisk indicates the average travel time savings were statistically different from zero ($p < 0.05$).
[a,b]Within each wood basket, average travel speeds not connected by the same letter are statistically different ($p < 0.05$).

Average one-way travel cost per route was significantly lower on interstate routes in six of the eight wood baskets (Figure 4). Travel cost savings per route were low and not statistically significant in Brunswick and Eastover. Cumulative annual travel cost savings across the six wood baskets with statistically significant cost savings were estimated at $7.4million (Figure 5). Estimated savings were highest in the Augusta wood basket at over $2.5million per year. Average annual savings per logging business were estimated to be $13.145 and ranged from $3,369 in Prattville to $21,492 in Brewton.

Less fuel was required per trip on interstate routes in six of the eight wood baskets (Table 7). Consequently, carbon dioxide emissions per trip were lower on interstate routes in those

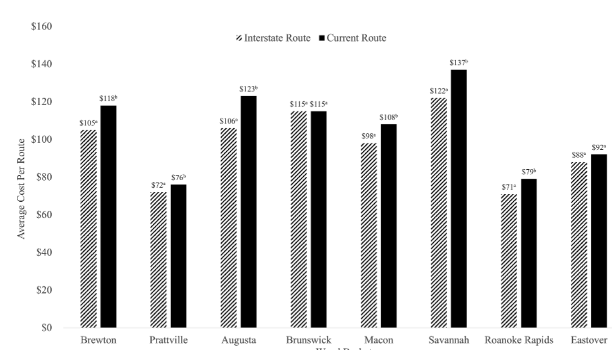

Figure 4. Average one-way travel cost per trip (USD) on interstate and current routes in eight wood baskets in the US South. Within each wood basket, values not connected by the same letter are statistically different ($p < 0.05$).

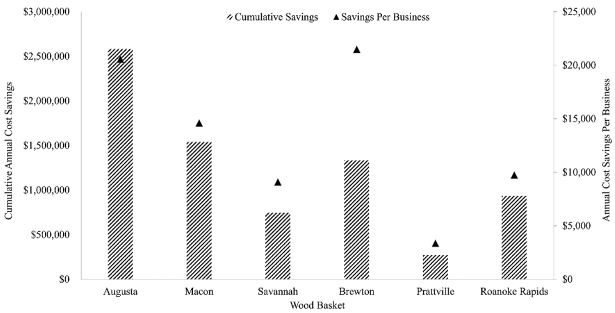

Figure 5. Estimated cumulative annual cost savings (USD) and annual savings per logging business in six wood baskets in the US South.

Table 7. Fuel consumption, CO_2 emissions, and pavement damage per trip (USD) on interstate and current routes in eight wood baskets in the US South.

Wood Basket and Route	Fuel Consumption (l)	CO_2 Emissions (kg)	Pavement Damage
Brewton			
Interstate	50.7^{a}	136^{a}	\$22^{a}
Current	54.1^{b}	145^{b}	\$33^{b}
Prattville			
Interstate	36.0^{a}	96^{a}	\$18^{a}
Current	37.1^{b}	99^{b}	\$19^{b}
Augusta			
Interstate	50.7^{a}	136^{a}	\$16^{a}
Current	56.0^{b}	150^{b}	\$21^{b}
Brunswick			
Interstate	55.3^{a}	148^{a}	\$22^{a}
Current	54.5^{a}	146^{a}	\$24^{b}
Macon			
Interstate	46.2^{a}	124^{a}	\$21^{a}
Current	50.0^{b}	134^{b}	\$24^{b}
Savannah			
Interstate	60.2^{a}	161^{a}	\$19^{a}
Current	64.4^{b}	173^{b}	\$24^{b}
Roanoke Rapids			
Interstate	32.2^{a}	86^{a}	\$24^{a}
Current	33.3^{b}	89^{b}	\$39^{b}
Eastover			
Interstate	41.3^{a}	111^{a}	\$15^{a}
Current	40.9^{a}	110^{a}	\$19^{b}

[a,b]Within each wood basket, values in columns not connected by the same letter are statistically different ($p < 0.05$).

Table 8. Cumulative estimated annual savings (USD) from allowing state-legal, loaded log trucks to operate on interstate highways in eight wood baskets in the US South.

Wood Basket	Fuel Consumption (l)	CO_2 Emissions (t)	Pavement Damage
Brewton	354,110	949	\$1,035,491
Prattville	94,090	252	\$112,140
Augusta	759,668	2,036	\$714,327
Brunswick	–	–	\$212,346
Macon	542,275	1,453	\$508,424
Savannah	195,429	524	\$266,778
Roanoke Rapids	140,624	377	\$1,626,019
Eastover	–	–	\$452,832
Total	2,086,196	5,591	\$4,928,357

Table 9. Safety, cost, and environmental impacts comparison of two individual timber deliveries on interstate and current routes.

	Warren County, GA to Augusta, GA		Greensville County, VA to Roanoke Rapids, NC	
Variable	Interstate	Current	Interstate	Current
Travel Time (min)	60	106	36	50
Distance (km)	95	105	50	53
Average Travel Speed (km h^{-1})	95	60	84	63
Number of Intersections	9	125	31	85
Number of Stop Signs/Lights	7	27	3	9
Towns/Cities	1	3	3	4
School Zones	0	1	1	2
Fatal Crash Risk (crashes $km^{-1} \times 10^8$)	0.81	2.42	1.21	2.52
Travel Cost (one-way, USD)	\$90	\$136	\$49	\$65
Pavement Damage Cost	\$9	\$17	\$11	\$14
Fuel Consumption (l)	48.8	55.6	22.3	27.3
CO_2 Emissions (kg)	131	149	59.8	73.2

same six wood baskets. Pavement damage was lower on interstate routes in every wood basket. Utilizing interstate highways was estimated to reduce annual fuel consumption by 2.1 million l (0.6 million gallons), CO_2 emissions by 5,591 t (6,163 tons), and pavement damage costs by $4.9million in the wood baskets analyzed (Table 8).

Interstate access benefits on individual routes

The difference in safety and cost of individual routes can be considerable. For example, on a timber delivery from a harvest site in Warren County, GA to a mill in the city of Augusta, GA, the interstate route reduced travel time by 46 minutes on a ~100-km (~60-mile) trip (Table 9). On this delivery, the log truck encountered 116 fewer intersections, 20 fewer stop signals, and one less school zone. The interstate route also reduced estimated fatal crash risk, travel cost, pavement damage, fuel consumption, and CO_2 emissions.

On a delivery from Greensville County, VA to a mill in Roanoke Rapids, NC, interstate access reduced travel time by 14 minutes on a ~50-km (~30-mile) trip (Table 9). Interstate access reduced intersections encountered from 85 to 31 and stop signals from 9 to 3. Fatal crash risk was reduced by more than 50%, and travel costs, pavement damage, fuel consumption, and emissions were also reduced.

Discussion

Wood basket comparison

Interstate access was most beneficial in wood baskets where a high percentage of kilometers could be traveled on interstate highways and/or large urban areas could be bypassed on interstate highways. For example, travel cost savings were not significant in Brunswick and Eastover because the flow of wood was not always in the same direction as interstate highways. Brunswick has only one interstate highway (I-95), which runs north and south, whereas most timber is transported east and west. In addition, timber delivered from the Brunswick wood basket to mills in Fernandina Beach, FL are unable to avoid traveling through a congested urban area on the way to these mills, even if interstate highway access is allowed. On the other hand, travel cost savings were substantial in the Augusta wood basket because of significant efficiency gains from bypassing the city of Augusta on I-520. Savings were also substantial in the Brewton wood basket because a high percentage of kilometers could be driven on interstate highways even though there are no large cities to be bypassed there.

Across the US South, there are a number of wood baskets that would benefit from interstate access. Some of these wood baskets may experience substantial benefits as was the case in Augusta and Brewton. Others may experience smaller benefits comparable to those estimated in Brunswick and Eastover. Others, such as in eastern North Carolina (Figure 2), may not benefit at all because there is currently no interstate highway nearby.

Safety

This study suggests that weight parity on interstate highways and state and US highways would improve both the safety and efficiency of timber transportation in the US South. This study estimated that 30–60% of loads delivered in the eight wood baskets could utilize interstate highways (Figure 3). In many areas, the transportation system for heavy trucks has been designed around interstate highways. For example, in the northern half of the Roanoke Rapids, NC wood basket (Figure 2), the city of Emporia, VA prohibits heavy trucks from driving through the city because it is assumed that trucks can bypass the city on I-95. The only bridges in the area that were designed to support heavy trucks are on the interstate or within the city limits, meaning that log trucks would not be able to travel from north of Emporia, VA to mills in northern North Carolina without a special exemption for forest products granted by the city of Emporia. Even with the exemption, traveling through Emporia is dangerous, slow, and costly compared to using I-95 (Table 9).

Shifting kilometers traveled from state and US highways (i.e. primary roads) to interstate highways reduces fatal crash risk (Figure 1; Table 4, 5). Between 2011 and 2015, almost 80% of fatal log truck crashes occurred on state and US highways (Cole et al. 2019). The critical pre-crash event in nearly 30% of log truck crashes was another motor vehicle encroaching into the log truck's lane from the opposite direction. Crashes caused by other vehicles crossing the center line from the opposite direction would be extremely rare on interstate highways because they are divided highways with one-way traffic.

The reduction in urban kilometers traveled was significant ($p < 0.05$) in every wood basket (Table 4). In Georgia, more than 60% of all log truck crashes occurred within urban areas between 2013 and 2016 (Conrad 2019). Conrad (2019) hypothesized that standardizing weight limits on interstate highways and state and US highways would reduce accident frequency and this idea is supported by the findings of this study.

The significant reduction in intersections encountered on interstate routes is particularly noteworthy since 40% of all crashes, 27% of fatal heavy truck crashes, and 23% of fatal log truck crashes occur at intersections in the US (NHTSA 2015; Cole et al. 2019; FMCSA 2019). The reduction in school zone encounters is noteworthy as well because of the potential for pedestrian traffic and probability of serious or fatal injuries if a heavy truck collides with a pedestrian.

While this study suggests significant safety improvements associated with allowing state-legal, loaded log trucks to operate on interstate highways, some may express concerns about the safety of loaded log trucks on interstate highways. Interstate highways often have higher speed limits than state and US highways (e.g. 113 km h^{-1} [70 miles h^{-1}] vs. 89 km h^{-1} [55 miles h^{-1}]). Collisions at higher travel speeds may result in higher likelihood of injury or death in a crash. Others may argue that the condition of log trucks makes them unsafe to operate on interstate highways. Indeed, research suggests that log trucks tend to be older and in worse mechanical condition than other heavy trucks (Greene et al. 1996, 2007; Cole et al. 2019; Conrad 2019). However, the condition of log trucks has improved in recent years and driving under the influence contributed to fewer log truck crashes than other heavy vehicle crashes in Georgia (Conrad 2019).

Interstate access may incentivize improvements in the condition and performance of log truck fleets. Log trucks operating on interstate highways may be subject to more frequent inspections by state enforcement agencies, which has been demonstrated to improve log truck condition (Greene et al. 1996). Log trucks will be forced to pass through weigh stations on interstate highways that they currently avoid. This may result in higher rates of compliance with state weight limits and encourage the adoption of in-woods scales, which would also improve average payload by reducing underloads (Hamsley et al. 2007; Reddish et al. 2011).

Transportation efficiency and cost

Approximately two-thirds of the harvest sites included in this study would benefit from interstate access, indicating cost savings would be achieved by the majority of logging businesses operating in the wood baskets studied here (Figure 3). Travel cost savings were estimated based on reduced travel time and fuel consumption. These estimates are probably conservative. The real benefit to logging businesses and log truck owners is the ability to transport additional loads with existing trucks. For example, in the Augusta wood basket interstate access reduced one-way travel time by 46 minutes on a ~100-km (~60-mile) trip (Table 9). Assuming 30-min turn-times at the mill and in the woods, a log truck could deliver three loads in a 10-h day, or perhaps even four if turn-times were reduced. On the other hand, if forced to use the current route, the log truck will deliver only two loads to this mill during a 10-h day. Delivering three loads per day instead of two increases revenue by 50%. Because that third load is so critical to a business's profitability, the log truck driver may be asked to work a 12 +hour day to deliver the third load. Even though the driver may be able to do this legally because he or she would have driven less than the limit of 11 hours as a result of waiting time, it is still problematic because working a long day increases the likelihood of a crash (Soccolich et al. 2013; Williamson and Friswell 2013) and also reduces a truck driver's job satisfaction. At the margins, increasing loads per truck per day means that fewer log trucks are needed in the system, which may help to alleviate some of the challenges of hiring qualified drivers (Koirala et al. 2017a, 2017b; Conrad 2018). In addition, improving transportation safety should reduce accident frequency and insurance claims, reducing future insurance premium increases.

Logging businesses should not rely on savings from interstate access to solve all of their challenges. This study estimated important transportation cost savings that could be achieved by log truck owners (Figures 4 and 5). While the savings estimated here are important, they represent a small percentage of log truck owners' annual expenditures. In Brewton, average annual savings per logging business were estimated to be \$21,492 (Figure 5) for a business harvesting 1,524 t wk^{-1} (1,680 tons wk^{-1}). A business of this size would need approximately four log trucks, each of which cost approximately 150,000 USD yr^{-1} to own and operate, meaning interstate access would reduce overall transportation costs by approximately 3.5%. This is not a large percentage reduction; however, given the challenges facing timber transportation (Koirala et al. 2017a, 2017b; Conrad 2018; Conrad et al. 2018), interstate access would certainly help. Combining savings from interstate highway access with savings from increasing percent-loaded km through centralized truck dispatching (Mendell et al. 2006), increasing payload consistency through the use of in-woods scales (Conradie et al. 2004; Hamsley et al. 2007; Reddish et al. 2011), and reducing turn-times at harvest sites and mills (Deckard et al. 2003; Dowling 2010) could reduce hauling costs by more than 10% and make the sector much more competitive.

There are also savings and efficiency gains associated with interstate highway access that are not easily quantified but may be substantial. Because log trucks cannot bypass large cities on interstate highways, mills may not purchase timber on the opposite side of those large cities. This reduces markets for landowners' timber, potentially reducing stumpage prices because of reduced competition. Similarly, logging businesses may be unable to expand their business geographically because they are not able to bypass large cities on interstate highways. The inability to bypass large cities carrying state-legal loads distorts timber markets, reduces efficiency, and increases supply chain costs. Some may argue that loggers should load their trucks to interstate weight limits. This is simply not cost-effective. Log trucks are often unprofitable when loaded to state weight limits (Conrad 2018); reducing payload further is not a viable option for log truck owners.

Environment and infrastructure

Reductions in fuel consumption and CO_2 emissions as a result of interstate highway access are equivalent to removing approximately 1,200 passenger vehicles from the road (Table 8) (EPA 2018). These savings represent a small percentage of overall fuel consumption and CO_2 emissions in the wood baskets analyzed. Nonetheless, they are important, especially when coupled with travel cost and safety savings.

Estimates of infrastructure damage cost savings are imprecise, although they are based on previous studies (FHWA 2000; Luskin et al. 2002; Carson 2011; Dey et al. 2014; Ahmed et al. 2015; Zhao and Wang 2015). While the magnitude of the differences in pavement damage between interstate routes and routes that use state and US highways varies, interstate highways are built to a higher standard than state and US highways and are less susceptible to damage from heavy trucks (Carson 2011; Ahmed et al. 2015; Zhao and Wang 2015). Some states limit permitted overweight loads to the national highway system (GDOT 2019), which includes the interstate highway system and other roads important to the nation's economy, defense, and mobility (FHWA 2017b). In contrast, log trucks are ineligible for overweight permits, because loads of timber are divisible, and are not allowed to operate at state-legal weight limits on interstate highways.

Conclusion

This study estimated significant safety and cost savings that would benefit logging businesses, log truck owners, forest industry mills, and society if state-legal, loaded log trucks were granted access to interstate highways. Most importantly, fatal crash risk was reduced by approximately 25%, intersections were reduced by 41%, and stop signals were reduced by 33% on interstate routes relative to routes currently traveled by log trucks (Table 5). Annual travel cost savings of \$7.4million were estimated across the study area (Figure 5).

Granting state-legal, loaded log trucks access to interstate highways will require federal legislation. In the meantime, log truck owners, loggers, and forest industry foresters should focus on variables that they control. First, driver training efforts, such as those through TEAM Safe Trucking (TEAM Safe Trucking 2017), should continue because driver training has been documented to improve transportation safety (Mooren et al. 2014; Camden et al. 2019). Second, log truck owners should renew their focus on improving the condition of their fleets (Greene et al. 1996, 2007; Cole et al. 2019; Conrad 2019). Investing in in-woods scales (Reddish et al. 2011) as well as dash cameras and GPS tracking can improve transportation safety and efficiency while reducing the probability of citations and litigation in the event of a crash (Locklear 2014; Conrad 2018). Third, improving efficiency through reduced turn-times at harvest sites and mills (Deckard et al. 2003; Dowling 2010), increasing percent-loaded km (Mendell et al. 2006), and improving payload consistency (Hamsley et al. 2007) will make timber transportation more competitive.

Finally, improving the public image of loggers and log trucks (Satterfield 1996; Egan and Taggart 2004; Egan 2009, 2011) is essential to maintain the public license to operate and alleviate fears associated with log trucks on interstate highways. While this study suggests an overall reduction in log truck crashes can be expected if state-legal, loaded log trucks are granted access to interstate highways, crashes on interstate highways will generate additional public and media scrutiny compared to crashes on current travel routes. A concerted effort to improve the image of log trucks in the US South may be needed to ensure that overall improvements in safety resulting from interstate highway access do not come at a cost of public trust because of a few high-profile crashes.

Note

1. The terms truck, tractor-trailer, and semi-trailer are used interchangeably in order to improve conciseness and conform with common terminology in the region.

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