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Trucks-to-trucks: a comparison of the raw forest products transportation industry and other forms of commercial trucking in the US South

Jack Derochers[a], Joseph L. Conrad[b], M. Chad Bolding[c], Mathew Smidt[d], and Bruno Da Silva[e]

[a]Graduate Research Assistant, University of Georgia, Athens, GA, USA; [b]Forest Operations, University of Georgia, Athens, GA, USA; [c]Forest Business, University of Georgia, Athens, GA, USA; [d]Research Forester, USDA Forest Service, Auburn, AL, USA; [e]Forest Finance, University of Georgia, Athens, GA, USA

ABSTRACT

Forest products transportation in the US South is an essential component of the wood supply chain connecting raw materials with manufacturing facilities. Owners and operators of log trucks face many challenges to business success. This review analyzed variables associated with owning and operating commercial trucks in the United States to compare raw forest products transportation and general trucking applications. The variables for both log trucks and general trucking included fuel costs, fuel economy, insurance, driver characteristics and availability, driver wages, truck and trailer configurations, fleet characteristics, weight limits, and safety. Log trucks were approximately 5 years older than other commercial trucks and operated in smaller fleets of 5–10 trucks. The smaller size of log truck fleets often placed them at a disadvantage to larger carriers in insurance and fuel costs, with smaller fleets having less opportunity to buy fuel in bulk and paying 0.006–0.025 USD more per kilometer for insurance than larger fleets. Knowledge gaps include inadequate estimates of the number of log truck operators and limited information related to log truck transportation costs. Continued research into challenges faced by log truck owners is critical to better understand the industry and identify solutions to profitability challenges.

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Introduction

Trucking is a common profession in the United States, surging after the creation of the interstate highway system, improvement of local roads, and deregulation of the industry in 1980 (Costello 2013). According to the US Bureau of Transportation Statistics, approximately 1.8 million tractor-trailers used the nation's roads in 2020 (US Department of Transportation 2021). There are many types of transportation services that trucks provide including general freight, oversize loads, flatbed service, and raw material transportation.

Raw material transportation is critical to the success of the US forest industry. Over 317 million tonnes of timber are harvested in the US annually, with approximately 60% of this harvest coming from forests in the US South (Oswalt et al. 2019). Log truck transportation encounters unique challenges and opportunities as compared to general freight trucking. General freight trucking, for the purposes of this review, includes any form of trucking using heavy-duty trucks weighing 11.8–15.0 tonnes (26,000–33,000 lbs, Class 7) and greater than 15.0 tonnes (33,001 lbs, Class 8) in the US for purposes other than hauling raw, unmanufactured forest products.

Forestry is a major contributor to the economy in the US South. In the state of Georgia alone, the forest industry employs over 57,000 workers and generates an estimated total revenue of $41.9 billion (USD) as one of the largest manufacturers in the state (Georgia Forestry Commission 2023). In 2022, timber transportation accounted for almost 33% of the delivered cost of low value products such as pulpwood, and approximately 22% of higher value sawtimber products (Timber-Mart South 2022, 2023). In the third quarter of 2024, timber transportation accounted for over 40% of the delivered cost of pulpwood and 26% of sawtimber products (Timber-Mart South 2024). For the purposes of this review, the US South is defined as the states of Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

In the US South, forest landowners grow, maintain, and sell standing timber that is harvested by independent logging businesses. Log trucks transport timber from the harvest site to a mill for processing into a finished product. The average haul distance is 80 km (Conrad 2023a; Timber-Mart South 2023; Conrad et al. 2024) using heavy-duty trucks traveling on the local and state road network. Harvested timber is typically transported by one of two types of truck drivers, independent contractors who specialize in trucking or employees of logging businesses who both harvest and transport timber. Independent contractors contract with logging companies to transport harvested timber using their equipment while logging company employee drivers use trucks and trailers owned by the logging business (Conrad 2023b). The logging and timber transportation industry is comprised of small, private, independent firms who have no obligation to provide information about their business, making the estimation of costs difficult.

The objective of this study was to compile and compare costs for timber transportation and general trucking in the US South. These industries have similar cost centers, such as fuel

CONTACT Jack Derochers Jackson.Derochers@uga.edu Graduate Research Assistant, University of Georgia, 180 E Green Street, Athens, GA 30602, USA

and tires, while sometimes competing for human resources, namely qualified drivers. This review was conducted to better understand the similarities and differences between timber transportation and general trucking, and to better understand the challenges facing the timber transportation sector in the context of the challenges facing every trucking sector. This information will be useful to trucking company owners, log truck owners, researchers, and other stakeholders as they work to better understand the costs for a crucial part of the supply chain.

Materials and methods

This review compiled and compared cost information for general trucking and log trucks in the US South in nine operational cost categories. These categories were identified as fuel costs, changes, and alternatives, fuel economy, insurance, driver characteristics and availability, driver wages, truck and trailer configurations, fleet characteristics, weight limits, and safety. These categories were derived from reviewing American Transportation Research Institute (ATRI) operational cost reports (e.g. Leslie and Murray 2023) and previous timber transportation surveys (Conrad 2018, 2021a, 2022, 2023a, 2023b; Turoski et al. 2023; Knight et al. 2024).

To gather relevant cost information, a search was conducted across the Web of Science and Google Scholar. Search terms included "commercial trucking," "log hauling," "truck driver," "driver shortage," and "trucking regulation." These terms were paired with the titles of cost categories or other categories of interest, such as "log hauling fuel costs" and "log truck driver availability." This search provided a large pool of results that were refined using tools within each database, refining results to those in the English language published between 1990 and 2024. Articles that met these conditions were selected for additional screening to determine if they were focused on comparable ownership costs or profitability aspects. Additional resources were identified from the literature cited in these articles. Federal databases, such as the US Energy Information Administration (US Energy Information Administration [EIA] 2024), provided diesel fuel cost data for the country. Some data, such as the EIA fuel data, was national in scope, but sources typically provided regional or state localized information. A total of 68 articles and other resources were included in the review including peer-reviewed articles, technical reports, books, and legal documents.

Results

Relevant studies came from various journals, the most common forestry sources being the *International Journal of Forest Engineering* and *Forest Products Journal*. General freight trucking sources included the *Journal of Transportation and Health, Journal of Advanced Transportation*, and the *Journal of Transportation Management*. Information on general freight also came from reports from ATRI and the American Trucking Associations (ATA). Approximately 51% of all results were peer-reviewed journal articles, 15% of sources were technical reports, and the remainder were books, web pages, and legal documents.

Many surveys and studies have been conducted on logging businesses (e.g. Greene et al. 2001; Milauskas and Wang 2006; Bolding et al. 2010; Baker et al. 2014; Conway et al. 2017) but often avoid a focus on timber transportation. Conrad (2018, 2021a, 2022, 2023a, 2023b), Knight et al. (2024), Turoski et al. (2023), and Mason et al. (2008) conducted surveys or other studies that focused on timber transportation.

In comparison, any trucking company, including log truck owners, can provide information to groups, such as ATRI, that publish annual reports on the trucking industry. ATRI is a not-for-profit research organization whose primary mission is transportation research focusing on a safe and viable transportation system in the United States. ATRI uses a series of surveys to collect data from respondents across the US about their business, then aggregates this data into meaningful trends when compared to previous responses. There is no obligation for truck owners to complete surveys conducted by ATRI or others. While log truck owners are not prohibited from responding to ATRI surveys, data from responding log truck owners is diluted by the greater number of general trucking companies that respond.

Operational costs for both general trucking and timber transportation can be categorized to better estimate hauling costs for both industries. Comparable cost categories include fuel, driver wages, and insurance premiums. Other aspects of trucking were also compared, including truck/trailer configurations, fuel economy, road and haul characteristics, driver characteristics, fleet characteristics, weight limits, and safety.

Fuel costs, changes, and alternatives

On-highway diesel fuel prices increased by 29% from 2020 to 2021 and by 52% between 2021 and 2022 (US Energy Information Administration [EIA] 2024). The US average annual price (USD) of ultra-low sulfur No. 2 diesel fuel in 2020 was \$0.68 L^{-1}, rising to \$0.87 L^{-1} in 2021, and rapidly increasing to an average of \$1.32 L^{-1} in 2022 (Figure 1) (EIA 2024). The 2020 price was lower potentially due to reduced travel and resulting reduced fuel demand during the COVID-19 pandemic. Average annual fuel prices decreased in 2023 by 16% to an average price of \$1.11 L^{-1}.

Rapid fuel cost fluctuations affect both general trucking and timber transportation, as both use on-highway diesel fuel. Large carriers (>100 trucks) have a greater ability to take advantage of economies of scale by buying fuel in bulk and negotiating prices compared to smaller fleets (Leslie and Murray 2023). Log truck fleets are almost always small fleets based on ATRI's classification (1–20 trucks), putting them at a disadvantage compared to larger general trucking carriers on securing lower fuel prices, with smaller fleets paying an average of \$0.063 more per kilometer for fuel in 2023 (Leslie and Murray 2023). However, in 2004 a group of loggers and farmers created the Southern Loggers Cooperative to give timber transportation, as well as farming and logging equipment, businesses the opportunity to purchase fuel at a discount. The cooperative had over 5,000 members in 2023 and works to provide price discounts on fuel, diesel exhaust fluid, tires, and parts (Southern Loggers 2024).

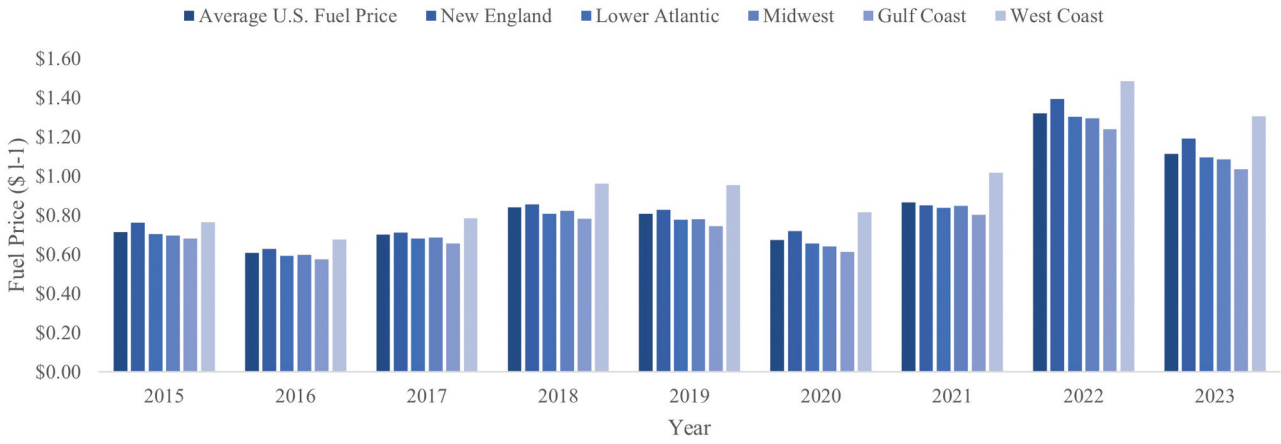

Figure 1. Annual national average and regional average prices of on-highway ultra-low sulfur No. 2 diesel fuel in the United States from 2015 to 2023.

Rising fuel costs and an increase in available powertrain options from manufacturers have increased interest in alternative options such as batteries or diesel-electric hybrids. Truck manufacturers, including Volvo and Freightliner, have started to introduce alternative technologies in some markets such as New Zealand (Lyu et al. 2023). However, in 2022 more than 91% of trucking fleets in the US did not use alternative fuels, as they are harder to implement and cost prohibitive in smaller fleets (Leslie and Murray 2023). General trucking in the US may be slowly adopting alternative fuels, as 8.2% of trucking fleets had at least one alternative fuel vehicle in 2022, up from 7% in 2021 (Leslie and Murray 2023). Battery electric and other alternative fuel vehicles have shown promise in reducing emissions compared to traditional diesel trucks but reduced payloads and high initial costs are a concern for possible adoption by both industries (Sen et al. 2016; Cunanan et al. 2021). Payload capacity is reduced on battery powered trucks due to battery weight. An equivalent battery electric truck had only 60% of the payload capacity as a diesel truck (Lyu et al. 2023). This reduction in payload capacity makes battery powered electric powertrain trucks currently unfeasible for timber transportation, as unmanufactured forest products typically have low value per unit of weight and consequently log trucks must maximize payload within legal limits to minimize hauling costs and remain profitable (Conrad 2021a). However, the repetitive routes of timber transportation present an opportunity for battery electric trucks to prosper if battery technology and vehicle charging infrastructure improve. Lengthy charging times for battery electric trucks may be limited by using regenerative braking along the elevation changes that log trucks face, where an electric vehicle is able to capture energy lost during braking and recycle it to the battery (Sessions and Lyons 2018). Regenerative braking has been shown to be able to reduce the size of the battery necessary for a battery electric truck, but areas with extended travel times on level ground would not benefit as greatly as those in steeper regions (Sessions and Lyons 2018). Regenerative braking and the provision of charging stations may become pieces of a larger logistical portfolio supporting the use of battery electric log trucks in the future.

In states such as Oregon, there are incentives to operate compressed natural gas or battery powered vehicles. Trucks in Oregon powered by these alternative fuels have an allowance of 907 kg (2,000 lbs) above the typical gross vehicle weight (GVW) limits for conventionally powered trucks (ODOT 2023). This style of regulatory allowance attempts to incentivize industry adoption of alternative fuel vehicles without directly subsidizing the manufacturer or purchaser of these trucks.

Fuel economy

Fuel economy studies specifically for timber transportation are rare due to the smaller industry size compared to general trucking. In Washington state, log truck company owners reported that their average fuel efficiency was 47.0 L 100 km^{-1} (Mason et al. 2008) similar to estimates from the US South (Conrad 2021a). However, most estimates remain imprecise because of a lack of data (Baker et al. 2014). The absence of accurate data on fuel economy makes it difficult for the sector to understand and manage transportation costs and respond to changes in fuel prices. In comparison, Finnish log trucks were slightly less fuel efficient per kilometer but were able to transport higher payloads. Sixty-eight tonne trucks ranged in efficiency from 58.6 L 100 km^{-1} to 48.3 L 100 km^{-1} while 76 tonne trucks ranged from 66.0 L 100 km^{-1} to 56.6 L 100 km^{-1} (Anttila et al. 2022). Assuming a general US weight limit of 36.3 tonnes, the Finnish trucks are moving much higher payloads, with the heaviest options over double the US limit for only marginal reductions in fuel economy per kilometer.

In general trucking, the average fuel economy among ATRI survey respondents in 2022 was 35.21 L 100 km^{-1}, a small improvement from the 2021 average of 35.37 L 100 km^{-1} (Leslie and Murray 2023). Previous surveys indicate a slight improvement in fuel economy across general trucking, with respondents reporting an average fuel economy of 36.98 L 100 km^{-1}, 35.97 L 100 km^{-1}, and 35.21 L 100 km^{-1} in 2018, 2020, and 2022, respectively. Respondents indicated that speed governors were extremely common in 2022, with 93% of respondents indicating that governors were present on their trucks to improve fuel economy (Leslie and Murray 2023). These reports illustrate that log trucks consume approximately 33% more fuel per 100 km traveled than general trucking, likely due to heavier payloads, typically older trucks, and less continuous routes

with more stops compared to general trucking (Mason et al. 2008; Conrad 2020, 2023b).

Fuel efficiency can be increased by modifying truck and trailer structure. Ogburn et al. (2008) analyzed the energy use in a "typical tractor-trailer" and found that 21% of energy inputs were lost to aerodynamic drag. Fuel economy could be improved by reducing drag, reducing weight in the engine and transmission, and choosing low profile tires. Drag could be reduced by skirting the underside of the trailer, using skirting panels to reduce the gap between the cab and trailer, utilizing a rear drag device (or trailer-tail), and using a more aerodynamic cab shape. Newer cab shapes can be effective compared to predecessors, as a newer cab design saves 3% of total fuel use compared to the previous design. Log trucks are able to use more aerodynamic cab designs, but most log trailers are incompatible with trailer extensions or covers between the cab and trailer due to the design of bolstered trailers and the dimensions of a roundwood load. Trailers specialized for products such as wood chips may be able to take advantage of skirting and trailer tails, as these trailers are enclosed and shaped very similar to a rectangular general freight trailer, making them potentially compatible with many available trailer efficiency devices such as skirting or trailer tails. However, the implementation of these systems in general trucking has been limited by their cost and lack of automation, with trailer tails requiring manual deployment and costing between $1,500 and $2,000 per truck (Sharpe et al. 2013).

Insurance

Liability insurance premiums have risen rapidly since 2012, with log truck premiums increasing from approximately $1,500 truck^{-1} year^{-1} in 2012 to $10,619 truck^{-1} year^{-1} in 2021 (Conrad 2023a). Insurance companies have suffered underwriting losses since 2011 due to rising costs of repair or replacement for damaged vehicles, medical expenses, and litigation settlements (Baker and Tyson 2017; NAIC 2023). In 2021, commercial auto liability and commercial multiple peril insurance incurred underwriting losses of 3.2% and 7.3%, respectively (NAIC 2023). Insurance companies have attempted to restructure their premiums, increasing premiums in multiple sectors in an attempt to reduce the losses and achieve profitability.

Smaller fleets have been impacted the most by insurance premium increases across the trucking industry (Leslie and Murray 2022a). According to the most recent ATRI survey, large truck fleets (>100 trucks) spent less per kilometer on insurance premiums in 2022 than in 2021, while smaller fleets paid an average of $0.006 – $0.025 more per km in 2022 compared to 2021 (Leslie and Murray 2023). Log truck fleets are almost always small, making them less likely to have the opportunity and capital resources to self-insure or take advantage of captive insurance, an arrangement in which the insurance company is owned by the insured party (Leslie and Murray 2022b; Conrad 2023a).

Insurance premiums in general trucking increased rapidly from $0.040 km^{-1} in 2012, $0.046 km^{-1} in 2015, to $0.052 km^{-1} in 2018 (Leslie and Murray 2023). ATRI survey respondents indicated stabilizing insurance costs between 2020 and 2021, with premiums averaging $0.054, $0.053, and $0.055 km^{-1} in 2020, 2021, and 2022, respectively (Leslie and Murray 2023). While remaining higher than previous levels, the last three years indicated a stabilization of insurance premiums in general trucking. When converted to the same unit as log trucks, insurance cost general trucking fleets an average of $6,863 truck^{-1} year^{-1}, $6,940 truck^{-1} year^{-1}, and $7,936 in 2021, 2022, and 2023, respectively.

Most forest products mills require log truck owners to have an insurance policy that covers a minimum of $1 million per incident and many log truck owners purchase additional coverage (Conrad 2023a). Fifty-two percent of respondents had a policy limit of $1 million per incident, 44% had $1 million plus an extra umbrella policy to help cover costs of larger claims, and 2% had less than $1 million in coverage. A quarter of logging businesses in the US South experienced a premium increase of $5,000 or more per truck from 2018 to 2021 and 19% had their insurance premiums double. Insurance premiums rose by an average of 55% from 2018 to 2021, and almost all logging businesses (92%) experienced a premium increase. Most companies involved in a crash who made insurance claims had total claims costs under $50,000, but 13% had claims costs in excess of $1 million (Conrad 2023a). These high claims explain some of the premium increases for log trucks, as a few high-cost claims impose disproportionate costs on insurers, who must recoup those payouts with premiums from policyholders.

The recent increases in insurance premiums for log trucks are likely connected to the rate and severity of crashes and the associated underwriting losses for insurance companies in the US South. From 2019–2021, log trucks owned by logging businesses in the US South were involved in 30 crashes per 100 million vehicle kilometers traveled (VKT) and contract haulers were involved in 44 crashes per 100 million VKT. This is a much higher rate of crashes than observed among 50 of the largest non-log trucking companies in the US, who were involved in approximately 21 crashes per 100 million VKT over the same period (Conrad 2023b).

Log trucks were involved in 389 total fatal crashes from 2011 to 2015, with 59 in 2011 and 79 crashes in 2015, an increase of over 33% (Cole et al. 2019). This compared to a 19% increase among general trucking fleets, with 2,219 fatal crashes in 2011 and 2,649 in 2015. Only 3.7% of fatal crashes involving a log truck occurred on interstate highways, with most occurring on state (46%) and US (34%) highways due to log trucks avoiding lower weight limits present on interstate highways. Nationally, log trucks involved in fatal crashes were 13 years old on average (Cole et al. 2019). A majority of overall large truck crashes from 2014 to 2018 where the major cause was mechanical failure (72.7%) involved contributing factors associated with tires (43.1%) and brake systems (29.6%) (Lee et al. 2021). Older trucks were also more likely to be involved in a fatal crash due to mechanical failure than newer trucks. The age of log trucks involved in fatal crashes and the challenging conditions log trucks encounter during off-road travel implies a greater need for vigilance in maintenance and repair, especially regarding brakes and tires.

Driver characteristics and availability

A driver shortage has been reported in both general trucking and timber transportation as early as 2005. Costello and Suarez (2015) reported that some early reports of a truck driver shortage of 20,000 drivers began in 2005, with some recovery after the recession of 2008, before expanding to a shortage of 38,000 drivers in 2014. This shortage would then be exacerbated by retiring drivers, with 45% of new hires only replacing retiring drivers without affecting the deficit (Costello and Suarez 2015). The shortage reached 60,800 drivers in 2018 but was expected to slow to almost 59,500 by the end of 2019 (Costello and Karickhoff 2019). In 2021, an ATA report estimated that the shortage of drivers would reach 80,000, due to a variety of factors including advanced age of current drivers, COVID-19, lifestyle issues, infrastructure, lack of truck parking, and traffic congestion (ATA 2021).

Comprehensive data around average age, wages, or total number of drivers specific to log truck drivers is difficult to obtain due to their combination in a larger truck driver category by the Bureau of Labor Statistics (Bureau of Labor Statistics 2022). Most insurers require multiple years of log truck driving experience for each driver they insure. Log truck drivers in the US South had an average of 16 years of experience driving log trucks (Conrad 2023a). Only 3% of respondents in the Conrad (2023a) survey stated that their typical driver had five or fewer years of experience driving log trucks. Experience requirements have become a barrier to entry for many prospective log truck drivers, as experience driving other commercial trucks often does not count toward the requirement. A majority of logging businesses indicated that it was extremely (82%) or somewhat (17%) difficult to hire qualified log truck drivers (Conrad 2023a), likely caused by a combination of the experience requirement and lack of competitive wages or benefits (Turoski et al. 2023; Knight et al. 2024).

This experience requirement also encourages log truck owners to incentivize aging log truck drivers to continue driving. According to a survey of logging business owners from across the US South, 18% of log truck drivers were 60 years-old or older and 57% of drivers were between 40 and 60 years old (Conrad 2023a). This finding agrees with a survey of 178 log truck drivers in Georgia conducted by Knight et al. (2024), where the average age of drivers was 48 years and ranged from 23 to 79 years.

A 2022 report from ATRI found 53% of drivers were between the ages of 41 and 60 years old (Markus and Murray 2022). General truck drivers younger than 40 years comprised 35% of the driver population and 12% of drivers were older than 60 years. Comparing these results with those of Conrad (2023a), more log truck drivers operated into their 60's and fewer log truck drivers younger than 40 years old entered the workforce. This disparity stems from factors including experience requirements for new drivers, lower hourly wages compared to general trucking, lack of benefits to attract new drivers, and older equipment in operation (Dowling 2010; Conrad 2018, 2023b; Turoski et al. 2023). More experienced log truck drivers may choose to stay in the industry to take advantage of rising wages, although they are lower than general trucking, and may be more comfortable with older equipment compared to younger drivers.

One ATRI report focused on driver detention and delays at delivery locations found that 13.3% of respondent truck drivers were female (Speltz and Murray 2019), while less than one percent of log truck drivers surveyed by Knight et al. (2024) were female. Markus and Murray (2022) observed a similar disparity in driver gender, where inspectors at one roadside facility saw approximately 10 female commercial truck drivers among the 21,000+ trucks who passed through the weigh station weekly. The inspectors saw more agricultural trucks and dump trucks driven by women, supported by the higher percentage of Class B and Class C commercial driver's licenses obtained by women compared to women with Class A licenses, required to drive the heaviest loads. These factors combined with female driver survey responses indicate that female drivers are more likely to pursue jobs that allow them to be home at night, rather than seek employment as over-the-road or long-haul truckers (Markus and Murray 2022). Advertising expected income and work/life balance may aid in the recruitment of women into the timber transportation workforce, alleviating some of the qualified driver shortage.

Health concerns commonly associated with all truck drivers include obesity, diabetes, and hypertension. The prevalence of these conditions in trucking was analyzed through a literature review by Mabry et al. (2016): obesity was found to affect 19 to 74% of truck drivers with three studies reporting a rate of overweight and obese drivers to range from 55% to 90%. Hypertension affected 5 to 48% of truck drivers and type 2 diabetes affected 1 to 22% of drivers in the reviewed studies. The wide range of percentages is a result of the differences in self-reported and measured data from within the reviewed studies. Because log truck drivers are typically older than other drivers, these health concerns may be greater for this industry.

Drivers in the US are required by law to be tested for drugs by their employer upon hire, at random intervals, upon suspicion of impairment, after receiving a citation following a crash, during a return-to-duty period and follow-up tests (US Department of Transportation 2023). Drivers are not required to be tested if they were not issued a citation after crashes resulting in bodily injury or property damage only. Drug tests are also conducted randomly throughout the year, including if there is any suspicion of driver intoxication. Drug tests can be either urine or hair based, with hair test results being harder to falsify and easier to collect. Hair tests were found to detect substances more often than urine tests, leading to some trucking companies to favor them (Mieczkowski 2010; Voss and Cangelosi 2020). New drivers were found to test positive almost three times more often than currently employed drivers (Mieczkowski 2010), implying that employed drivers understand the expectation of sobriety in their employment and this screening effectively reduced rates of impaired driving.

Driver wages

Log truck drivers in the US South are compensated by a variety of methods. Drivers can be paid an hourly rate, salary,

a percentage of gross revenue, an hourly rate plus a percentage of revenue, per load, per tonne per kilometer, per unit volume or weight transported, and others (Conrad 2021a; VanderSchaaf et al. 2023). These options can lead to drastic differences in driver compensation, depending on haul distance, average turn time, and other factors. Drivers may also be compensated using production bonuses, incentivizing productivity. Other benefits, such as health insurance or retirement packages may be provided to drivers but vary widely from company to company (VanderSchaaf et al. 2023).

Research suggests that log truck drivers, especially in the US South, receive lower wages than log truck drivers in other regions of the country and lower wages than general freight drivers in the US South. Log truck drivers in the US South earned an average hourly wage of \$21.82 hr^{-1} in 2021, compared to \$22.52 hr^{-1}, \$27.07 hr^{-1}, and \$27.56 hr^{-1} for log truck drivers in the Northeast, Lake States, and West, respectively during 2021 (Turoski et al. 2023). Wages have been rising, however, increasing from a regional average in the US South of \$15.71 hr^{-1} in 2012, to \$21.82 hr^{-1} in 2021 (Turoski et al. 2023). Surveyed log truck drivers indicated their average annual salary was \$63,674, with salaries ranging from \$33,600–\$140,000 (Knight et al. 2024). This increase in wages is likely due to competition with general trucking for qualified drivers.

General trucking has also increased wages to attract and retain qualified drivers. According to the most recent ATRI survey, driver wages have increased to a national average of \$29.20 hr^{-1} in 2022, rising 15.9% from 2021. Wages for general truck drivers in the US South were \$21.49 hr^{-1} in 2018 before increasing to \$24.66 hr^{-1} in 2021, almost \$3 hr^{-1} higher than log truck drivers in the same region in 2021 (Turoski et al. 2023). General freight drivers can expect health insurance and some paid vacation time, as these were the most common benefits offered by carriers in 2022 (Leslie and Murray 2023). This rise in general trucking driver wages was spurred by rising inflation, a competitive labor market, and increasing wages in competing industries.

Many drivers consider not only the monetary payment but work/life balance as well when choosing an employer. Often, over-the-road or other general truck drivers are away from home for days at a time without a set return time, while log truck drivers are typically home each night. Knight et al. (2024) found that the most attractive factor for log truck drivers to stay in the industry was income, directly followed by being home at night and work/life balance. Lower wages than other transportation industries played a significant role in discouraging some from becoming log truck drivers, as it was the second most cited reason behind lack of benefits for respondents to be uninterested in driving a log truck (Knight et al. 2024).

Truck and trailer configurations

Log trucks carry roundwood of varying dimensions, leading to many truck and trailer configurations. Tare, or the weight of an unloaded truck is an important consideration for log truck owners, as the goal is to move as much payload as possible in each trip to minimize hauling costs and maximize revenue. The average tare weight of the lightest log truck and trailer in Georgia and Florida in 2022 was approximately 12,428 kg (Conrad et al. 2024). However, log truck tare weight has changed very little since 2004, with a tare weight reduction of only 123 kg between 2004 and 2020 (Thompson et al. 2021). The lack of improvement was attributed to perceived effects lighter equipment may have on durability and capability. Log trucks in the US South are rarely self-loading trucks, affording a lower tare weight. Self-loading trucks commonly used in Europe have an approximate tare weight of 20 tonnes, 3.5 tonnes higher than a semitrailer truck due to the weight of the loading crane and all-wheel drive (Kogler et al. 2020). European trucks are also commonly a cabover design, where the cab of the vehicle rests above the engine, reducing the overall vehicle length.

Log trucks operating in the US South are predominantly five-axle tractor semi-trailers (Greene et al. 2007), with trailers connected to the tractor using a fifth-wheel hitch system. Other log truck variants operate in specific environments such as mountainous terrains, with different truck and trailer designs such as a non-articulating straight truck that has room for logs on the truck itself. Mountainous areas across the US South may have tandem or tri-axle straight trucks with small pup trailers to assist with switchbacks and other road conditions, while log trucks in less mountainous areas often use traditional tractor semi-trailer configurations (Bolding et al. 2010). The transported product can also change the configuration used, as wood chips are transported in enclosed chip vans. Typical semi-trailers can have four or more bolsters to help contain the logs, as well as specialized bunks to better control-specific lengths. In 2017, Conrad (2018) estimated that a new log tractor and semi-trailer cost an average of \$136,091. Used tractors were estimated to cost \$30,333, or approximately 25% of a new one depending on model and options. Average used two year old sleeper model trucks often used for general trucking cost \$96,970 at auction (J.D. Power Valuation Services 2024), a 29% decrease from March 2023. Used vehicle prices have fluctuated since the production delays caused by the COVID-19 pandemic (Leslie and Murray 2023). Some log truck owners preferred to purchase used trucks to avoid models with modern emissions control systems. This initial cost savings comes at a likely cost of higher maintenance and repair costs for used trucks (Conrad 2018). Used log trailers were estimated to cost approximately \$15,000, implying that a log truck owner could begin work with used equipment costing \$45,000, roughly one-third of the cost of a new tractor and semi-trailer (Mason et al. 2008; Conrad 2018).

General trucking uses several common truck and trailer configurations depending on the product being transported. Specialized trailers such as refrigerated or tankers are often built to transport specific commodities, such as oil, milk, or grains in tankers and perishable foods in refrigerated trailers. Trailers generally range in length from 8.5 to 16.2 m and, on roads that allow, trucks can add additional trailers to transport additional payload. It is not uncommon for two 8.7 m or 14.6 m trailers to be connected to one tractor, sometimes even three 8.7 m trailers are connected in a triple-trailer combination (Ogburn et al. 2008). The total number of

axles varies based on trailer configuration, but most general trucks have one steering axle, one or two drive axles, and two trailer axles, although the number of axles can be lowered when payloads are low and higher for oversize loads. The most common enclosed 16.1 m trailer has two axles and is typically pulled by a tractor with three axles, for a total of five axles.

Fleet characteristics

Log trucks are typically older than other commercial heavy duty trucks. Milauskas and Wang (2006) reported that the average age of log trucks in West Virginia was 8.8 years. Conrad (2023b) reported that log trucks owned by southern logging businesses were 8.7 years old on average, while contract trucks were approximately 14 years old. Log trucks in every region of the US were older than other commercial trucking fleets, as general trucking had an average vehicle age of 4.7 years in 2022 (Conrad 2023b; Leslie and Murray 2023). Log truck owners may prefer older models for familiarity with the systems, ease of repairs, reduced purchase price, or reduction in emissions system complexity. Log truck fleets in the US South averaged 7.6 trucks, with estimates ranging from 4.7 trucks in Arkansas to 10.0 trucks per fleet in South Carolina (Conrad 2023a).

Respondents to the most recent ATRI survey indicated that most for-hire fleets were larger than log truck fleets, with 49.3% of respondents having 100 or fewer trucks in their fleet, and 23.2% had fewer than 26 trucks (Leslie and Murray 2023). When reviewing the total number of carriers in the US that own at least one truck, 99.7% operate 100 or fewer, and 95.8% operate 10 or fewer, indicating an underrepresentation of small fleets in some ATRI data (ATA 2024).

Weight limits

Both log trucks and general freight trucks use public roads to connect their pickup and delivery locations; therefore, both must abide by state and federal gross vehicle weight (GVW) limits. Southern states have GVW limits on state highways and roads ranging from 38,101 kg in Texas to 41,730 kg in Louisiana, including special permits and tolerances. Some states have recently increased weight limits, such as Georgia increasing the limit in 2023 (Public Law Georgia House Bill 189 2023) to 36,287 kg with a 10% variance, allowing vehicles to legally weigh 39,916 kg without penalty. Louisiana increased the state GVW to 41,730 kg in 2020 (Public Law Louisiana Act 84 2020), North Carolina and Virginia increased GVW limits to 40,823 kg in 2012 and 2015, respectively (Public Law North Carolina Session Law 2012–78 2012; Public Law Virginia House Bill 2072 2015). In other US regions, some states allow weights of 45,359 kg or even 72,574 kg in the state of Michigan. However, this higher limit requires additional axles, compared to the common five-axle tractor-trailer combinations used in the South. This increased number of axles distributes the total weight across the extra surface area, reducing pavement damage while also providing additional braking capacity.

Internationally, GVW limits range from below 30 tonnes in Japan to more than 70 tonnes on eight or more axles in Argentina, Australia, Brazil, Finland, South Africa, Sweden, Uruguay, and Canadian provinces of Alberta, British Columbia, and Ontario (Kärhä et al. 2024). Exceptions to the limits may be present on certain sections of road and maximum limits are directly correlated with number of axles used. Temporary increases are also allowed in windstorm or beetle infestation conditions in Austria and Germany (Kogler et al. 2020; Kärhä et al. 2024). In Canada and the US state of Minnesota, it is possible to haul higher weights in winter months and many countries provide the option to purchase overweight permits to temporarily increase the limit for the permit holder (Kärhä et al. 2024).

In Finland and Sweden, weight limits were increased between 2010 and 2020. Log trucks in Finland range in capacity from 60 to 64 tonnes, 68 tonnes, and 76 tonne variants. Loggers and log truck company owners are shifting to larger truck options from older 60–64 tonne trucks for the increased payload options, reduced cost of hauling, and reduced emissions per tonne. Since the weight limit increase, approximately 64% of trucks were 76 tonne variants in 2018 (Väätäinen et al. 2020; Anttila et al. 2022).

In the US, interstate highways are crucial to general trucking, but log trucks almost entirely avoid utilizing them when loaded. Interstates are subject to federal weight limits, different from state limits, restricting GVW to 36,287 kg (US FHWA 23 CFR Ch 1 Part 658). Although log trucks are allowed to travel on interstate highways, this lower weight limit forces log trucks to travel on state and county roads to maximize legal payload and minimize hauling costs. This decision to travel on local and state roads takes log trucks through cities, school zones, and other congested areas. Avoiding interstates means that log trucks encounter more traffic, lower speed limits, and more intersections than they would face if utilizing interstate highways. Conrad (2020) found that if log trucks could travel on interstate highways at state-legal GVW, they would encounter an average of 41% fewer intersections and 33% fewer stop signals compared to current routes. Log trucks would also avoid more school zones, cities, and small towns where speed limits are reduced, traffic increases, and crashes are more likely. Use of interstates would also reduce fuel consumption, carbon dioxide emissions, and pavement damage (Conrad 2020; Blinn et al. 2024).

Safety

Log truck safety is not just a priority to the forest products industry, it is critical to maintaining a social license to operate. Drivers of log trucks, other commercial vehicles, or passenger vehicles can be severely injured or killed in a crash. Specifically for log trucks, if commercial drivers perceive them as less safe to operate than other commercial trucks, they may not consider employment as a log truck driver. Crashes also affect the perception of the entire trucking industry, log truck or otherwise. If the general public perceives any large truck as a danger to their safety, societal opinions may shift and contribute to a hostile business environment for trucking in all forms.

General trucks were involved in 38,797 crashes reported to the Federal Motor Carrier Safety Administration)FMCSA) from January 2017 to December 2018 (Markus and Murray

2022). These crashes were mostly towaway crashes (66%), while 32% of crashes involved injuries, and only 2% involved fatalities (Markus and Murray 2022). Almost 94% of general truck drivers did not report any crashes during the same timeframe, with only 6% of drivers reporting one crash, and <1% reported being involved in more than one crash. Drivers that avoid crashes are often able to take advantage of a safety bonus, providing a personal financial incentive for the driver to drive safely, leading to fewer crashes (Rodriguez et al. 2006; Faulkiner and Belzer 2019). The Insurance Institute for Highway Safety (IIHS) reported 0.87 fatal crashes involving large trucks per 100 million VKT in 2021 (IIHS 2023). In 2021, 4,714 people died in crashes involving large trucks, 68% of fatalities were passenger vehicle occupants; 16% were truck occupants, and 15% were pedestrians, bicyclists, or motorcyclists. In crashes involving one passenger vehicle and a large truck, 97% of fatalities were occupants of the passenger vehicles (IIHS 2023). Fatal crashes were more common on major roads other than interstates and freeways, with 48% occurring on other major roads, compared to 36% on interstates and freeways in 2021.

Safety technologies available to large trucks such as electronic stability control, forward collision warnings, and automatic emergency braking have potential to greatly reduce crashes or their severity. Forward collision warnings were associated with a 22% reduction in the rate of crashes, with a 44% reduction in rear-end collisions by large trucks (Teoh 2021). Use of forward collision warning systems was associated with a 12% reduction in the number of crashes overall and a 41% reduction in rear-end crashes. Automatic braking was activated in 43% of rear-end crashes, reducing speed of the large truck by over half between activation and impact (Teoh 2021). Automatic emergency braking systems are likely on the path to being mandated in all new vehicles in the US weighing over 4,536 kg, as the National Highway Safety Administration announced in 2023 a Notice of Proposed Rulemaking that would require heavy vehicles to have automatic emergency braking systems installed if this rule is adopted (NHTSA 2023). Electronic stability control has been required on all new large trucks and buses in the US since August 2019 and is designed to intervene when a truck's motion becomes unstable (IIHS 2023). This could prove beneficial, as log trucks are significantly more likely to roll over during crashes compared to general trucking, except tanker trailers (Cole et al. 2019). Other technologies including side view assist could be used in conjunction with other technologies to reduce crash risks even further. The use of these technologies could prevent or reduce the severity of over 12,000 injury crashes and 835 fatal crashes each year (Jermakian 2012; IIHS 2023).

Technology is helping to prevent or reduce the number of crashes involving large trucks. A common safety feature, antilock brakes, reduced truck crash risk by almost 65% (Teoh et al. 2017). Dash mounted cameras are seeing high rates of adoption in log trucks, as 71% of log trucks in Georgia and 64% in Florida used these cameras in 2022 (Conrad et al. 2024). Dash mounted cameras were used by a minority of fleet owners to train drivers and provide regular coaching, but log truck fleets engaging in this practice had 30% lower average insurance premiums per truck per year compared to fleets that used cameras but did not use the recordings for training (Conrad 2023a). Cameras were also used to provide a video record of events if a crash occurred to avoid citations or blame being falsely placed on the log truck. Advanced safety features are less common on log trucks compared to general trucks. For example, only 7% of log trucks were equipped with automatic emergency braking or blind spot monitoring systems, and 6% or less were equipped with lane departure warning systems, forward collision warning systems, or back-up sensors (Conrad 2023a). Fleets that used GPS tracking, dash mounted cameras, driver coaching, held regular safety meetings, and required pre-trip inspections tended to be larger than fleets that did not implement these techniques and safety technologies.

Traffic present on the roadway has an impact on the rate of log truck crashes. Conrad (2023b) found that the crash rate of log trucks in the US South was 176% higher than log trucks in the Lake States, but age and condition of the trucks did not explain the difference. Conrad (2023a) reported that only 58% of log truck crashes from 2018 to 2021 led to a liability insurance claim, implying that many of the crashes were not the fault of the log truck. One explanation for why log trucks in the US South experience higher crash rates is the higher volume of traffic encountered, as roadway conditions and traffic are often cited as a contributor to crash risk (Mason et al. 2008; Conway et al. 2017; Conrad 2021b). In the wake of the COVID-19 pandemic and ensuing economic responses, people began to move from areas with higher costs of living to states with lower costs of living. In 2021 alone, over 107,000 people moved from California to Texas, and over 91,000 people moved from New York to Florida (Ismail et al. 2023). In 2022, Florida, Texas, North Carolina, and South Carolina were among the states with the largest influx of people, with Florida alone gaining approximately 319,000 people (Picchi 2023). This influx of people to the US South is increasing the number of vehicles on state roads and interstate highways, thus increasing traffic and the likelihood of a crash involving a large truck. Mill locations have also become increasingly suburban or urbanized, as previously rural areas have experienced population growth.

Discussion

Results from this review indicate that log truck owners share many similar challenges with general trucking, but only a few aspects are faced equally by both industries. Fuel price instability, insurance premiums, driver wages, repair and maintenance, and initial equipment purchase are operational cost categories that are common for both industries. However, larger general trucking companies typically have lower operational costs per kilometer than smaller log truck fleets. Differences such as fuel economy, potential use of the interstate highway system, and truck configurations will continue to set log trucks apart from general trucking fleets.

Log truck fleets continue to face increasing insurance and fuel costs and the scale disadvantage of operating small fleets (Leslie and Murray 2023). The smaller size of log truck fleets makes them less likely to use captive insurance or purchase fuel in bulk, increasing costs for both compared to larger fleets. Some log truck owners have joined together in a co-op system

to help reduce fuel costs (Southern Loggers 2024), but this is not available in all areas of the US South.

Lower wages, lack of benefits, and insurance experience requirements continue to be a hurdle for attracting and employing new log truck drivers. Wages continue to increase for log truck drivers, but still lag behind general trucking in the US South by \$2 to 3 hr^{-1} (Turoski et al. 2023). Log truck fleets vary widely on driver offered benefits, while general truck drivers often receive health insurance and paid vacation time (Conrad 2021a; Leslie and Murray 2023). Requirements for multiple years of driver experience from insurance companies are a challenge for employing new log truck drivers and increase the value of experienced drivers. A majority of log truck owners (82%) indicated that it was extremely difficult to hire qualified log truck drivers (Conrad 2023a), likely due to a combination of low pay, experience requirements, and other factors. This difficulty to hire new log truck drivers may explain why approximately 75% of log truck drivers are older than 40 years compared to only 65% of general truck drivers (Markus and Murray 2022; Conrad 2023a).

Log trucks are almost always equipped with different trailer configurations than general trucks to accommodate for loading and unloading of various roundwood loads. While general trucking can typically use products such as trailer tails to maximize the aerodynamics of trucks and trailers, this is often not possible for log trucks due to varying dimensions of roundwood loads. Unique trailer configurations also limit the ability to perform back-hauls, which results in low percent-loaded km and high hauling costs. Log truck owners are concerned with vehicle tare weight to ensure as much payload is moved in each load as possible, however little change has occurred in the US since 2004 (Thompson et al. 2021). As roundwood is typically bound by weight and volume, log truck payloads are especially bound by GVW restrictions. Lighter and more fuel efficient vehicles along with higher GVW limits could help reduce costs per tonne for log truck owners by increasing available payload for each trip.

Safety technologies are helping reduce crash numbers and severity. Technology such as forward collision warnings, automatic emergency braking, and cameras are helping to reduce crash risk and insurance premiums. Automatic emergency braking was associated with a 41% reduction in rear-end crashes, and when activated, reduced the speed of the large truck by over half before impact, greatly reducing the severity of the crash (Teoh 2021). Antilock brakes have been standard in the US for years and stability control was mandated for all new large trucks in the US in 2019. Cameras and regular safety training meetings were associated with a 30% lower average insurance premium compared to those who only had cameras, and less than ten percent of log trucks used more complex safety devices such as automatic emergency braking or forward collision warning systems (Conrad 2023a). Crashes are likely to be more common in the US South due to increasing populations and urbanization in states such as Georgia, Florida, Texas, and North Carolina. As the population of the US South increases, drivers of both industries will face more challenges with traffic, school zones, and reduced speed limits, causing an increase in transportation costs.

Log truck fleets in other regions and countries face similar challenges to those in the US South, typically with different regulations and requirements. This comparison, while focused on the US South, benefits from a glimpse into other operational norms, especially into different weight limits, truck configurations, and fuel costs. The US South typically has lower fuel costs than other regions of the United States, but trucks are limited to lower weight limits than some northern states and several other countries. Trucks are configured differently in the US South due to traditional harvest operations eliminating the need for self-loading vehicles, reducing the tare weight and increasing the payload potential of log trucks in the region. Gentle topography in most of the region and vehicle length regulations also play a part in the typical truck configurations found in the US South.

Conclusions

This review discovered knowledge gaps and aging data related to log trucks in the US South, including no estimate of the number of log truck drivers and limited data available to reliably assess operational costs. Knowledge gaps about expected wages in both industries were also present. Current data can also be limited in scope, such as fuel economy not taking road conditions or whether a truck is loaded into account. These similarities and differences between log trucks and general trucking may have been known anecdotally to industry specialists, but rarely scientifically documented on a broader level. This review documented these similarities and differences along with current cost saving methods for each industry to employ.

Log truck owners are facing challenges in almost every cost component of owning and operating log trucks. As costs continue to rise in almost every category, researchers should work to better estimate or help reduce these costs to help improve profitability for this crucial element of the forest products supply chain. Log trucks are critical to the success of forestry in the US South and the substantial contribution of forest industry to the region's economy. The cost information presented in this review is often scattered throughout multiple different sources, creating difficulties for wood procurement managers, researchers, and truck owners to find accurate information on the total cost of owning and operating log trucks. Researchers and forest industry representatives often use transportation costs to plan for new mill locations (e.g. Khanal et al. 2024) with sometimes erroneous assumptions. The information compiled in this review can provide more accurate information in a single source. In addition, the methodology employed here can be replicated in other regions or in other applications to assess transportation systems, update previously created cost estimation tools and models, and measure changes in common cost categories, such as driver wages over time. Continued research should focus on safety, drivers, and how to better improve the efficiency of log trucks, in order to increase profitability of the industry. Further research into costs and other challenges faced by log truck owners is necessary and should be continued, especially focusing on granular data for fuel, insurance, vehicle purchase costs, and other background costs. Research should explore the adoption of safety

technologies by both log trucks and general freight to assess how insurance costs, crash rates, and driver perceptions of the technologies have changed over time.

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