Evaluating Profitability of Individual Timber Deliveries in the US South

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Abstract: Timber transportation is an essential and often unprofitable segment of the wood supply chain. This study evaluated the profitability of individual timber deliveries for log truck owners in the US South. Origin and destination data were collected from 909 deliveries from 257 harvest sites. Travel time and distance were estimated using ArcGIS and GPS tracking. Monte Carlo Simulation was used to calculate 1000 unique combinations of payload, harvest site turn-time, mill turn-time, and percent-loaded km, yielding a dataset of 909,000 deliveries. Hauling costs and revenues for each delivery were estimated using published estimates. Driver wages were estimated in two ways: an hourly wage of $30.60 (USD) and 30% of the gross revenue from the load being delivered. Logistic regression was used to evaluate the relationship between six dependent variables and profitability. Only 14% of deliveries were profitable when the driver was paid an hourly wage versus 42% when the driver was paid 30% of gross revenue. Deliveries with one-way haul distances between 49 and 113 km (31–70 mi) were least likely to be profitable. Many deliveries could be profitable if logging businesses and mills reduced turn-times to under 20 min at mills and 30 min at harvest sites.

Keywords: log trucks; timber transportation; turn-time; efficiency; logging; timber harvesting

1. Introduction

Forestry and the forest products industry are responsible for approximately 2% of gross regional product and over one million jobs in the US South [1]. The region’s wood supply chain consists of landowners, foresters, logging businesses, and mills. Most forestland is owned by individuals and families [2]. Real estate investment trusts (REITs) such as Weyerhaeuser and Rayonier own millions of hectares of forestland and timber investment management organizations (TIMOs) manage millions of hectares of forestland on behalf of individual and institutional investors, such as pension funds [3]. Public ownership generally accounts for less than 20% of forestland area and a lower percentage of harvest volume.

The movement of timber from forests to mills in the US South involves multiple independent businesses, each with the opportunity for profit or loss. A typical timber sale begins with a decision by a forest landowner to sell timber. The landowner may hire a consulting forester to market the timber to potential buyers [4]. The timber may be purchased by an independent timber buyer (most common), often referred to as a “wood dealer” or “supplier” [5]; a logging business; or purchased directly by a mill (least common) [6]. Mills pay the timber buyer a “delivered price” for timber that is harvested and delivered to a mill. The timber buyer generally negotiates the delivered price so that it covers the stumpage price paid to the landowner, the cost of harvesting the timber, the cost of transporting timber to the mill, and profit to the timber buyer. Transactions between landowners, timber buyers, logging businesses, and mills are heterogeneous and so other arrangements are possible.

Timber is transported to mills by log trucks owned by logging businesses or contract haulers. Contract haulers are often independent owner-operators, but some contract haulers own multiple trucks. Most logging businesses rely on contract haulers for a portion
of their timber transportation [6]. The contract hauler is typically compensated by either the wood dealer or the logging business.

Timber transportation is one of the greatest challenges facing logging businesses and forest industry in the eastern US. Nearly all timber is transported from harvest sites to mills by truck, and trucking can account for up to 25% of the delivered cost of timber [7,8]. Logging business owners are struggling to attract and retain drivers, liability insurance premiums have been increasing, and log truck crashes are an ongoing concern [6,9–13].

Previous research has identified opportunities to improve timber transportation efficiency. For example, in-woods scales reduce payload variability and hauling costs [14–16]. Long turn-times at harvest sites and mills cost the wood supply chain millions of dollars per year [17–20]. Increasing legal payload by reducing tare weight and/or increasing state gross vehicle weight limits reduces hauling costs [21–24]. Sharing truck resources and centrally dispatching log trucks can reduce unloaded kilometers and hauling costs [25–27].

Few studies have evaluated the profitability of timber transportation, especially of individual timber deliveries. Conrad [11] found that timber transportation was often unprofitable over the course of a year. Grebner et al. [28] evaluated individual haul routes from one county in Mississippi to eight markets. Their study found that the cost of delivering timber using new trucks exceeded market haul rates. The same study found that reducing gross vehicle weight limits increased hauling costs substantially.

Logging businesses and contract haulers may persist for some time even when suffering losses on timber transportation. In some cases, timber transportation may serve as a “loss leader” for an otherwise profitable logging or timber purchasing business [11]. In other cases, companies may operate unprofitable businesses when cash flow is positive, even though the company is losing money because of unrecovered depreciation [29–31]. These businesses are said to be “running on equity”. Running on equity is not sustainable; nonetheless, these businesses may operate for months or years before insolvency, hoping for a turnaround.

Driver compensation is typically the largest cost component associated with owning and operating both log trucks and other types of heavy trucks [11,32]. Log truck drivers are compensated in a variety of ways [11]. Some drivers receive an hourly wage, some are paid a percentage of the gross revenue generated by the truck (e.g., 30%), while others receive a base hourly wage plus some percentage of gross revenue. Bonuses (e.g., performance, starting, retention) are an important source of compensation in some cases [32].

Log truck owners, either logging businesses or contract haulers, are typically compensated with a haul rate that is calculated per tonne per loaded km. Log truck owners are not compensated for unloaded km. Log truck owners receive compensation for a minimum haul calculated using the minimum haul rate (USD t\(^{-1}\) loaded km\(^{-1}\)) multiplied by the minimum haul distance, usually 64 km (40 mi) (Equation (1)) [8]. If the actual one-way haul distance exceeds the minimum haul distance, the log truck owner is compensated for the distance in excess of the minimum haul distance, termed the incremental haul distance, at the incremental haul rate. The incremental haul rate may be the same, greater than, or less than the minimum haul rate. Under this compensation system, all deliveries up to the minimum haul distance receive the same compensation. This system was designed to compensate log truck owners for the disproportionate amount of time spent loading and unloading on short hauls. Some log truck owners have privately suggested that short and long hauls can be profitable, but intermediate hauls (e.g., 64–97 km [40–60 mi]) are often unprofitable under this system.

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\text{Log Truck Revenue Per Delivery (USD)} = \text{Minimum Haul Distance (km)} \times \left( \text{Minimum Haul Rate (USD t}^{-1}\text{loaded km}^{-1}) + \text{Incremental Haul Distance (km)} \times \text{Incremental Haul Rate (USD t}^{-1}\text{km}^{-1}) \right)
\]

The goal of this study was to analyze the profitability of individual timber deliveries in the US South. For the purposes of this study, a timber delivery was defined as profitable.
when revenue from that delivery exceeded all costs associated with that delivery. Profitability is evaluated for the log truck owner paid market haul rates for timber deliveries. The specific objectives of the study were to (1) evaluate the impact of previously identified variables (e.g., payload, turn-times, percent-loaded km, etc.) on the profitability of individual timber deliveries, (2) compare hauling profitability when log truck drivers are paid an hourly rate similar to the average compensation of truck drivers in other industries to compensation based on the revenue generated by the log truck, and (3) assess whether the industry standard compensation model disadvantages specific timber deliveries.

2. Materials and Methods

Data was collected from actual timber deliveries from harvest sites to mills in the US South during 2019 and the first quarter of 2020. A total of 909 unique haul routes from 257 harvest sites were analyzed. Travel times and distances for each delivery were calculated using a combination of onboard GPS tracking software and ArcGIS Online [33]. ArcGIS Online’s settings were configured to minimize trucking time. However, interstate highway access was not allowed because state-legal loaded log trucks are not compliant with current federal weight limits on interstate highways [34].

Additional variables affecting the time and costs of timber deliveries were estimated using Monte Carlo simulation based on values from previous studies. Monte Carlo Simulation has been used in a number of applications in forestry research such as lumber recovery [35], lumber drying [36], evaluating the profitability of selection harvests [37], estimating the financial returns of southern pine (Pinus spp.) plantations [38], valuing timber harvest contracts [39], and estimating the probability of logging business profitability [40]. In this study, Monte Carlo simulation was used to calculate turn-times at harvest sites, turn-times at mills, percent-loaded km, and payload. For each of the 909 timber deliveries with travel times and travel distances, 1000 simulations of the other variable were generated, yielding a dataset of 909,000 timber deliveries.

Mill turn-times were based on the distribution of turn-times from Deckard et al. [20]. While that study was conducted nearly 20 years ago, discussions with foresters and loggers suggest that the turn-times reported by Deckard et al. [20] were representative at the time of this study. A random number generator in Microsoft Excel was used to create a distribution of turn-times in which 50% of turn-times were between 8 and 20 min, 40% of turn-times were between 20.1 and 47 min, 5% of turn-times were between 47.1 and 68 min, and 5% of turn-times were between 68.1 and 122 min. While turn-times shorter than 8 min and longer than 122 min are possible, they are sufficiently rare that their exclusion should not have a meaningful impact on the results.

Turn-times at harvest sites were estimated using values from Dowling [17] and US Endowment for Forestry and Communities [27]. Microsoft Excel was used to generate turn-times at harvest sites using the inverse of the normal cumulative distribution with a mean of 53 min, standard deviation of 66.6 min, and a minimum of 10 min.

Percent-loaded km were calculated based on values from the US Endowment for Forestry and Communities [27]. Microsoft Excel was used to generate percent-loaded km using the inverse of the normal cumulative distribution with a mean of 53 min, standard deviation of 66.6 min, and a minimum of 10 min.

Payload was estimated based on values from Hamsley et al. [15] and Reddish et al. [16]. Microsoft Excel was used to generate payloads using the inverse of the normal cumulative distribution with a mean of 25.4 tonnes (28 US tons) and a standard deviation of 1.5 tonnes (1.7 US tons). The payload distribution was based on a maximum legal gross vehicle weight of 38.1 tonnes (84,000 lbs) in Georgia and South Carolina, average tare weight of approximately 12.7 tonnes (28,000 lbs) [23] along with payload variability estimates from published studies [15,16].

Hauling costs were calculated using the following hourly costs for owning and operating log trucks. Driver wages were calculated in two ways. The first was to assume the driver was paid $30.60 per hour, including wages and benefits [32]. The second approach was to pay the driver 30% of the gross revenue generated by the truck. The combined
cost of truck/trailer lease or purchase payments, repair and maintenance, truck insurance, and tires were assumed to cost $21.99 per hour [32]. Total time devoted to each haul was calculated as the sum of turn-time at the harvest site, turn-time at the mill, and total travel time. Total travel time was calculated using values from GPS tracking and ArcGIS Online combined with percent-loaded km from simulation.

Fuel costs were estimated assuming on-highway diesel cost $0.77 l−1 ($2.92 gal−1) [41]. Fuel consumption was calculated assuming fuel economy of 2.1 km l−1 (5.0 miles per gallon) [32,34,42] and travel distance from GPS tracking and ArcGIS Online combined with percent-loaded km from simulation. Using percent-loaded km from simulation assured that empty km during trips home and from home to harvest sites were accounted for.

Haul revenue was estimated assuming a minimum haul distance of 64 km (40 miles), a minimum haul rate of $0.09 per tonne per loaded km ($0.13 ton−1 mi−1), and an incremental haul rate of $0.10 per tonne per loaded km ($0.15 ton−1 mi−1) [8] (Equation (1)). The profit from each haul was calculated as the difference between estimated revenue and cost.

Logistic regression was used to measure the relationship between the following variables and the profitability of individual timber deliveries: tract turn-time, mill turn-time, percent-loaded km, payload, average travel speed, and haul distance. The dependent variable, profitability, was treated as a binary variable (1 = profitable, 0 = not profitable). All of the independent variables with the exception of haul distance were continuous variables. One-way haul distance was treated as a dummy variable with the following categories: 1–16 km (1–10 mi), 17–32 km (11–20 mi), 33–48 km (21–30 mi), 49–64 km (31–40 mi), 65–80 km (41–50 mi), 81–97 km (51–60 mi), 98–113 km (61–70 mi), 114–129 km (71–80 mi), 130–145 km (81–90 mi), 146–161 km (91–100 mi), and >161 km (>100 mi). If a one-way haul distance fell into a given category, it was coded as 1, otherwise it was coded as 0. Data analysis was conducted using JMP 14.3.0 at α = 0.05 [43].

3. Results

The majority of the simulated deliveries were unprofitable. Eighty-six percent of the simulated timber deliveries were unprofitable when the driver was paid hourly (Figure 1). The average estimated loss was $62.65 (Table 1). Net revenue ranged from a $394.40 loss to a $187.33 profit.

![Figure 1. Percent of deliveries by profit and loss categories.](image-url)
Table 1. Summary statistics for timber deliveries analyzed in the study ($n = 909,000$).

| Variable                                | Mean      | Standard Deviation |
|-----------------------------------------|-----------|--------------------|
| Haul distance (one-way, km [mi])        | 79.6 (49.5) | 40.0 (24.9)        |
| Average travel speed (km h$^{-1}$ [mi h$^{-1}$]) | 74.8 (46.5) | 7.8 (4.9)          |
| Average one-way travel time (min)       | 63.4      | 30.6               |
| Percent-loaded km                       | 44.3%     | 1.1%               |
| Percent of total time traveling loaded  | 27.0%     | 8.2%               |
| Payload (t [US tons])                   | 25.4 (28.0) | 1.5 (1.7)          |
| Mill turn time (min)                    | 28.3      | 20.7               |
| Harvest site turn time (min)            | 63.4      | 52.3               |
| Profit per delivery when driver paid hourly | $-62.65$ | $61.90$            |
| Profit per delivery when driver paid 30% of gross revenue | $-5.37$ | $30.60$            |

When the driver was paid 30% of the gross revenue generated by the truck, 58% of deliveries were unprofitable (Figure 1). The average estimated loss was $5.37 and net revenue ranged from a loss of $149.97 to a profit of $166.90 (Table 1). Drivers compensated 30% of gross truck revenue received the equivalent of $17.17 per hour on average (median = $16.35 h$^{-1}$).

Profitability varied considerably by haul distance (Figure 2). At haul distances under approximately 48 km (30 mi), a large percentage of timber deliveries were profitable. Likewise, long hauls ($\geq$ 130 km, 70 mi) were often profitable, especially if the driver was paid a percentage of the truck’s revenue. In contrast, hauls between 49 and 113 km (31–70 mi) were profitable in a minority of cases. Unfortunately, 59% of timber deliveries were transported between 49 and 113 km (31–70 mi) (Figure 3).
The percentage of profitable deliveries declined linearly with mill turn-time (Figure 4). When the driver was paid 30% of gross revenue, 52% of timber deliveries were profitable when mill turn-time was under 10 min. In contrast, fewer than 25% of timber deliveries were profitable when mill turn-time was one hour or longer. The same trend was observed with turn-times at harvest sites (Figure 5). More than half of timber deliveries were profitable when harvest site turn-time was under 40 min and the driver was paid 30% of gross revenue. When harvest site turn-time exceeded one hour, fewer than 35% of timber deliveries were profitable. Log trucks spent an average of just 27% of their time traveling loaded (Table 1).

![Figure 3. Percentage of deliveries in the sample by haul distance.](image)

![Figure 4. Percentage of profitable timber deliveries by mill turn-time.](image)
Higher log truck payload led to a greater percentage of profitable timber deliveries (Figure 6). When the driver was paid 30% of gross revenue, fewer than 40% of timber deliveries were profitable at payloads less than 25.4 t (28.0 tons). Increasing percent-loaded km improved the likelihood that timber deliveries would be profitable, especially when drivers were paid 30% of gross revenue (Figure 7).

Figure 5. Percentage of profitable timber deliveries by harvest site turn-time.

Higher log truck payload led to a greater percentage of profitable timber deliveries (Figure 6). When the driver was paid 30% of gross revenue, fewer than 40% of timber deliveries were profitable at payloads less than 25.4 t (28.0 tons). Increasing percent-loaded km improved the likelihood that timber deliveries would be profitable, especially when drivers were paid 30% of gross revenue (Figure 7).

Figure 6. Percentage of profitable timber deliveries by payload.
At average travel speeds below 56 km h\(^{-1}\) (kph) (35 miles per hour (mph)), the majority of timber deliveries were profitable when the driver was paid 30% of gross revenue (Figure 8). Likewise, when average travel speed was 88 kph (55 mph) or greater, most deliveries were profitable. The majority of deliveries with travel speeds between 56 and 88 kph (35–55 mph) were unprofitable.

All variables in the logistic regression models were statistically significant \((p < 0.0001)\). The overall model predicting timber delivery profitability when the log truck driver was paid per hour fit the data well \((\chi^2 = 599,280.5, p < 0.0001)\) (Table 2). This model accounted for 81.6% of the uncertainty in the data \((\text{RSquare } [U] = 0.816)\). Likewise, the overall model predicting timber delivery profitability when the driver was paid 30% of gross revenue fit
the data well ($\chi^2 = 976,918.8, p < 0.0001$) (Table 3). This model accounted for 79.0% of the uncertainty in the data (RSquare [U] = 0.790).

Table 2. Results of logistic regression analysis of the probability of an individual timber delivery being profitable when the driver was paid hourly (Model Fit: $\chi^2 = 599,280.5, p < 0.0001$, RSquare (U) = 0.816).

| Variable                  | Estimate (Std Error) | p-Value |
|---------------------------|----------------------|---------|
| Intercept                 | −79.972 (0.434)      | <0.0001 |
| Haul distance             |                      |         |
| 1–16 km (1–10 mi)         | 23.882 (0.107)       | <0.0001 |
| 17–32 km (11–20 mi)       | 17.880 (0.082)       | <0.0001 |
| 33–48 km (21–30 mi)       | 10.276 (0.059)       | <0.0001 |
| 49–64 km (31–40 mi)       | 3.554 (0.052)        | <0.0001 |
| 81–97 km (51–60 mi)       | 1.927 (0.053)        | <0.0001 |
| 98–113 km (61–70 mi)      | 2.913 (0.052)        | <0.0001 |
| 114–129 km (71–80 mi)     | 4.167 (0.054)        | <0.0001 |
| 130–145 km (81–90 mi)     | 4.925 (0.055)        | <0.0001 |
| 146–161 km (91–100 mi)    | 5.636 (0.063)        | <0.0001 |
| >161 km (>100 mi)         | 7.915 (0.058)        | <0.0001 |
| Mill turn-time (min)      | −0.150 (0.001)       | <0.0001 |
| Harvest site turn-time (min) | −0.156 (0.001)   | <0.0001 |
| Percent-loaded km         | 64.548 (0.664)       | <0.0001 |
| Payload (t)               | 1.359 (0.007)        | <0.0001 |
| Average travel speed (km h$^{-1}$) | 0.193 (0.001)   | <0.0001 |

1 Reference haul distance was 65–80 km (41–50 mi).

Table 3. Results of logistic regression analysis of the probability of an individual timber delivery being profitable when the driver was paid 30% of the gross revenue generated by the truck (Model Fit: $\chi^2 = 976,918.8, p < 0.0001$, RSquare (U) = 0.790).

| Variable                  | Estimate (Std Error) | p-Value |
|---------------------------|----------------------|---------|
| Intercept                 | −101.274 (0.359)     | <0.0001 |
| Haul distance             |                      |         |
| 1–16 km (1–10 mi)         | 26.200 (0.106)       | <0.0001 |
| 17–32 km (11–20 mi)       | 19.430 (0.061)       | <0.0001 |
| 33–48 km (21–30 mi)       | 10.510 (0.035)       | <0.0001 |
| 49–64 km (31–40 mi)       | 3.084 (0.020)        | <0.0001 |
| 81–97 km (51–60 mi)       | 2.256 (0.020)        | <0.0001 |
| 98–113 km (61–70 mi)      | 4.157 (0.021)        | <0.0001 |
| 114–129 km (71–80 mi)     | 5.834 (0.027)        | <0.0001 |
| 130–145 km (81–90 mi)     | 7.628 (0.032)        | <0.0001 |
| 146–161 km (91–100 mi)    | 8.587 (0.042)        | <0.0001 |
| >161 km (>100 mi)         | 12.318 (0.047)       | <0.0001 |
| Mill turn-time (min)      | −0.116 (0.000)       | <0.0001 |
| Harvest site turn-time (min) | −0.114 (0.000)   | <0.0001 |
| Percent-loaded km         | 64.548 (0.664)       | <0.0001 |
| Payload (t)               | 1.359 (0.007)        | <0.0001 |
| Average travel speed (km h$^{-1}$) | 0.217 (0.001)   | <0.0001 |

1 Reference haul distance was 65–80 km (41–50 mi).

Log truck owners and forest industry mills control many of the variables that affect the profitability of timber deliveries. This is especially true of harvest site and mill turn-times and payload. The logistic regression models were used to estimate the probability of timber deliveries being profitable at various haul distances if mill turn time was 17 min, the median turn-time at benchmark mills in a study by Deckard et al. [20]; harvest site turn-time was 30 min, which should be achievable based on the findings of Dowling [17]; log trucks achieved 44.3% loaded km [27]; payload was 25.4 t (28.0 tons), the maximum legal payload for a typical log truck in Georgia and South Carolina; and average travel
speed was 74.8 kph (46.5 mph), the average from the sample. When log truck drivers were paid per hour, there was a high probability of a timber delivery being profitable at haul distances of 48 km (30 mi) or less (Figure 9). When the driver was paid 30% of gross revenue, timber deliveries with haul distances of 48 km (30 mi) or less or more than 113 km (70 mi) had greater than a 70% predicted probability of being profitable.

Figure 9. Predicted probability of a timber delivery being profitable at various haul distances using the logistic regression models assuming 17 min mill turn-time, 30 min harvest site turn-time, 44.3% loaded km, 25.4 t (28.0 tons) payload, and average travel speed of 74.8 km h⁻¹ (46.5 mi h⁻¹).

4. Discussion

This study supports the findings of previous studies demonstrating the difficulties of making a profit transporting timber in the US South [9–11,28]. This begs the question of how log truck owners continue to operate. First, logging business owners may offset losses from timber transportation with profits from harvesting timber [11]. Second, log truck owners may reduce transportation costs by operating very old equipment. Indeed, studies have found that the average log truck involved in a crash is five or more years older than other heavy trucks [12,44]. Third, some companies continue operating when they are losing money as long as their cash flows are positive [29–31]. These companies are said to be “running on equity”. Fourth, many companies, especially owner-operator contract haulers, have left the industry in recent years [11,45].

It was especially difficult for timber deliveries to be profitable when log truck drivers were paid $30.60 per hour, including benefits, the average compensation for truck drivers according to the American Transportation Research Institute’s trucking cost study [32]. At current haul rates [8], timber transportation cannot support the wages paid in other trucking industries. Paying 30% of gross revenue reduced equivalent hourly compensation by 44% compared to the hourly rate from Murray and Glidewell [32]. A major benefit to the log truck owner of paying the driver a percentage of gross revenue is that the cost of long turn-times at harvest sites and mills is shared by the driver.

Log truck drivers can return home every night, unlike long haul truck drivers. Log truck owners should recruit drivers based on quality of life rather than on compensation alone. However, outside of the logging industry, the percentage of local driving jobs has been increasing and the percentage of jobs in long haul operations has been declining, due in part to changes in freight movement associated with e-commerce [46]. This could increase competition for log truck drivers and put pressure on log truck driver wages, which were already rising [47].
One of the reasons that it is difficult for log truck owners to pay competitive wages is that fewer than half of all log truck km generate revenue [11,27]. Increasing percent-loaded km, even by small amounts, can increase the profitability of timber transportation (Figure 7). In other trucking industries, it is common for fleets to achieve better than 80% loaded km [32]. Log trucks will never achieve 80% loaded km because of the need for unloaded log trailers to arrive at harvest sites and loaded ones to be delivered to mills. Log trailers are generally designed for a single product, which limits their ability to pick up backhauls. Nonetheless, previous research demonstrates that by sharing truck resources between multiple logging crews and centrally dispatching log trucks, log truck fleets can increase percent-loaded km to above 50% and haul more timber with the same number of trucks [25,26,48]. Only 25%–30% of log trucks’ time is spent traveling loaded (Table 1) [13,49]. Clearly, there are opportunities to increase the percentage of time and km that generate revenue.

The current timber transportation compensation model makes a large percentage of timber deliveries between 49 and 97 km (31–60 mi) unprofitable (Figures 2 and 3). Log truck owners face legal and practical constraints on the timing of timber deliveries that, combined with the current compensation model, make some haul distances unprofitable. The US limits drivers to eleven hours of driving during a fourteen-hour period [50]. In addition, while many large pulp mills accept timber deliveries 24 h per day, most other mills accept timber deliveries only during normal business hours (e.g., 7:00 am–5:00 pm). These time constraints mean that, in most cases, log trucks can deliver at least four loads per day at haul distances under 48 km (30 mi), between approximately 48 km (30 mi) and 97 km (60 mi) log trucks can deliver three loads per day, and beyond 97 km (60 mi) only two loads may be delivered. Consequently, because log truck owners are compensated for tonnes and kilometers, at haul distances under approximately 48 km (30 mi), log trucks can be profitable because they deliver a large number of tonnes per day (Figure 2). At haul distances over 97 km (60 mi), log trucks can be profitable because they generate a large number of loaded km per day. In many cases, at haul distances between 48 km (30 mi) and 97 km (60 mi), log trucks generate neither enough tonnes nor kilometers per day to make a profit.

Actions that increase log truck payload will increase the profitability of timber transportation (Figure 6). Log truck owners have invested in lighter weight tractors and trailers and have increased legal payload availability by 907–1361 kg (2000–3000 lbs) since the 1990s and 2000s [11,14,15,22,23]. Using in-woods scales can increase payload consistency and avoid costly underloads [14–16]. Unfortunately, a minority of logging businesses have adopted in-woods scales [6]. While purchasing light-weight tractors and trailers and using in-woods scales make meaningful differences in hauling costs, major increases in legal payload will require changes to state gross vehicle weight (GVW) limits [21]. GVW limits in the US South range from 38,102–41,731 kg (84,000–92,000 lbs) while states in other regions have limits near 45,359 kg (100,000 lbs) and Canadian provinces allow approximately 63,500 kg (~140,000 lbs) [34,51].

In the short term, it appears that the best opportunity to improve the profitability of timber transportation is to drive down turn-times at harvest sites and mills. The percentage of profitable deliveries declined linearly with increasing turn-times at both harvest sites and mills (Figures 4 and 5). Previous research indicates that mills can reduce turn-times to under 20 min [20] and turn-times at harvest sites could be cut to 30 min or less [17–19]. With these turn-times and typical values for travel speed, percent-loaded km, and legal payload, the logistic regression model predicted that deliveries under 64 km (40 mi) and over 97 km (60 mi) had a high probability of being profitable (Figure 9). Previous research found that slow turn-times at mills cost the southern wood supply chain between $44 and $87 million annually [20] and slow turn-times at harvest sites probably cost at least as much.

There are a number of tactics that can be employed to reduce turn-times. Some mills may need to add one or more scales at their wood yard. Others may need to increase
unloading capacity [20]. Scheduling timber deliveries to mills and staggering log truck arrivals at harvest sites can also reduce turn-times and improve efficiency [48,52–54]. Using set-out trailers where feasible would reduce turn-times at harvest sites [17,19]. Using set-out trailers requires capital investment by loggers and they must have enough space at harvest sites to store the additional trailers. However, using set-out trailers allows log truck drivers to drop off an empty trailer and immediately pick up a loaded trailer rather than waiting at the harvest site to be loaded. Tactical planning at harvest sites can also affect turn-times. Using an appropriate number of landings and maintaining reasonable skidding distances will enable the harvesting crew to keep enough timber volume on the landing to ensure quick loading.

5. Conclusions

This study demonstrated how difficult it is to deliver timber profitably under market haul rates, existing forest industry and logging industry practices, and current state gross vehicle weight limits. Some logging businesses expect timber transportation to be unprofitable and some even consider it a “loss leader” [11]. The situation is not hopeless, however. There are solutions that can improve the profitability of timber transportation over the short and long terms.

In the short term, logging businesses and forest industry mills should focus on reducing turn-times at harvest sites and mills. Many timber deliveries can be profitable when turn-times are 20 min or less at mills and 30 min or less at harvest sites (Figure 9), which is feasible based on previous research [17–20]. Reducing turn-times is within the control of logging businesses and forest industry mills. Other short term actions such as increasing the use of in-woods scales to reduce payload variability [14–16], using central truck dispatching and sharing log trucks between crews to increase percent-loaded km [25–27], and adjusting haul rates on 64–97 km (40–60 mi) hauls would also be helpful. These actions should be prioritized because they do not require legislation or action by those outside the supply chain.

In the long term, increasing gross vehicle weights in southern states and permitting state-legal log trucks to operate on interstate highways would reduce transportation costs [21,34]. Increasing weight limits requires state and/or federal legislation. In addition, meaningful increases in gross vehicle weight would require logging businesses to invest in new log truck configurations. Logging businesses and forest industry should not forego short term solutions within their control in hopes that state or federal legislation will solve timber transportation problems.

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References

1. Brandeis, C.; Hodges, D.G. Forest sector and primary forest products industry contributions to the economies of the southern states: 2011 update. J. For. 2015, 113, 205–209. [CrossRef]

2. Butler, B.J.; Hewes, J.H.; Dickinson, B.J.; Andrejczyk, K.; Butler, S.M.; Markowski-Lindsay, M. Family forest ownerships of the United States, 2013: Findings from the USDA Forest Service’s national woodland owner survey. J. For. 2016, 114, 638–647. [CrossRef]
3. Zhang, D.; Butler, B.J.; Nagubadi, R.V. Institutional timberland ownership in the US South: Magnitude, location, dynamics, and management. *J. For.* 2012, 110, 355–361. [CrossRef]

4. Grove, P.M.; Conrad, J.L., IV; Harris, T.G., Jr.; Dahlen, J. Consulting forester timber sale practices in the US South. *For. Sci.* 2020, 66, 221–229. [CrossRef]

5. Flick, W.A. The wood dealer system in Mississippi: An essay on regional economics and culture. *J. For. Hist.* 1985, 29, 131–138. [CrossRef]

6. Conrad, J.L., IV; Greene, W.D.; Hiesl, P. The evolution of logging businesses in Georgia 1987–2017 and South Carolina 2012–2017. *For. Sci.* 2018, 64, 671–681. [CrossRef]

7. TimberMart-South. *Delivered Timber Summary 1st Quarter 2020; Norris Foundation, University of Georgia: Athens, GA, USA, 2020; Volume 45.*

8. TimberMart-South. *Logging Rates Report 1st Quarter 2020; Norris Foundation, University of Georgia: Athens, GA, USA, 2020.*

9. Koirala, A.; Kizha, A.R.; De Urioste-Stone, S.M. Policy recommendations from stakeholders to improve forest products transportation: A qualitative study. *Forests* 2017, 8, 434. [CrossRef]

10. Koirala, A.; Kizha, A.R.; Roth, B.E. Perceiving major problems in forest products transportation by trucks and trailers: A cross-sectional survey. *Eur. J. For. Eng.* 2017, 3, 23–34.

11. Conrad, J.L., IV. Costs and challenges of log truck transportation in Georgia, USA. *Forests* 2018, 9, 650. [CrossRef]

12. Cole, N.B.; Barrett, S.M.; Bolding, M.C.; Aust, W.M. An analysis of fatal log truck crashes in the United States from 2011 through 2015. *Int. J. For. Eng.* 2019, 30, 121–131. [CrossRef]

13. Conrad, J.L., IV. *Forest Logistics Summit Identifies Opportunities to Address Log Trucking Challenges; Forest Resources Association: Rockville, MD, USA, 2019.*

14. Gallagher, T.; McDonald, T.; Smidt, M.; Tufts, R. *Let’s Talk Trucking: Weights and Loading Methods; Forest Resources Association: Rockville, MD, USA, 2005.*

15. Hamsley, A.K.; Greene, W.D.; Siry, J.P.; Mendell, B.C. Improving timber trucking performance by reducing variability of log truck weights. *S. J. Appl. For.* 2007, 31, 12–16. [CrossRef]

16. Reddish, R.P.; Baker, S.A.; Greene, W.D. Improving log trucking efficiency by using in-woods scales. *S. J. Appl. For.* 2011, 35, 178–183. [CrossRef]

17. Dowling, T.N. An Analysis of Log Truck Turn Times at Harvest Sites and Mill Facilities. Master’s Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA, 2010.

18. Baker, S.; Lowe, R., III; Greene, D. Follow that Tractor: What Truck-Mounted GPS Tells Us About Log Truck Performance. In Proceedings of the 39th Council on Forest Engineering Annual Meeting, Vancouver, BC, Canada, 22–24 September 2016.

19. Daniel, M.; Gallagher, T.; McDonald, T.; Mitchell, D. Utilization of Phone Application Technology to Record Log Truck Movement facing timber operations. *J. For. Hist.* 2018, 110, 131–138. [CrossRef]

20. Deckard, D.L.; Newbold, R.A.; Vidrine, C.G. Benchmark roundwood delivery cycle-times and potential efficiency gains in the southern United States. *For. Prod. J.* 2003, 53, 61–69.

21. Siry, J.P.; Greene, W.D.; Harris, T.G., Jr.; Izlar, R.L.; Hamsley, A.K.; Eason, K.; Tye, T.; Baldwin, S.S.; Hyldahl, C. Wood supply chain efficiency and fiber cost: What can we do better? *For. Prod. J.* 2006, 56, 4–10.

22. Greene, W.D.; Marchman, S.C.; Baker, S.A. Changes in Logging Firm Demographics and Logging Capacity in the US. South. In Proceedings of the 36th Council on Forest Engineering Annual Meeting, Missouri, MT, USA, 7–10 July 2013.

23. Conrad, J.L., IV. *Production Up, Transportation Challenging: Georgia Logger Survey Results 2017; Forest Resources Association: Rockville, MD, USA, 2018.*

24. Väätäinen, K.; Laitila, J.; Anttila, P.; Pälkeläinen, A.; Asikainen, A. The influence of gross vehicle weight (GVW) and transport distance on timber trucking performance indicators–Discrete event simulation case study in Central Finland. *Int. J. For. Eng.* 2020, 31, 156–170. [CrossRef]

25. McDonald, T.; Taylor, S.; Valenzuela, J. Potential of Shared Log Transport Services. In Proceedings of the 24th Council on Forest Engineering Annual Meeting, Snowshoe, WV, USA, 15–18 July 2001.

26. Mendell, B.C.; Haber, J.A.; Sydor, T. Evaluating the potential for shared log truck resources in middle Georgia. *S. J. Appl. For.* 2006, 30, 86–91. [CrossRef]

27. US Endowment for Forestry and Communities. 2019. *The Timber Logistics Improvement Project.* Available online: https://www.usendowment.org/wp-content/uploads/2019/05/the-timber-logistics-improvement-project-.pdf (accessed on 3 December 2020).

28. Grebner, D.L.; Grace, L.A.; Stuart, W.; Gilliland, D.P. A practical framework for evaluating hauling costs. *Int. J. For. Eng.* 2005, 16, 115–128. [CrossRef]

29. Germain, R.; Bick, S.; Kelly, M.; Benjamin, J.; Farrand, W. Case study of three high-performing contract loggers with distinct harvest systems: Are they thriving, striving, or just surviving? *For. Prod. J.* 2016, 66, 97–105. [CrossRef]

30. Regula, J.; Germain, R.; Bick, S.; Zhang, L. Assessing the economic viability of loggers operating tree-length harvest systems in the Northeast. *J. For.* 2018, 116, 347–356. [CrossRef]

31. Rissman, A.R.; Geisler, E.; Gorby, T.; Rickenbach, M.G. “Maxed out on efficiency”: Logger perceptions of financial challenges facing timber operations. *J. Sustain. For.* 2020. [CrossRef]
32. Murray, D.; Glidewell, S. *An Analysis of the Operational Costs of Trucking: 2019 Update*; American Transportation Research Institute: Arlington, VA, USA, 2019.

33. Esri. ArcGIS Online. Available online: http://usg.maps.arcgis.com/ (accessed on 4 December 2020).

34. Conrad, J.L., IV. Would weight parity on interstate highways improve safety and efficiency of timber transportation in the US South? *Int. J. For. Eng.* 2020, 31, 242–252. [CrossRef]

35. Cassens, D.L.; Gibson, H.; Friday, J.S. Modeling lumber manufacturing processes using Monte Carlo computer simulation. *For. Prod. J.* 1993, 43, 41–48.

36. Elustondo, D.M.; Avramidis, S. Comparative analysis of three methods for stochastic lumber drying simulation. *Dry. Technol.* 2005, 23, 131–142. [CrossRef]

37. Moore, T.Y.; Ruel, J.-C.; Lapointe, M.-A.; Lussier, J.-M. Evaluating the profitability of selection cuts in irregular boreal forests: An approach based on Monte Carlo simulations. *Forestry* 2012, 85, 63–77. [CrossRef]

38. Mei, B.; Clutter, M.L.; Harris, T.G. Timberland return drivers and timberland returns and risks: A simulation approach. *South. J. Appl. For.* 2013, 37, 18–25. [CrossRef]

39. Petrasek, S.; Perez-Garcia, J.M. Valuation of timber harvest contracts as American call options with modified least-squares Monte Carlo algorithm. *For. Sci.* 2010, 56, 494–504.

40. McConnell, T.E. Unit costs and trends within Louisiana’s logging contract rate. *For. Prod. J.* 2020, 70, 50–59.

41. Energy Information Administration. Gasoline and Diesel Fuel Update. Available online: https://www.eia.gov/petroleum/gasdiesel/ (accessed on 3 December 2020).

42. Rizet, C.; Cruz, C.; Mbacke, M. Reducing freight transport CO₂ emissions by increasing the load factor. *Procedia–Soc Behav Sci.* 2012, 48, 184–195. [CrossRef]

43. JMP. JMP Pro 14.3.0; SAS Institute Inc.: Cary, NC, USA, 2018.

44. Conrad, J.L., IV. Analysis of timber transportation accident frequency, location, and contributing factors in Georgia, USA 2006–2016. *Int. J. For. Eng.* 2019, 30, 109–120. [CrossRef]

45. Williams, E. SC Forest Industry Margins Chopped by Rising Transportation Costs. Available online: https://www.postandcourier.com/ (accessed on 11 February 2021).

46. Hooper, A.; Murray, D. *E-Commerce Impacts on the Trucking Industry*; American Transportation Research Institute: Arlington, VA, USA, 2019.

47. Baker, S.; Mendell, B. *Compensation Indices for Logging and Trucking Occupations*; Wood Supply Research Institute: Valley Head, WV, USA, 2016.

48. Murphy, G. Reducing trucks on the road through optimal route scheduling and shared log transport services. *S. J. Appl. For.* 2003, 27, 198–205. [CrossRef]

49. Lautala, P.; Pouryousef, H.; Stewart, R.; Ogard, L.; Vartiainen, J. *Analyzing Log and Chip Truck Performances in the Upper Peninsula of Michigan with GPS Tracking Devices*; National Center for Freight & Infrastructure Research & Education, University of Wisconsin-Superior: Superior, WI, USA, 2011.

50. Federal Motor Carrier Safety Administration. Hours of Service. Available online: https://www.fmcsa.dot.gov/regulations/hours-of-service (accessed on 20 November 2020).

51. Conrad, J.L., IV. *Safety and Efficiency of State-Legal Log Trucks on Interstate Highways in Eight Wood Baskets in the US South*; Georgia Forestry Foundation Center for Forest Competitiveness and Forest Resources Association: Forsyth, GA, USA; Rockville, MD, USA, 2020.

52. Bolding, M.C.; Dowling, T.N.; Barrett, S.M. *Safe and Efficient Practices for Trucking Unmanufactured Forest Products*; Virginia Cooperative Extension: Blacksburg, VA, USA, 2009.

53. Huynh, N. Reducing truck turn times at marine terminals with appointment scheduling. *Transp. Res. Rec.* 2009, 2100, 47–57. [CrossRef]

54. Malladi, K.T.; Sowlata, T. Optimization of operational level transportation planning in forestry: A review. *Int. J. For. Eng.* 2017, 28, 198–210. [CrossRef]