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Waits and Delays in Road Freight Transport

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This paper studies waits and delays in the trucking industry of a developing country: Colombia. We follow 186,000 long-haul trips over 926 routes between 2015 and 2019, using GPS devices located in trucks. We find that waits, rather than periods when the truck is moving, are the largest drivers of travel times: on average, trucks spend 38% of their travel time moving between origin and destination, 38% parked at the side of the road, and 24% parked before or after the trip. Furthermore, waiting time accounts for 82% of the variation in travel times across trips, whereas moving time only explains 18%. Overall, the cost of waits amounts to 46% of freight rates, whereas the cost of delays amounts to 7%. Most of the cost of delays is generated during waits, rather than when the truck is moving. Shipper, carrier, truck and driver characteristics, as well as the day of the week and the hour of the day in which loading and unloading occurs, explain 35% of the variation in waiting times across trips. There are large potential gains from reducing waiting times and delays through capacity building and optimization.

KEYWORDS
Transport Costs, Vehicle time utilization, Travel time, Freight, Trucking, Roads, Colombia

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Esperas y retrasos en el transporte de carga por carretera

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Este trabajo estudia las esperas y retrasos en el transporte de carga por carretera de un país emergente: Colombia. Seguimos a 186,000 viajes de larga distancia sobre 926 rutas entre 2015 y 2019, usando dispositivos GPS ubicados en los camiones. Encontramos que las esperas, en vez del tiempo en movimiento, son los principales determinantes de los tiempos de viaje: en promedio, los camiones gastan 38% del tiempo moviendose entre origen y destino, 38% estacionados junto a la carretera y 24% estacionados antes o después del viaje. Además, el tiempo de espera da cuenta del 82% de la variación en tiempos entre viajes, mientras que el tiempo en movimiento solo da cuenta del 18%. En el agregado, el costo de las esperas alcanza el 46% del valor pagado a los transportadores, mientras que el costo de los retrasos alcanza el 7%. La mayoría de los costos por retrasos ocurre durante las esperas, no cuando el camión se está moviendo. Las características de generadores de carga, empresas de transporte, camiones y conductores, juntos con las horas de cargue y descarga, explican el 35% de la variación en tiempos de espera entre viajes. Hay grandes ganancias potenciales en reducir esperas y retrasos mediante construcción de capacidades y optimización.

KEYWORDS

Costos de transporte, Utilización del tiempo del vehículo, Tiempo de Viaje, Carga, Camiones, Carreteras, Colombia

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1 | INTRODUCTION

Waits and delays in trucking increase transportation costs and disrupt supply chains, wasting resources and reducing productivity (McKinnon, 1999; Sankaran et al., 2005; McKinnon et al., 2009). In consequence, governments, shippers and carriers implement costly policies to reduce waits and delays (Golob and Regan, 2000, 2003; Kuipers and Rozemeijer, 2006; Goodchild et al., 2012). Understanding the trade-offs associated with these policies, including regulations and road improvements, requires a quantitative assessment of the magnitude and determinants of waits and delays.

This paper uses GPS devices in trucks to study the magnitude and determinants of waits and delays in the Colombian trucking sector. We define a wait as a time interval in which the truck is parked or moving at a speed lower than $5\mathrm{km}/\mathrm{h}$. We define a delay as a trip with a travel time that is atypically large for its route. We measure the impact of delays on travel times using the skewness of the distribution of travel times in each route: since delays are outliers at the right of the distribution of travel times, delays increase the skewness of the distribution, which in turn is costly for industry stakeholders and society as a whole (van Lint et al., 2008; Cedillo-Campos et al., 2019).

We study 186,000 long-haul trips over 926 routes between 2015 and 2019. Our data provides the location of each truck every hour, from the moment the truck is loaded until the moment the truck is unloaded. Therefore, we can measure waits within ports and loading zones at the start or the end of the trip, as long as such waits last longer than an hour. We also can measure trip stops for eating, resting or sleeping, as long as such waits last longer than an hour. Furthermore, we have access to anonymized identifiers of the shippers, carriers, trucks and drivers related to each trip.

With this information, we study: (i) the contribution of waits and delays to the variation of travel times in Colombian roads, (ii) the separate contributions of shippers, carriers, trucks, drivers, loading hours and route characteristics to the length of waits and the impact of delays on travel times, and (iii) the cost of waits and delays in the Colombian road freight sector. Hence, our study provides insights on the trade-offs associated with investing in better roads, ports, trucks, logistic optimization or training for drivers. It also provides insights on the gains from adopting driverless truck operations.

We find that waits, rather than periods when the truck is moving, are the largest drivers of total travel times. Waits amount to 62% of travel times and 82% of the variation in travel times, as measured with a Shorrocks-Shapley decomposition of R^2s (Shorrocks, 2013). In fact, waits during the trip –such as stops for sleeping, resting and eating– explain almost thrice the variation in travel times than periods when the truck is moving. The cost of waits amounts to 46% of the freight rates paid to carriers.

In addition to route characteristics, variation in waiting times during the trip is explained by improvements in roads and ports between 2015 and 2019 (4%), the day of the week and hour of the day in which the trip starts and ends (13%), and shipper, carrier, truck and driver characteristics (23%). There are large potential gains from reducing waiting times and delays through capacity building, optimization, training and technology adoption by ports, loading zones, shippers, carriers, truck owners and drivers.

The cost of delays amounts to 7% of the value of freight rates. Most of this cost is generated during waits, rather than movement time: the cost of delays during movement time is only 2% of freight rates.

In the concluding section, we discuss the potential policy implications of our results for policy makers, shippers and carriers.

2 | LITERATURE REVIEW

Our paper contributes to the literature on vehicle time utilization. An audit study on the UK food industry revealed that trucks spent 28% of their time running on the road, 16% of their time loading or unloading, and 15% of their time preloaded and awaiting departure (McKinnon and Ge, 2004). A survey on long-haul truck drivers in the US revealed that idling accounts for 34% of total engine run time (Lutsey et al., 2004). Among urban distribution drivers in Sweden, only 30% of the time is spent driving, whereas 15% of the time is spent on breaks (Sanchez-Diaz et al., 2020). In the Houston-Galveston area of the US, trucks are idle for an average of 3 hours per day (Farzaneh et al., 2020)[1]. Our main contribution to this literature is to decompose the variation in waiting and movement times into the contribution of shippers, carriers, trucks, drivers, loading hours and road characteristics. We are able to do so thanks to the breadth of our GPS dataset, which contains trips by 5 thousand shippers, 235 carriers, 19 thousand drivers and 15 thousand trucks over the course of five years.

Our paper also contributes to the literature on travel time reliability. One approach to measure delays and their causes is to ask carriers about delays in the last 48 hours for each of their trucks. Using this approach for seven sectors in the UK, McKinnon and Ge (2004) and (McKinnon et al., 2009) find that 26% of journey legs are subject to delays, with large variation in delay prevalence and duration across sectors. 31% of delay time is due to actions by the carrier itself, 28% by problems at the delivery point, 22% by road congestion, 9% by problems at the collection point, and 10% due to other causes (McKinnon et al., 2009). Another approach is to use GPS data, as in Cedillo-Campos et al. (2019), who find that congestion induces skewness in the distribution of travel times for trucks in a Mexican highway. Our contribution to this literature is twofold. First, to use GPS data to study delays over 926 routes and 5 years. Second, to study the determinants of the impact of delays on the distribution of travel times.[2]

There is also a literature on the valuation of lower travel times and higher reliability, with large differences in estimates across methodologies, countries and industries (Fowkes et al., 2004; Zamparini and Reggiani, 2007; Zamparini et al., 2011; de Jong et al., 2014; Shams et al., 2017). Our study does not estimate the valuation of shorter waits and delays from the point of view of shippers, but contributes to that literature insofar as either: (a) reductions in delays within a route might increase the valuation of shorter delays (b) differences in valuations between routes induce differences in reliability across routes.

More generally, we contribute to the literature on travel times as trade barriers. For US imports, each additional day of expected transit is equivalent to an ad-valorem tariff between 0.6 and 2.1% (Hummels and Schaur, 2013). Furthermore, on average across countries, an additional day of transit from the factory gate to the ship reduces trade by more than 1% (Djankov et al., 2010). In fact, adding one custom officer at each US land border crossings would reduce waiting times for imports, which in turn would increase US GDP by 350 thousand dollars (Avetisyan et al., 2015). In Colombia, travel time related costs amount to 23% of total costs for truck owners –not including travel time costs for shippers and good owners (Mesquita et al., 2013). [3] Delays are also important: unexpected delays are more expensive than expected increases in travel times because delays disrupt supply chains. As a result, trade costs and flows respond to customs delays, port-of-entry delays, and reduced customs inspections (Volpe et al., 2015; Carballo et al., 2016; Fernandes et al.,

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[1] That is, the engine is on but the truck does not move for at least 5 minutes

[2] The determinants of delays have also been studied in the context of airlines (Mazzeo, 2003; Bendinelli et al., 2016) and trains (Gorman, 2009; Agbelie and Libnao, 2018)

[3] For the most popular class of truck used in the country

2020). Furthermore, congestion in the transportation network increases the variance of shipping times which in turn increases costs and reduces revenues for the firms that ship goods through the network (Firth, 2019). We contribute to this literature by quantifying the maginitude, sources and costs of waits and delays in the road freight sector, which account for 81% of tonnage transported within Colombia in 2019 (Ministerio de Transporte, 2020).

3 | TRUCKING IN COLOMBIA

Trucks accounted for 81% of tonnage transported within Colombia in 2019 -97% for land transport excluding coal and oil (Ministerio de Transporte, 2020). Most Colombian firms participate in the long-haul market instead of using their own trucks (Allen et al., 2021).[4]

The Colombian long-haul market connects three types of agents: shippers, carrier companies registered with the Ministry of Transport, and independent carriers. Colombian regulation prevents shippers from hiring independent carriers directly, with few exceptions including the transport of beer and agricultural goods[5]. Instead, shippers contract with carrier companies to move goods from one location to other. Carrier companies insure the goods and move the goods themselves or outsource shipping to independent carriers. Independent carriers account for 80% of trucks and 90% of shipping capacity in the Colombian market (Allen et al., 2021).

4 | DATA

Our GPS data was provided by *SABI Tech*, a business analytics company especialized in the trucking sector. In GPS data, trackings are the observation units. A tracking is an observation containing a location and a time. SABI gave us access to tracking level data for GPS devices in trucks. In addition, they gave us access to anonymized identifiers for shippers, carriers, trucks and drivers. Our data contains information on seven million trackings corresponding to 186,000 long-haul trips, 926 routes from 157 origins to 131 destinations, 5 thousand shippers, 235 carriers, 19 thousand drivers and 15 thousand trucks.[6]

GPS devices report the location of the truck at fixed time intervals -one hour during most of the trip, for most trips. However, some routes have segments in which the truck does not report its location because of low or nonexistent connection to the cellphone network. In those segments, time between trackings can be longer than an hour. Table 1 shows that median tracking frequency is one hour across all trackings (row 1, column 50%). In fact, the 75th percentile of frequency is one hour as well (row 1, column 75%). However, outliers in areas of bad access to the cellphone network increase the mean frequency to 1.7 hours (row 1, column "mean"). All routes have a median frequency of one hour or lower.

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[4] Only 27% of industrial firms, 27% of agricultural firms, and 19% of commercial firms own a truck (Departamento Nacional de Planeación, 2018, p. 694)

[5] Carrier companies are a required actor in transport contracts (Decree 1079 of 2015, chapter 7, article 2.2.1.7.3). For exceptions, see decree 2044 of 1988.

[6] The 157 origins and 131 destinations belong to 53 and 47 municipalities.

TABLE 1 Frequency of trackings

	N	Mean	Desv. Est.	Min	Max	25%	50%	75%
Trackings	6,940,520	1.7	3.8	0.0	124.0	0.5	1.0	1.0
Route; Means	926	1.9	0.5	0.5	3.4	1.6	1.8	2.1
Route; Medians	926	0.9	0.8	0.5	1.0	1.0	1.0	1.0

We know the location of the trucks after the cargo is loaded, but before the truck leaves the port or the loading platform. We continue observing the location of the truck until the cargo is unloaded, which occurs after entering into ports and loading platforms.[7] Hence, we are able to observe congestion within ports and loading platforms, as long as such congestion lasts longer than an hour, occurs after loading, and occurs before unloading.[8]

Overall, our data includes information from 186 thousand long-haul trips and 7 million trackings. We arrived at this number of observations by imposing two restrictions in our data. First, we only include long-haul routes because we only observe the location of trucks every hour, so location information is not precise for short routes[9]. Second, we excluded routes with less than 50 trips across five years in order to reduce noise in route-level aggregates.

Our final dataset includes all major long-haul routes in Colombia, representing 22% of trade flows in Colombia in 2019[10]. The correlation of the number of trips per route between our data and official data on trade flows is 77%[11]. In order to better represent trade flows, all statistical calculations in this paper weight each trip by $\frac{N_{TF}}{N_{SABI}}$, where N_{TF} is the number of trips between the municipalities of origin and destination in official data on trade flows, and N_{SABI} is the number of trips between the municipalities of origin and destination in our data.

In order to estimate the cost of delays, we also use information on route-level freight rates and estimated transportation costs from the Colombian Ministry of Transport.

5 | METHODS

5.1 | Definition of Routes

A route is an ordered pair containing and origin and a destination. Rather than defining origins and destinations by municipality, we divided Colombia in a grid of cells of 0.1 degrees of longitude by 0.1 degrees of latitude. Our method of defining origins and destinations overcomes two problems of municipality-level data.

First, a large share of trips do not leave from the main urban area of the municipalities. For example, the oilfield located in coordinates 4.489722, -72.7198 is 41km away from the urban area of Villanueva municipality. In a municipality-level dataset, the oilfield and Villanueva would be in the same location. With our method, the oilfield and Villanueva are in different locations.

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[7] In 61% of trips, location data begins when the truck is loaded. For the remaining trips, location data begins before the cargo is loaded into the truck. In those cases, we identify loading times by looking for keywords on employee reports. Similarly, for 55% of trips, location data ends when the truck is unloaded. For the remaining trips, location data ends after the truck is unloaded. In those cases, we identify unloading times by looking for keywords on employee reports.

[8] The one hour restriction follows from the one-hour frequency of hour data

[9] In particular, we only include routes of more than 100km

[10] Own calculations from the National Freight Registry

[11] Own calculations from the National Freight Registry

Second, in large cities, a trip from downtown is not comparable to a trip from the outskirts because of traffic. Our method divides Bogota, Colombia's capital city, in five locations (center, S, W, NW and SW) and Buenaventura, Colombia's main port, in four locations (City, Port, SE and NE).

5.2 | Definition and Classification of Waits

We classify travel time in four categories:

- Wait before: A time segment at the start of the trip in which the truck moves less than 5 km from its initial position. This category includes movements within ports or loading zones at the start of the trip, after loading the cargo.
- Wait during: The union of all time segments in which the truck moved less than 5 km in an hour during the trip. This category includes sleep breaks and lunch breaks, as long as such breaks last longer than an hour
- Wait after: A time segment at the end of the trip in which the truck moves less than 5 km from its final position. This category includes movements within ports or loading zones at the end of the trip, before and during the cargo unload.
- Movement: The union of all time segments in which the truck moved more than 5km in an hour. This category includes stops that lasted less than an hour.

Total travel time for a trip is the length of the union of the four categories for such trip:

$$\text{Total Travel Time} = \text{Movement} + \text{Wait during} + \text{Wait before} + \text{Wait after} \tag{1}$$

Table 2 is an example of our time classification for the route between the center of Cartagena and the West of Bogota. N is the number of trips in that route and $N(t > 0)$ is the number of trips with times greater than zero in each category. The remaining columns are descriptive statistics for times in each category. On average, trucks spend 4.7 hours waiting at the start of the trip, 23.8 hours waiting during the trip, 15.7 hours waiting at the end of the trip, and 30 hours in movement between Cartagena and Bogota. Total time including waits and movement time is 74 hours on average and 71 hours for the median trip.

TABLE 2 Time travel from Cartagena (city) to Bogotá (W)

Route	N	N(t>0)	Mean	St.Dev	Min	Max	25%	50%	75%
Total time	4636	4636	74.2	23.2	21.0	129.7	53.0	70.7	92.1
Wait Before	4636	3317	4.7	7.2	0.0	74.3	0.0	2.0	6.0
Wait During	4636	4377	23.8	17.9	0.0	99.0	11.0	19.0	33.0
Wait After	4636	4385	15.7	17.3	0.0	96.3	2.5	8.0	23.2
Movement	4636	4636	30.0	7.0	4.0	97.0	26.0	28.6	32.4

5.3 | Measurement: Importance of Waits

We use two methods to measure the importance of waits within total travel times. First, by calculating the share of total travel time spent in movement, waiting during the trip, waiting before the trip, and waiting after the trip.

Second, by calculating the share of the variation in travel times across trips that is explained by waiting time, as opposed to movement time. In particular, we decompose the R^2 of the following ordinary least squares regression, where each observation is a trip:

$$\text{Total Time}_i = \beta_1\text{Movement} + \beta_2\text{Wait during} + \beta_3\text{Wait before} + \beta_4\text{Wait after} + u_i \quad (2)$$

By the definition in Equation 1, we have: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 1$, $u_i = 0$ and $R^2 = 1$. That is, by definition, waiting times and moving times explain 100% of the variation in total travel times. I decompose this 100% into the variation of each component of travel times, using two methods:

The ordered decomposition method consists in two steps. First, estimate a regression between *Total Travel Time* and *Movement Time*, and calculate the R^2. This R^2 is the marginal contribution of *Movement Time* to the variation in *Total Travel Time*. Then add the remaining components sequentially and calculate the increase in R^2 in each step. Such increase is the marginal contribution of the component added in that step to the variation in *Total Travel Time*.

A disadvantage of the ordered decomposition is that results depend on the order in which the components are included in the regression: when two variables are correlated, the first variable added to the decomposition captures the joint variation of both variables. Hence, the same variable will have a larger contribution if introduced first than if introduced at a later stage. In order to tackle this disadvantage of the ordered decomposition, we implement a second method: a Shorrocks-Shapley decomposition of R^2, which is invariant to the order of inclusion (Shorrocks, 2013).

5.4 | Measurement: Determinants of Waits

We study the determinants of waiting times before, during and after the trip. We use two methods. First, we estimate expected waiting times as a function of observable route characteristics and fixed effects by shipper, carrier, driver, and truck. In particular, we write the waiting time of trip i from origin o to destination d carrying goods of shipper s through carrier c in truck tr driven by driver d as follows:

$$\begin{aligned}\text{Waiting Time}_{i,o,d,s,c,tr,d} = \; & \beta_1\text{Trip moving time}_i \\ & + \beta_2\text{Route mean moving time}_{o,d} + \beta_3\text{Distance}_{o,d} \\ & + \beta_4\text{Port}_o + \beta_5\text{Port}_d \\ & + \beta_6\text{Land border}_o + \beta_7\text{Land border}_d \\ & + \beta_8\text{Population}_o + \beta_9\text{Population}_d \\ & + \beta_{10}\text{Net altitude gain}_{o,d} \\ & + \gamma_s + \gamma_c + \gamma_d + \gamma_{tr} \\ & + u_i\end{aligned} \quad (3)$$

where continuous variables are transformed using the inverse hyperbolic sine transformation, instead of logarithms, to take into account that some components of waits are zero for a subset of trips (e.g. if the driver did not make stops while on the road, waiting time during the trip is zero). We estimate elasticities and semielasticites using the formulas in Bellemare and Wichman (2019).[12]

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[12] Elasticities between continuous varaibles are approximately β, while semielasticities for large samples –like

Our second method is to decompose the variation of total, moving and waiting times into the variation of two types of variables. First, observed characteristics of the route: $\mathrm{Distance}_{o,d}$, whether the origin or destination are ports, whether the origin or destination are land crossings to other countries, the population of origin and destination, and the net altitude gain between origin and destination. Second, a set of fixed effects: origin, destination, route, year, day of the week, time of the day, shipper, carrier, driver and truck fixed effects. In particular, let $\mathrm{Time}_{i,o,d,y,ldw,lh,udw,uh,s,c,d,tr}$ be the travel time of trip i, from origin o to destination d, on year y, loading day of the week ldw, loading hour lh, unloading day of the week udw, unloading hour uh, carrying goods of shipper s through carrier c in truck tr operated by driver d. As before, continuous variables are transformed using the inverse hyperbolic sine transformation (Bellemare and Wichman, 2019).

For example, an ordered decomposition of the variation of waits during the trip is performed as follows. First, regress waiting time during the trip on distance from origin to destination:

$$\mathrm{Time}_{i,o,d,y,ldw,lh,udw,uh,s,c,d,tr} = \beta_0 + \beta_1 \mathrm{Distance}_{o,d} + u_i \tag{4}$$

The marginal contribution of distance to the variation in waiting times is defined as the R^2 of the model in Equation 4. Next, add a vector of additional route characteristics to the previous model:

$$\mathrm{Time}_i = \beta_0 + \beta_1 \mathrm{Distance}_{o,d} + \beta_2 \text{Route Characteristics}_{o,d} + u_i \tag{5}$$

The marginal contribution of the additional route characteristics is defined as the difference in R^2 between the estimated model of Equation 5 and the estimated model of Equation 4.

Next, estimate the model including route fixed effects and dropping route observable characteristics from the model:[13]

$$\mathrm{Time}_i = \gamma_{o,d} + u_i \tag{6}$$

The marginal contribution of unobserved route characteristics is defined as the difference in R^2 between the estimated model of Equation 6 and the estimated model of Equation 5.

Next, add the remaining groups of fixed effects in a sequential manner and calculate the marginal contribution to R^2 in each stage. In the last stage, the estimated equation is:

$$\begin{aligned}\mathrm{Time}_i = \quad & \gamma_{od,y} \\ & + \gamma_{o,ldw} + \gamma_{o,lh} \\ & + \gamma_{d,udw} + \gamma_{d,uh} \\ & + \gamma_s + \gamma_c + \gamma_d + \gamma_{tr} \\ & + u_i \end{aligned} \tag{7}$$

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ours– are approximately $e^{\beta} - 1$

[13] Route observable characteristics and the constant are dropped from the model because they are perfectly collinear with the fixed effects by route.

As in subsection 5.3, a disadvantage of this ordered decomposition is that results depend on the order of inclusion of the explanatory variables. In particular, the order of the decomposition can have a large impact within the set of shippers, carriers, trucks and drivers because drivers operate the same truck multiple times, trucks work for the same carrier multiple times and carriers work with the same shipper multiple times. In consequence, a given variable will have a larger contribution if introduced first than if introduced at a later stage. In subsection 5.3 we adressed this concern by implementing a Shorrocks-Shapley decomposition (Shorrocks, 2013). However, a Shorrocks-Shapley decomposition is computationally unfeasible in this case because of the high dimensionality of the fixed effects and the high number of observations.

We propose a second-best solution: (i) add first the groups of fixed effects related to route, day of the week and loading hours, (ii) add next the shipper, carrier, truck and driver groups of fixed effects, but perform separate decompositions for the $4! = 24$ possible orderings of these groups of fixed effects, and (iii) calculate average marginal contributions across the 24 decompositions estimated in (ii)[14].

5.5 | Delays

We define a delay as a trip in which travel time is atypically long –an outlier in the right tail of the distribution of travel times. Delays increase the skewness of the distribution of travel times, which in turn is costly for industry stakeholders and society as a whole (van Lint et al., 2008; Cedillo-Campos et al., 2019). This result occurs because distributions of travel times and waiting times are right-skewed in routes in which delays are frequent or long. In consequence, we measure the relevance of delays in a particular route with the method of moments' estimator of Pearson's coefficient of skewness. Skewness is negative when the distribution is left-skewed, zero when the distribution is symmetric, and positive when the distribution is right-skewed. Hence, the relevance of outliers in a given route is higher when skewness is higher.

We estimate the determinants of delays by estimating the following equation at the route level, for each segment of travel times:

$$\begin{aligned} skewness = \quad & \beta_1 \text{Median time for segment}_{o,d} \\ & + \beta_2 \text{Distance}_{o,d} \\ & + \beta_3 \text{Port}_o + \beta_4 \text{Port}_d \\ & + \beta_5 \text{Land border}_o + \beta_6 \text{Land border}_d \\ & + \beta_7 \text{Population}_o + \beta_8 \text{Population}_d \\ & + \beta_9 \text{Net altitude gain}_{o,d} \\ & + u_{o,d} \end{aligned} \tag{8}$$

where median times and populations are in logarithms because their distributions are right-skewed. We use median times as an explanatory variable, rather than average times, because average times are influenced by outliers, but medians are not. Net altitude gain is transformed using the inverse hyperbolic sine transformation, rather than logarithms, because net altitude gain takes the value of zero when origin and destination have the same altitude.

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[14] We thank Carlos Juncosa and Lian Allub at CAF for proposing this solution

5.6 | Cost of Waits

We make a back of the envelope calculation of the cost of waits and delays for a given route[15]. It only includes costs for the trucking industry, as it is based in the estimated cost of an additional hour of waiting for independent carriers, according to the Ministry of Transport. Hence, it does not include the cost of waits for shippers nor for other actors of the supply chain.

The Colombian Ministry of Transport provides a simulator of the total cost of serving a subset of routes, depending on the type of truck, the route, loading times and waiting times.[16]. We obtain the marginal cost of waiting hours for each type of truck by simulating the increase in total costs that would occur if waiting times were increased by one hour, using the platform of the Ministry.[17]. After obtaining the marginal cost for each type of truck, we use the National Freight Registry of the Ministry of Transportation to calculate the number of total trips made by each type of truck in each route in 2019. Next, we calculate the total cost of waits in 2019 as follows:

$$\text{Cost of waits} = \sum_{r} \sum_{tc=1}^{6} Numtrips_{tc,r} \times AverageWaitDuration_{r} \times MC_{tc,r} \tag{9}$$

where $Numtrips_{tc,r}$ is the number of trips of truck class tc in route r according to the National Freight Registry, $AverageWaitDuration_r$ is the average wait duration in our GPS data for that route, and $MC_{tc,r}$ is the marginal cost of waiting hours for truck class tc in route r. We make a separate calculation for waits before, during and after the trip.

The Ministry of Transport also provides information on the average freight rate, by truck type, that is paid by carriers to independent truck owners in each route. We multiply such fee by the number of trips in each route by each truck type to obtain an estimate of the market value of the service provided by trucks. We finish our calculation by dividing the costs of waits by this market value.

5.7 | Cost of Delays

We define the cost of delays as:

$$\text{Cost of delays} = \sum_{r} \overline{MC_r} \times \sum_{i=1}^{n_r} \left(t_{ir} - t'_{ir}\right) \tag{10}$$

where $\overline{MC_r}$ is the weighted average of the marginal cost across classes of trucks for route r; t_{ir} is the time of trip i in route r and t'_{ir} is the time of trip i in a counterfactual distribution with no delays.

Since average times are influenced by outliers, but median times are not, we make the following assumptions about the distribution of travel times in each route: (i) the medians of the factual and the counterfactual distributions of travel times are equal (ii)

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[15] Since the calculation uses data from the Ministry of Transport, which is at the municipality level, origins and destinations are aggregated at the municipality level for this calculation

[16] `https://plc.mintransporte.gov.co/`. Retrieved on 2021/03/30

[17] The Ministry provides a *Cost of additional hour*, but it includes fixed costs in the calculation. Instead, we make our calculations using the definition of marginal cost: the increase in total cost from an additional hour of waiting

in the counterfactual distribution with no delays, the average travel time and the median travel time are equal. There are multiple approaches to constructing such counterfactual distribution in the absence of delays. One possible approach is to assign median travel times to the trips in the right tail of the distribution until the average equals the median of the distribution. However, regardless of the approach followed, assumptions (i) and (ii) imply that the average time in the counterfactual distribution equals the median time in the factual distribution of times. Hence, equation 10 can be rewritten as follows:

$$\text{Cost of delays} = \sum_r \overline{MC_r} \times (AverageTime_r - MedianTime_r) \times NumTrips_r \tag{11}$$

where $AverageTime_r$ is the average travel time in route r, $MedianTime_r$ is the average travel time in route r, and $NumTrips_r$ is the number of trips in route r in the National Freight Registry. As with waits, we finish our calculation by dividing the cost of delays by the market value of the service provided by trucks.

6 | RESULTS

6.1 | Importance of Waits

Across all routes, total waiting time is larger than total movement time. Trucks spend 38% of travel time moving between origin and destination, 38% parked on the side of the road, 8% parked after loading and 16% parked before or during unloading (Table 3).

Columns 2 and 3 of Table 3 show the results of the ordered decomposition and the Shorrocks-Shapley decomposition of the variation in total travel times. Under both methods, the variation in travel times is mostly explained by variation in waits, especially during and after the trip. Moving times only explain 18% of the variation in travel times under the Shorrocks-Shapley decomposition of R^2 (column 3). Waits on the road explain 52% of the variation in travel times. Hence, the main driver of variation in travel times on the road are waits, not time in movement.

TABLE 3 Movement time and waits as a share of travel time

	Share of total time	Variance Contribution (Ordered)	Variance Contribution (Shorrocks-Shapley)
Movement	37.8	30.5	18.4
Wait during trip	38.1	39.1	51.5
Wait before trip	8.2	9.3	8.1
Wait after trip	15.9	21.1	21.9
Total	100.0	100.0	100.0

Notes: Observations weighted to National Freight Registry flows.

6.2 | Determinants of Waits

Before and after the trip, waiting times are inelastic to route length, as measured with the average movement times in the route (Table 4, row 1, columns 1 and 3). In contrast, waits during the trip are elastic to route length: waiting times during the trip grow more than proportionally with average movement times (Table 4, row 1, column 2). However, trips with higher movement times than the average trip in the same route –e.g. because of congestion– have shorter waits than other trips (Table 4, row 2, columns 1 and 3). This result suggests that carriers and drivers shorten waiting times in response to delays on the road.

TABLE 4 Determinants of wait length

	Wait Before	Wait During	Wait After
Route mean movement time	0.20***	1.15***	0.31***
	(0.03)	(0.04)	(0.04)
Trip movement time	-0.08***	-0.09***	-0.30***
	(0.02)	(0.03)	(0.03)
Distance	-0.10***	-0.07***	0.20***
	(0.02)	(0.01)	(0.02)
Origin is port	0.12***	-0.06***	-0.01
	(0.02)	(0.02)	(0.02)
Destination is port	-0.01	0.00	0.03
	(0.02)	(0.02)	(0.02)
Origin is land border	0.39***	-0.09	-0.09
	(0.05)	(0.05)	(0.06)
Destination is land border	-0.05	0.14***	0.26***
	(0.04)	(0.04)	(0.04)
Origin population	0.05***	0.03***	-0.02***
	(0.00)	(0.00)	(0.00)
Destination population	-0.04***	-0.00	0.05***
	(0.01)	(0.01)	(0.01)
Year FE	Yes	Yes	Yes
Shipper FE	Yes	Yes	Yes
Carrier FE	Yes	Yes	Yes
Truck FE	Yes	Yes	Yes
Driver FE	Yes	Yes	Yes
N	186452	186452	186452
R^2	0.35	0.45	0.37

Notes: Standard errors in parentheses. Continuous variables use the inverse hyperbolic sine transformation. Observations weighted to National Freight Registry flows.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

If one route is longer than another in distance, but both routes have the same average movement time, the longer route has likely the road with better quality. Given average movement times, longer roads by distance have shorter waits before and during the trip, but longer waits after the trip (Table 4, row 3). Hence, roads with better quality have shorter waits before and during the trip, but longer waits after the trip. In addition, before the trip, waits at land borders take longer than at ports, which in turn take longer than in the interior of the country.

We now decompose the variation of travel times into route characteristics and shipper, carrier, driver, and truck unobserved characteristics. Table 5 shows the marginal contribution of each variable. Each row contains the increase in R^2 after adding a variable to the model.

TABLE 5 Marginal contribution to variation in waits, average across orderings

	Total Time	Movement Time	Wait During	Wait Before	Wait After
Distance	13.9	48.6	2.4	0.1	0.0
Other Route Observed Characteristics*	3.8	4.5	1.7	1.1	1.0
Route FE	17.0	16.5	14.1	12.4	9.8
Year and Route x Year FE	3.2	2.0	4.0	4.4	3.3
Day and Hour FE**	14.1	4.0	12.6	10.2	13.9
Shipper FE	4.4	1.7	4.0	3.7	3.6
Carrier FE	2.6	0.7	1.5	1.1	2.2
Truck FE	6.2	3.6	7.9	8.0	8.1
Driver FE	7.7	4.4	9.9	10.0	10.3
Total R^2	72.9	86.0	58.1	51.0	52.2

Notes: Marginal contribution: increase in R^2 after adding the variable to the model. Route level variables are added sequentially to the model, in the order presented in the table. Trip level variables are added after route level variables, but results for trip level variables are averages across all 24 orderings within trip level variables. When route FE are added to the model, route level variables are dropped from the model and the marginal contribution of route FE is calculated relative to the model with route level variables. Total $R^2 = R^2$ of the model with all variables = sum of the marginal contributions of all variables. Observations weighted to National Freight Registry flows.*Port, land border and population at origin and destination as well as net altitude gain. **Includes interactions with origin and destination FE

Distance explains 49% of the variation in movement time across trips, but only 2% of the variation in waiting times on the road (e.g stops to sleep, rest and eat). Route FE, which captures unobserved characteristics of roads such as roughness and remoteness, explain an additional 17% of movement time, 14% of waits during the trip, 12% of waits before the trip, and 10% of waits after the trip.

The marginal contribution of $Year$ and $Route \times Year$ fixed effects represent the share of the variation in travel times that results from improvements in roads, ports and loading zones between 2015-2019. Such contribution explains 2% of the variation in movement times, between 3% and 4% of the variation in waiting times and 3% of the variation in total travel times. Days and hours of loading and unloading explain 10% of waiting times before the trip, 14% of waits after the trip and 13% of waits during the trip.

Shippers and carriers explain less of the variation in travel times than trucks and drivers. Differences across trucks explain 8% of the variation in waits, but only 4% of the variation in movement times. Differences across drivers explain 10% of the variation in waits, but only 4% of the variation in movement times. Overall, differences across shippers, carriers, trucks and drivers contribute 20% of the variation in total travel times across trips -more than road distance.

6.3 | Delays

We use the skewness of the distribution of times within a route to measure the importance of delays in that route. Table 6 shows that delays are present in all stages of trips, but are more important before the trip than at the remaining stages of the trip. In addition, skewness for total time is lower than for its components, which suggests that drivers compensate delays in one segment of the trip by reducing waits and increasing speeds.

TABLE 6 Importance of delays measured with skewness

Segment	Mean Skewness	Median Skewness
Total	0.9	0.9
Movement	2.2	2.1
Wait during	1.4	1.4
Wait before	3.5	3.2
Wait after	2.6	2.4

Delays have a larger impact in routes with lower median travel times, possibly because there is less room to compensate for delays by increasing speed or shortening waits (Table 7). The same result occurs within each segment of the trip, especially with movement times and waits before the trip. For example, the distribution of waiting times before the trip is less skewed when median waiting times are higher.

Given median movement times, longer roads (by distance) have a more skewed distribution of movement times. In other words, if two roads have the same median movement times, delays are more important in the longer route. This result suggests that delays are *less* important in rougher routes and that the impact of roughness on travel times occur mostly trough median times, not delays.

Regarding other route characteristics, delays in movement times are more important when the destination is a land border or a port, instead of a location in the interior of Colombia. In contrast, delays in waits after the trip are *less* important when the destination is a port.

6.4 | Cost of Waits and Delays

The cost of waits during the trip –including stops to rest, eat and sleep– is equivalent to 29% of the value of freight rates (Table 8).[18] In other words, if waiting time during the trip fell by a third in Colombia, freight rates could potentially fall by ten percentage points[19]. Waits before and after the journey cost the transportation sector an additional 18% of freight rates.

The cost of delays, on the other hand, is equivalent to 7% of the value of freight rates

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[18] This amount is heterogeneous across routes. For example, it is 31% in the route that connects the main port (Buenaventura) and the largest city (Bogotá), but 53% in the route that connects the largest city (Bogotá) with the second largest city (Medellín).

[19] If the freight road sector was competitive. The reduction in rates could be higher or lower depending on whether shippers or carriers have market power.

TABLE 7 Determinants of delays measured with skewness

	Total Time	Movement Time	Wait During	Wait Before	Wait After
Median time for segment*	-1.40***	-1.27***	-0.81***	-1.16***	-0.82***
	(0.04)	(0.19)	(0.03)	(0.08)	(0.04)
Distance	0.39***	0.50***	0.01	-0.08	-0.10
	(0.03)	(0.18)	(0.03)	(0.11)	(0.06)
Origin is port	-0.07**	-0.22**	0.02	-0.02	-0.18**
	(0.03)	(0.11)	(0.04)	(0.15)	(0.08)
Destination is port	0.03	0.29**	0.01	-0.26	-0.23***
	(0.03)	(0.12)	(0.04)	(0.16)	(0.09)
Origin is land border	-0.00	-0.42*	-0.06	-0.39	-0.14
	(0.06)	(0.22)	(0.08)	(0.31)	(0.17)
Destination is land border	0.06	0.58**	0.13	-0.50	-0.15
	(0.06)	(0.22)	(0.08)	(0.31)	(0.17)
Origin population	-0.01**	0.08***	0.02**	0.08***	-0.02
	(0.01)	(0.02)	(0.01)	(0.03)	(0.02)
Destination population	-0.01	0.04	0.02***	0.06*	0.05***
	(0.01)	(0.02)	(0.01)	(0.03)	(0.02)
Net altitude gain	0.01***	0.02**	0.00	-0.01	-0.02***
	(0.00)	(0.01)	(0.00)	(0.01)	(0.01)
Constant	5.00***	2.04***	3.39***	2.75***	4.16***
	(0.17)	(0.56)	(0.20)	(0.74)	(0.42)
N	926	926	926	926	926
R^2	0.65	0.12	0.60	0.22	0.41

Notes: Standard errors in parentheses. Continuous variables use the inverse hyperbolic sine transformation. Observations weighted to National Freight Registry flows.* For example, for the column Wait Before: median time waiting before the trip in each route * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

TABLE 8 Cost of waits as a share of freight rates*, 2019

Segment	Cost (% of freight rates)
Waits during the trip	29
Waits before the trip	6
Waits after the trip	12
Total	46

Notes: * Aggregate cost of waits as a share of aggregate freight rates

(Table 9). Most of these costs are generated during waits, rather than movement time: the cost of delays during movement time is only 2% of freight rates.[20]

TABLE 9 Cost of delays as a share of freight rates*, 2019

Segment	Cost (% of freight rates)
Movement time	2
Waits during the trip	7
Waits before the trip	5
Waits after the trip	7
Total time	7

Notes: *Aggregate cost of waits as a share of aggregate freight rates

7 | CONCLUSIONS AND IMPLICATIONS FOR POLICY AND LOGISTICS

This paper studies the relevance and determinants of waits and delays in the Colombian trucking industry. It finds that waiting times constitute 62% of travel times and explain 82% of the variation in travel times across trips. In fact, waits during the trip –such as stops for sleeping, resting and eating– explain almost thrice the variation in travel times than periods when the truck is moving. In other words, even while the truck is on the road, the main source of variation in travel times are waits, not time in movement. We estimate that the cost of waits amounts to 46% of freight rates, whereas the cost of delays amounts to 7% of freight rates. Furthermore, most of the cost of delays occurs during waits.

Low and middle income countries spend 4% of their GDP in infrastructure investments (Fay et al., 2019). One goal of these investments is to reduce transportation costs by increasing speeds and reducing distances between markets. However, improvements in road and port infrastructure between 2015 and 2019 only explain 3% of the variation in travel times between 2015 and 2019, a period with large investments in road infrastructure (Table 5, row 4). This paper highlights a potential channel for further reductions in travel times: reductions in waits and delays through capacity building and optimization by ports, shippers, carriers, truck owners and drivers.

The day and hour of loading and unloading account for only 4% of the variation in movement times, but 14% of the variation in total travel times, thanks to its impact on waiting times. Hence, lower congestion, better procedures, better scheduling of loading times, and a wide offer of opening hours at ports and loading platforms have a large potential of reducing travel times through reductions in waiting times.

The characteristics of shippers, carriers, trucks and drivers explain 10% of the variation in movement times, but 23% of the variation in waiting times during the trip. In fact, driver characteristics explain 10% of the variation in waiting times during the trip; more than half of the variation explained by route characteristics –observed and unobserved. Hence there are large potential gains from better optimization by shippers and carriers, fleet management, and driver training and tracking.

The potential gains from driverless trucks are large. Driverless trucks could potentially

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[20] The cost for the stages do not add up to the cost of total times because drivers compensate delays in one stage by decreasing times in the remaining stages.

eliminate the need for stops to sleep, eat and rest, which accounts for most of waits on the road. Engholm et al. (2020) predict that costs per 1,000 ton-kilometer are between 29% and 45% lower with driverless trucks than with manually driven trucks. Our results suggest that the gains from driverless trucks through reductions in waits and delays are potentially large in the case of Colombian roads.

Overall, there are large potential gains from reducing waiting times through capacity building, optimization, training and technology adoption. Policy makers, shippers and carriers might consider paying greater attention to policies that encourage capacity building, optimization and technology adoption in the sector, rather than paying too much attention to increasing speeds on the road.

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