Choosing My Own Path: Revealing Differences in Route Choice Preferences across Long-Haul, Medium-Haul, and Short-Haul Trucking

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Abstract

The rapid growth in e-commerce activities and the constant specialization of industries have aroused an unparalleled demand for trucking in urban areas, leading to growing concern over its interference to the transportation system. Understanding truck route choice preferences across long-haul, medium-haul, and short-haul trips can offer insights for designing the truck route network tailored to specific freight demand types, so as to effectively reduce their interference to passenger transportation. However, limited research has been conducted to explore the heterogeneity or similarity of route choice preferences across those freight demand types. This study utilizes the Path Size Logit Model to explore the characteristics of preferred route across long-haul, medium-haul, and short-haul trips, and reveal the underlying route choice mechanism behind enormous trucking activities. By employing truck GPS data from China, we find that (1) although the characteristics of preferred routes vary across long-haul, medium-haul, and short-haul trips, those trips collectively reflect full consideration of travel efficiency, safety, and reliability; (2) all these freight demand types incline to the routes with shortest travel distances instead of those with shortest travel time, while short-haul trips exhibit the highest sensitivity to travel distance; (3) drivers in both long-haul and medium-haul trips favor routes that combine motorways and sub-arterial roads, while long-haul trips present higher sensitivity; (4) drivers in short-haul trips show preferences for routes featuring fewer turns, and sub-arterial roads given last-mile delivery demand. Finally, we propose suggestions for designing urban truck route network to accommodate diverse freight demand in high-density urban areas with limited road resources.

Keywords: truck route choice, GPS data, path size logit model, truck route network

1. Introduction

The rapid growth of e-commerce and the constant specialization of industries have raised an unparalleled rise in demand for goods delivery (Giuliano et al., 2016; Yang et al., 2021b). Given the convenience of road transportation, it remains the primary mode for goods delivery in urban areas, leading to a significant and persistent increase in truck travel on urban roads (Holeczek, 2019; Shoman et al., 2023). This considerable reliance on road transportation brings a series of negative externalities, including severe traffic congestion, traffic accidents, air pollution, and road damage (Ma et al., 2016; Sharma et al., 2022; Yang et al., 2021a; Yu et al., 2023; Yu et al., 2024; Yuan and Wang, 2021). Investigating truck route choice preferences can provide the theory basis for constructing the truck route network, thereby enabling effective management of truck traffic flows, and mitigating their impact on the urban transportation system (Nadi et al., 2022; Qin et al., 2023; Ramirez-Rios et al., 2023; Tao and Zhu, 2020).

Truck route choice preferences exhibit heterogeneity across long-haul, medium-haul, and short-haul trips (Luong et al., 2018; Toledo et al., 2020). Specifically, variations in travel distance often entail differences in delivery requirements, encompassing the value of goods, delivery timeliness, and costs (Feng et al., 2013; Kinjarapu et al., 2022; Yang et al., 2022a). These discrepancies significantly impact the sensitivity of route decision-makers to route economics, safety, and reliability, thereby influencing the outcomes of route choice (Rowell et al., 2014; Wang and Zhang, 2017; Wang and Goodchild, 2014). Examining this heterogeneity aids in developing a more tailored truck route network, which not only ensures truck operational efficiency but also minimizes its impact on the urban traffic system.

Previous studies have employed questionnaire data or large-scale GPS data to analyze truck route choice behavior, with some specifically investigating route preferences in different travel scenarios, such as long-haul, intercity trips, peak and off-peak travel (Feng et al., 2013; Luong et al., 2018; Sharma et al., 2022; Toledo et al., 2020; Wang and Goodchild, 2014). However, there is limited empirical research comparing the truck route preferences across varying freight demand in travel distance. On the other hand, even though several studies have delved into route choice preferences across long-haul, medium-haul, and short-haul travel scenarios, the predominant focus has been on passenger transport (Deng et al., 2020; Jou and Yeh, 2013; Yamamoto et al., 2018). Given the factors such as weight and/or size of the truck, driving restriction, and convenience for goods loading and unloading, the findings regarding route choice preferences in passenger transport may not directly apply to truck travel. Therefore, further investigation is warranted into the similarities or disparities in truck route choice preferences among long-haul, medium-haul, and short-haul distances.

To address the understudied issue, we categorize trips into three distinct scenarios based on travel distance: long-haul, medium-haul, and short-haul. We employ large-scale truck GPS data to empirically analyze truck route choice preferences across these freight demand. Compared to traditional Revealed Preference (RP) and Stated Preference (SP) survey data, GPS data offers more specific information about truck travel routes, making a more accurate identification of the disparities in truck route choice preferences. Subsequently, we propose a framework for the trucks route decision-making mechanisms. Based on this framework, we investigate the influences of different route attributes on truck route choice preferences and conduct a comprehensive analysis of the route choice mechanisms. Then, given the similarity among available routes, we employ the Path Size Logit (PSL) Model to quantify the effects, and compare the results obtained from the Multinomial Logit (MNL)Model. Finally, based on the findings, we put forward suggestions for designing rules for urban truck route network under long-haul, medium-haul, and short-haul.

The potential theoretical and practical contribution of this study is two-fold. From a theoretical perspective, this study introduces a framework for understanding the mechanism behind truck route decision-making. This framework enables us to construct a comprehensive set of factors that influence preferred routes and facilitates a systematic analysis of the route choice mechanism. From a practical perspective, we discern differences and similarities in truck route preferences across long-haul, medium-haul, and short-haul. Our findings can provide insights for constructing the tailored truck route network, so as to effectively manage the truck traffic flow and reduce their impacts on the urban transportation systems.

The paper is organized as follows: Section 2 provides the literature review for truck route choice behavior and route choice preferences in various distance scenarios. Section 3 outlines the methodology, including decision rules, Multinomial Logit Model and Path Size Logit Model. Section 4 details the data collection and process, and Section 5 presents the results. The policy implications of truck route network for long-haul, medium-haul, and short-haul are provided in Section 6, followed by the conclusions in the final section.

2. Literature review

2.1 Trucks route choice behavior

Numerous studies have been conducted to analyze the route choices made by truck drivers or freight forwarders. Among them, the typical studies focus on the choice outcomes and influencing factors when it comes to toll roads (Toledo et al., 2013; Wang and Zhang, 2017; Wood, 2012; Zhou et al., 2009). Specifically, Tsirimpa et al. (2019) focused on examining the effect of toll payment on the route choice behavior of freight forwarders and truck drivers by conducting a stated preferences (SP) survey experiment. The results showed that the value of time (VOT) varies between the alternatives (toll road and national road), and the value of VOT is higher on the toll road. Similarly, Sun et al. (2013) also conducted an SP experiment where drivers were asked to choose between two route alternatives with toll costs significantly differing. Rowell et al. (2014) investigated the truck routing priorities of freight companies through a survey involving shippers, carriers, and receivers concerning each item's influence on route choice. The results showed that minimizing travel costs and meeting customer requirements were priorities. Moreover, Feng et al. (2013) found that light truck drivers are significantly sensitive to road pricing, when exploring the influence of truck drivers' heterogeneity on route choice.

The above studies mainly used questionnaire data to explore the truck route choice behavior. Some scholars have shifted from using survey data to large-scale GPS records in recent years, to discuss the influencing factors or the preference characteristics of the truck route choice. Specifically, Toledo et al. (2020) use large streams of truck-GPS data to analyze intercity truck route choices incorporating toll road alternatives, and identify the influencing factors of route attributes, including travel times, tolls, distances, and road classifications. Luong et al. (2018) use the extensive database of 73,000 truck routes derived from 200 million GPS records to explore the trucks route choice diversity. The analysis suggests that short-haul truck travel exhibits greater diversity in route choice than long-haul travel, regarding the number of unique routes observed. Sharma et al. (2022) proposed a new two-step approach to fuse automated vehicle identification data and loop-detector data and use latent class choice analysis to capture the route choice preference in different segments of truck drivers based on these data sources. This type of data can offer advantages regarding positional precision and large sample size, and help to identify route features. (Demissie and Kattan, 2022; Luong et al., 2018; Wang and Goodchild, 2014).

Furthermore, a few studies have provided valuable insights into route choice preferences in specific travel scenarios, with a particular emphasis on topics such as long-haul or intercity trips. Specifically, Knorring et al. (2005) conducted an empirical analysis of long-haul truck drivers' route choice decision-making as they navigate the U.S. highway network, and found that time is a significant factor in the decision-making process. Toledo et al. (2020) also focused their analysis on intercity truck route choices incorporating toll road alternatives, and found that vast heterogeneous choices among drivers with different employment types and availability of electronic toll collection tags. Maoh et al. (2021) constructed six border delay scenarios to explore trucks' movements between Ontario, Canada, and the United States, and found that long-haul trips tend to favor the Ambassador Bridge crossing, which connects Windsor, Ontario, to Detroit, Michigan. In addition, Wang and Goodchild (2014) found that travel time, travel time reliability, and toll rates significantly influenced route choices during both peak and off-peak periods when they used truck GPS data to observe empirical responses to tolling.

While numerous studies have utilized diverse datasets to examine truck route choices, with some specifically delving into route preferences in distinct travel scenarios, limited research has been conducted to compare truck route preferences across varying distances. The disparities in the value of goods, considerations for timeliness, and cost control at different distances may lead to unique requirements for route attributes, shaping specific route preferences (Feng et al., 2013; Kinjarapu et al., 2022; Luong et al., 2018).

2.2 Route choice preference in various distance scenarios

Existing studies have suggested that route choice preferences vary across different travel distances. Specifically, Jou and Yeh (2013) employed a mixed logit model to investigate the freeway passenger car drivers' choice behavior concerning travel time and route choice across three distinct travel distances: short-distance, medium-distance, and long-distance. Their findings revealed a higher proportion of local road travelers opting for off-peak freeway routes, particularly when there was a greater percentage of toll reduction. This pattern also mirrored the preferences observed in short-distance trips; however, for medium-distance trips, the opposite trend was observed. In addition, they observed that the proportion of drivers choosing local roads for long-distance trips is relatively low, resembling the trend seen in medium-distance trips. Deng et al. (2020) analyzed the heterogeneous trip distance-based route choice behavior using the taxi trajectory data. The analysis of the marginal rate of substitution across short, medium, and long distances models indicated that a one-unit increase in left turns required a reduction in travel time by 1.02, 0.98, and 1.05 minutes for short, medium, and long distances, respectively. Yamamoto et al. (2018) discussed the heterogeneity of trip distance in the pedestrian route choice behavior, and found that the same level of detouring has a larger impact on route choice for shorter trips than on longer trips.

While several studies have delved into route choice preferences across long-haul, medium-haul, and short-haul travel scenarios, the predominant focus has been on passenger transport. In contrast to passenger transport, the realm of goods delivery introduces distinctive factors that influence truck route choice behavior. Drivers, in this context, typically factor in considerations such as the weight and/or size of the truck, driving restriction, and the sequence of addresses when making route decisions. Furthermore, large and heavy vehicles impose additional criteria on route choice, encompassing road accessibility, gradient, and convenience for goods loading and unloading (Feng et al., 2013; Quak and de Koster, 2006). Hence, the results about the route choice preferences of passenger transport are not fully suitable for truck travel. Understanding the specifics of differences or similarities in truck route preferences between various distances and uncovering the underlying reasons for such variations need to be further explored.

3. Methodology

3.1 Decision rules

The truck travel routes typically rely on individual decisions made by truck drivers or freight forwarders, and their decision-making result is influenced by the delivery demand and route characteristics (Jiang and Zhang, 2019; Tsirimpa et al., 2019). Specifically, truck travel is typically driven by the delivery demand. Before departure, route decision-makers obtain the delivery information including the value of the goods, the designated time window for delivery, and the imperative for cost control (Rowell et al., 2014). Subsequently, they need to make the route choice to ensure the complete and punctual delivery of goods at a minimal cost. In this process, the route decision-makers systematically evaluate the economic, safety, reliability, and driving convenience of the available routes, based on the characteristics of road geometry, tolls, and driving distance. Finally, they opt for the travel route that maximizes individual utility.

Diverse delivery demands entail distinct criteria encompassing economic, safety, reliability, and driving convenience when choosing the routes (Han et al., 2021; Jiang and Zhang, 2019; Kordonis et al., 2019; Papadopoulos et al., 2021; Xu et al., 2017). This diversity gives rise to varying preferences for routes based on specific demands. In addition, significant differences exist in delivery demands among long-haul, medium-haul, and short-haul. To be specific, long-haul freight often entails crossing urban agglomeration boundaries or covering considerable distances between cities. Long-haul delivery goods typically comprise higher-value items, such as commodities, manufactured goods, and raw materials. Furthermore, they have lower requirements for timeliness, and travel costs tend to be higher and difficult to control (Cantillo et al., 2021; Hu et al., 2018; Zhu et al., 2023). For medium-haul trips, the goods typically consist of consumer goods, retail products, and items of moderate value, with flexible delivery timeliness and moderate costs and benefits (Akter and Hernandez, 2023; Pani et al., 2023; Zhu et al., 2023). However, in terms of short-haul trips, goods may mainly involve food, daily necessities, express parcels, etc. In this type of freight scenario, quick delivery is typically necessary, often strict requirements for timeliness while striving for lower costs (Akter and Hernandez, 2023; Giuliano et al., 2020; Zhu et al., 2023).

Based on the above content, we propose a framework for truck route decision mechanisms, as shown in Fig. 1. Based on this theoretical framework, we examine the differences in truck route preferences across three freight scenarios: long-haul, medium-haul, and short-haul.

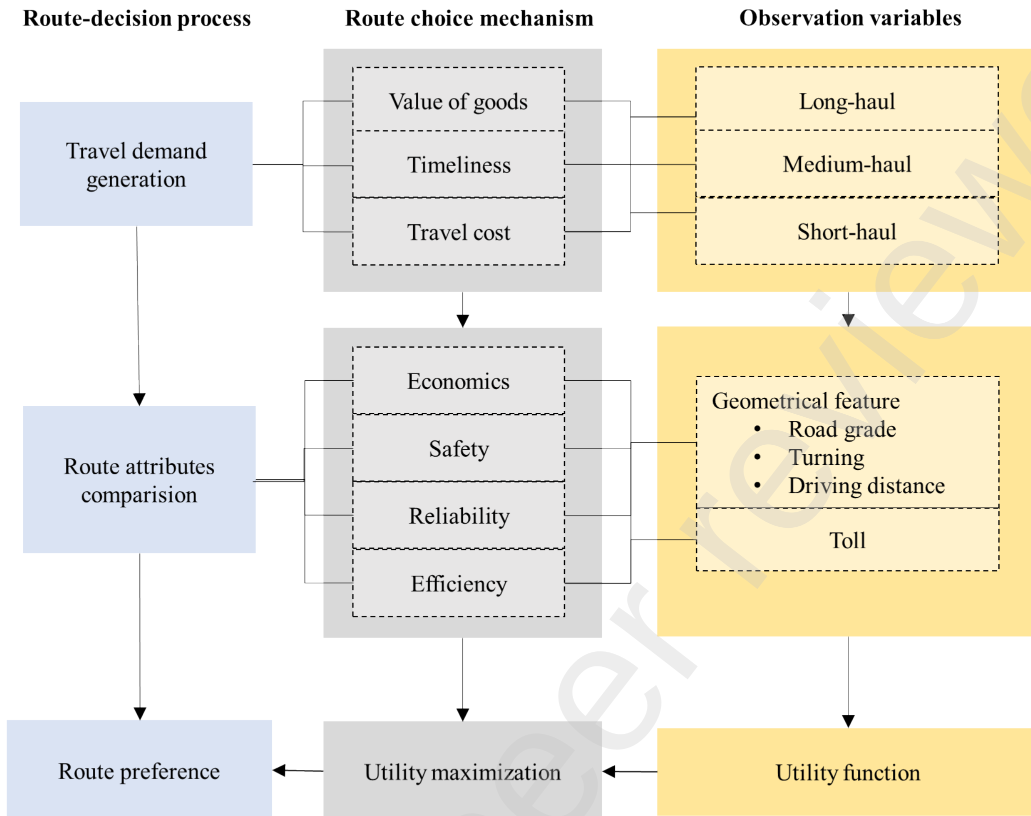


Fig. 1. Framework of route decision mechanism

3.2 Multinomial Logit Model

The Multinomial Logit (MNL) Model is commonly used to describe individual travel choice behavior. The model is based on the random utility theory, which assumes that drivers will choose the option with the greatest utility among their perceived alternatives. If we assume that the error terms of the utility function are independent and identically Gumbel distributed, the choice probability of each alternative *i* can be expressed as Equation 1. The model assumes a linear relationship between utility and each influencing factor. Hence, we have $V_{in} = \sum_{k=1}^{k_i} \beta_{ik} X_{\mathrm{ink}}$. K is the influencing factor.

$$P_{in} = e^{V_{in}} / \sum_{i=1}^{N} e^{V_{in}} \tag{1}$$

where P_{in} is the probability of driver *n* choosing alternative *i*; V_{in} is the utility of driver *n* choosing alternative *i*; N is the number of choice set.

3.3 Path Size Logit Model

Typically, the alternative routes are often overlapping. Hence, this model introduces a path size correction term to address the issue of path overlap. This correction term partially mitigates the Independence of Irrelevant Alternatives (IIA) problem arising from the traditional Logit model's assumption of independently and identically distributed (IID) error terms. The path size correction factor quantifies the similarity of a route alternative with other route options present in the choice set and its values range from 0 to 1. A distinct route, which is unique and does not overlap with other route alternatives in the choice set, has a path size of 1. The path size correction for a route alternative *i* corresponding to a truck driver *n* is defined in Equation 2 as:

$$PS_{\mathrm{in}} = \sum_{a \in \Gamma_{\mathrm{in}}} \left(\frac{l_a}{l_{\mathrm{i}}} \right) \frac{1}{\sum_{j \in C_n} \delta_{aj}} \tag{2}$$

where a is a link in the route alternative *i;* Γ_{in} is the set of links present in the route alternative *i*; l_a is the length of link *a*; l_{i} is the length of route alternative *i*; $\sum_{j \in C_n} \delta_{aj}$ indicates the total number of route alternatives in choice set C_n, present in the choice set of a driver *n*, sharing link *a*.

By including a path size (PS) correction factor, we deal with the correlation among route alternatives. Thus, the choice probability of a driver n to choosing a route alternative *i* is given by Equation 3. β_{ps} is the coefficient of the path-size term.

$$P_{in} = e^{(V_{in} + \beta_{ps} PS_{in})} / \sum_{i=1}^{N} e^{(V_{in} + \beta_{ps} PS_{in})} \tag{3}$$

4. Data collection and process

We utilize GPS data obtained from heavy trucks in China, each with a weight exceeding 12 tons, to investigate their route choice preferences. The dataset comprises records from 2337 vehicles*days, collected at 30-second intervals. Each record in the dataset encompasses key information, including the vehicle number, system timestamp, vehicle operation details, and vehicle location information. In this section, we elucidate the methodological steps involved in organizing the GPS data into trips and matching them with maps, generating the alternative choices set, and recognizing three travel scenarios.

4.1 Trips process

The original trajectory data requires further processing before it can be effectively modeled for route choice, including identification of trips and map matching. For the analysis, trips are characterized as travel originating from loading points to subsequent drop-off points, serving as destination stops. In practice, heavy trucks may pause at specific locations for various reasons, including loading and unloading activities, taking temporary rests, or encountering traffic congestion. We introduce two distinct categories of stops: freight-related stops and non-freight-related stops. Freight-related stops pertain to halts induced by freight-related activities like loading or unloading goods, necessitating specific identification. Conversely, non-freight-related stops encompass activities unrelated to freight behaviors, such as waiting at intersections, and encountering traffic congestion, which are not recognized as valid stops. Drawing on findings from freight surveys, the loading and unloading time for trucks often exceeds 10 minutes, and it's also similar to previous literature (Gong et al., 2015; Sarti et al., 2017; Yang et al., 2014). Hence, we establish a 10-minute threshold. Records exhibiting dwell times surpassing this duration are identified as destination points, contributing to the precision of trajectory segmentation in capturing substantive freight-related stops while excluding non-relevant pauses.

In terms of map matching, we adopt the geometric matching method, which involves querying road segments based on a buffer zone. Within this buffer zone, all road segments within a specific range (set at 50 meters in this study) are considered as candidate road segments for the current observation. Conversely, road segments beyond this range are excluded from consideration and assigned a probability of 0. The probability of a truck traveling on a specific candidate road segment is higher when the distance between the candidate road segment and the observation is smaller. In addition, the road network data used for map matching were extracted from the OpenStreetMap (OSM) GIS database.

4.2 Alternative choice set generation

Analyzing route decision-making requires knowledge not only of the chosen option but also of the other available alternatives that were considered during the decision-making process. Therefore, a complete set of potential choices, known as the choice set, is essential for gaining insights into decision-making behavior. We utilized the AMap (AutoNavi Map) API to systematically create the set of alternative choices for each origin-destination (OD) pair. As a crucial navigation tool for drivers, this platform offers over ten route strategies, making it a preferred option among truck drivers when searching for travel routes.

Considering route searching costs and the possibility of route duplication, we employ the platform to investigate routes commonly recommended by the navigation system. These routes encompass options such as the shortest distance route, fastest route, lowest cost route, less highway route, and highway priority route. Subsequently, we conduct a thorough examination to identify and eliminate duplicates within the alternative choices set. This systematic approach ensures a comprehensive analysis of various route characteristics while addressing the potential issue of redundancy in the dataset. The sample of the chosen route and alternative route are shown in Fig.2.

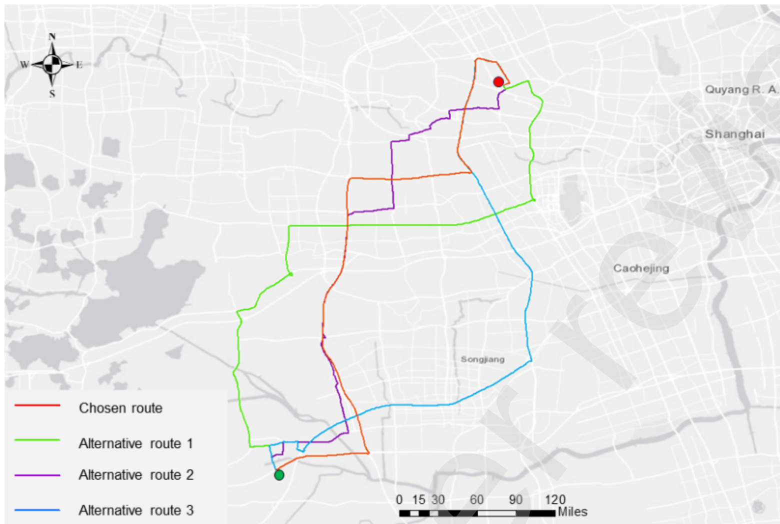


Fig. 2. Sample of chosen route and alternative routes

4.3 Recognition of travel scenarios

We categorize trips into long-haul, medium-haul, and short-haul using an index of travel distance, a method commonly employed in the literature (Deng et al., 2020; Jou and Yeh, 2013; Łukawska et al., 2023). To determine the thresholds for these categories, we initially distribute the samples evenly based on the distribution of trip lengths, as illustrated in Fig. 3. This method has been used in Łukawska et al. (2023). Among them, approximately 40% of the trips cover distances less than 50 km, while 30% fall within the 50 km to 150 km range, and about 30% extend beyond 150 km. Utilizing these delineations, trips covering less than 50 km are categorized as short-haul, those spanning 50 km to 150 km are classified as medium-haul, and trips exceeding 150 km are designated as long-haul. Secondly, in conjunction with the Origin-Destination (OD) distribution for each type of trip (Fig. 4), it becomes evident that short-haul trips predominantly pertain to intra-city travel, medium-haul trips encompass journeys between a city and its adjacent regions, and long-haul trips entail extensive distances between cities and provinces. Therefore, the classification of the three scenarios, as outlined above, is deemed reasonable.

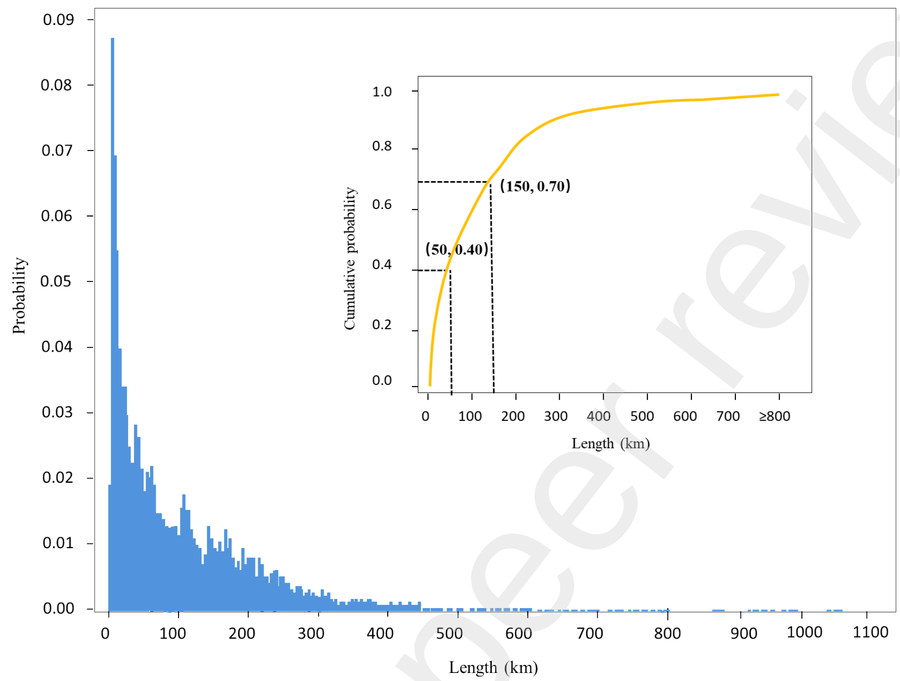


Fig. 3. Distribution of the length of trips

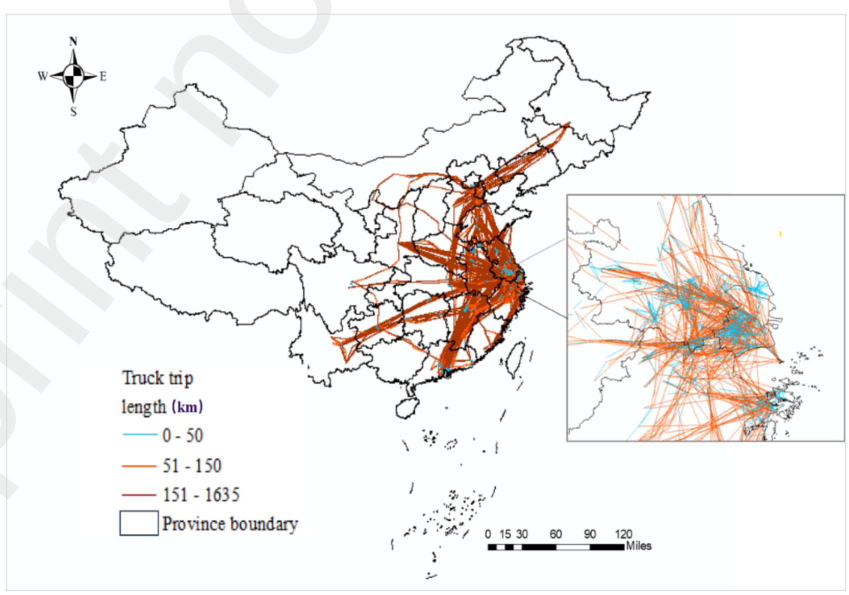


Fig. 4. Spatial distribution of all trips

5. Results

5.1 Statistical analysis

The dataset employed for model estimation consists of a total of 6966 trips, including 1982 for long-haul travel, 2047 for medium-haul travel, and 2937 for short-haul travel. In addition, a total of 17376 alternative routes have been generated for these trips, with about 3 alternative routes per trip on average. In addition, we initially selected nine attributes of routes that we hypothesized to affect truck route choice preference. The descriptive statistics of attributes for chosen routes and alternative routes are as shown in Table 1. It reveals that for the variable of tolls, the statistical indicators of chosen routes surpass those of alternatives. Conversely, regarding the variable of turns, the opposite outcomes are observed. Regarding the motorway and sub-arterial road, the mean values of chosen routes exceed those of the alternatives. However, the results of arterial road and branch road are opposite.

Moreover, we conduct a comparative analysis of the characteristics of the chosen routes across long-haul, medium-haul, and long-haul trips, as presented in Table 2. The findings reveal considerable variation in tolls and fractions on specific roads among these three scenarios. Specifically, long-haul trips exhibit generally elevated statistical indicators for tolls and motorway, in comparison to short-haul and medium-haul trips. Conversely, short-haul trips demonstrate the highest values in terms of turns, arterial road, sub-arterial road, branch road, and path size.

1 Table 1 Description of variables and descriptive statistics of the chosen routes and alternatives

Variables	Description	Chosen route			Alternatives		
		Max	Mean	Min	Max	Mean	Min
Motorway	Fraction of route distance that used motorway/freeway (%)	0.99	0.44	0.00	0.99	0.28	0.00
Arterial Road	Fraction of route distance that used trunk and primary roads (%)	1.00	0.36	0.00	1.00	0.53	0.00
Sub-Arterial Road	Fraction of route distance that used secondary and tertiary roads (%)	1.00	0.16	0.00	1.00	0.11	0.00
Branch Road	Fraction of route distance that used unclassified and residential roads (%)	1.00	0.03	0.00	1.00	0.09	0.00
Turns	Number of turns per kilometer (turns/km)	2.45	0.18	0.00	2.78	0.23	0.00
Travel distance	Length of route (km)	1959.22	133.27	1.02	2033.75	179.02	1.10
Tolls	Toll cost amount (RMB)	2137.00	95.02	0.00	929.00	55.23	0.00
Path Size	The overlap indicator for alternative paths for the same trip	0.82	0.46	0.08	0.88	0.51	0.25

Table 2 Descriptive statistics of the chosen routes across three scenarios

Variables	Scenarios	Max	Mean	Min	S.D.
Motorway	Long-haul	0.99	0.82	0.00	0.32
	Medium- haul	0.99	0.47	0.00	0.41
	Short-haul	0.82	0.16	0.00	0.31
Arterial Road	Long-haul	1.00	0.15	0.00	0.28
	Medium- haul	1.00	0.42	0.00	0.37
	Short-haul	1.00	0.64	0.00	0.33
Sub-Arterial Road	Long-haul	0.70	0.03	0.00	0.05
	Medium- haul	0.86	0.09	0.00	0.13
	Short-haul	0.93	0.11	0.00	0.28
Branch Road	Long-haul	0.16	0.00	0.00	0.01
	Medium- haul	0.34	0.01	0.00	0.03
	Short-haul	1.00	0.05	0.00	0.12
Turns	Long-haul	0.20	0.04	0.00	0.03
	Medium- haul	0.56	0.10	0.01	0.06
	Short-haul	2.24	0.33	0.02	0.24
Travel distance	Long-haul	1959.22	342.57	150.03	278.35
	Medium- haul	149.94	93.56	50.04	28.68
	Short-haul	50.00	21.54	2.55	13.58
Tolls	Long-haul	2137.00	281.24	0.00	348.71
	Medium- haul	430.00	44.53	0.00	62.26
	Short-haul	194.00	5.93	0.00	20.63
Path Size	Long-haul	0.79	0.35	0.09	0.27
	Medium- haul	0.80	0.47	0.08	0.28
	Short-haul	0.82	0.52	0.08	0.31

5.2 Model results

5.2.1 Model comparison

Table 3 presents the parameter estimated results of MNL models and PSL models of long-haul, medium-haul, and short-haul trips. It shows that the significance and the symbolism of the influencing factors for PSL model and MNL model are almost the same in each scenario.

However, the adjusted R-squared of PSL model surpasses those of MNL model in each scenario, indicating that the PSL model with the route overlapping parameter, can more accurately capture the genuine patterns of the truck route choice preference. Hence, our subsequent analysis of truck route choice preferences will be grounded on the insights derived from the PSL model.

5.2.2 Route choice preference

Based on the parameter estimated results of PSL models in Table 3, we identify the characteristics of preferent roads among long-haul, medium-haul, and short-haul trips. For long-haul trips, the variables related to motorways and sub-arterial roads exhibit significantly positive effects on route preferences. Conversely, the variable associated with arterial roads shows no significant impact, while the branch road variable demonstrates significantly negative effects. Similar patterns are observed for medium-haul trips, indicating a preference for routes comprising a combination of motorways and sub-arterial roads for long-haul and medium-haul trips. For short-haul trips, while all types of roads exhibit significantly negative impacts on route preferences, the negative effect of sub-arterial roads stands out as the least among them, indicating a preference for sub-arterial roads over other types in short-haul trips.

Based on the above results, we find that branch roads are not prioritized across the three trip categories, while sub-arterial roads are the preferred choice. This implies that sub-arterial roads function as terminal ways to deliver goods to their ultimate destinations, thereby drawing a significant usage of trucks. Secondly, arterial roads are not considered choices for long-haul and medium-haul trips, while motorways are favored for these two scenarios. The reason may be that their relatively lower speed and safety standards compared to motorways, as well as reduced accessibility compared to sub-arterial roads. In contrast, motorways primarily accommodate long-haul and medium-haul trips. This preference may be because motorways offer advantages such as higher speed, enhanced safety, and greater stability, making them the preferred choice for relatively long distances.

In addition, the variable of turns exhibits a significantly negative impact on medium-haul and short-haul trips, meaning that the routes with fewer turns are favored for these two trips. This phenomenon may be because the high fraction of urban local roads for medium-haul and short-haul trips. Given the complexities involved in navigating heavy-duty trucks, the route-maker decision often favors the route with fewer turns to ensure the safety of both the vehicle and its cargo. However, this effect is not significant for the long-haul trip.

Furthermore, there are some shared characteristics observed in the parameters of travel distance and tolls among these three trips. Specifically, travel distance has a significantly negative effect on route choice preference, as expected. However, the toll variable exhibits significantly positive effects on all three types of trips. This phenomenon may be attributed to the preference for motorways observed in both long-haul and medium-haul trips, along with the secondary preference for motorways evident in short-haul trips. This indicates that despite the additional cost, route decision-makers may opt for toll roads due to their potential advantages, such as faster travel times, better road conditions, or safer driving. In addition, the truck travel dataset in this paper primarily focuses on the Yangtze River Delta region, where goods of high value are predominant. Consequently, there may be less attention paid to toll costs.

Variable related to path size aims to account for the impact of route overlap, with larger values indicating reduced overlap among routes. The coefficient for the logarithm of Path Size (Ln(Path Size)) exhibits different effects across the three scenarios. Specifically, it has a significant negative effect on long-haul and medium-haul trips, suggesting that route decision-makers tend to prefer routes that have higher congruence with other routes. This phenomenon may be attributed to the relatively limited inter-city road network, leading attractive routes to often coincide with other options in the choice set. Moreover, these highly congruent routes may provide the additional advantage of flexibility, allowing for route adjustments to address sudden traffic issues. However, for short-haul, the parameter of path size shows a positive effect on preference route, which means short-haul trips tend to favor routes with lower congruence. This may be because that short-haul trips frequently take place within urban environments characterized by a higher density of intersections. Compared to the roads with high congruence, lower congruence roads typically entail fewer intersections and more direct, thereby offering truck drivers a more ease and safer driving experience, while also helping them circumvent typical traffic congestion.

Table 3 Parameter estimation results for three scenarios

parameters	PSL model			MNL model		
	value	std err	p-value	value	std err	p-value
Long-haul						
Constant	-3.970	1.725	0.021	-2.801	1.699	0.099
Motorway	3.636	1.727	0.035	3.726	1.704	0.029
Arterial Road	1.727	1.735	0.319	1.207	1.711	0.481
Sub-Arterial Road	4.769	1.784	0.008	4.130	1.762	0.019
Branch Road	-47.64	3.875	0.000	-54.074	3.985	0.000
Turns	0.067	0.473	0.887	0.002	1.631	0.033
Travel distance	-0.005	0.000	0.000	-0.006	0.000	0.000
Tolls	0.009	0.001	0.000	0.009	0.001	0.000
Ln(Path Size)	-0.887	0.073	0.000			
Observations	7672			7672		
Adjusted rho square	0.457			0.440		
Log-likelihood	-2379.9			-2455.9		

Medium-haul						
Constant	-1.210	0.750	0.107	-0.541	0.759	0.476
Motorway	1.688	0.747	0.024	1.888	0.759	0.013
Arterial Road	0.766	0.745	0.304	0.810	0.757	0.285
Sub-Arterial Road	2.116	0.762	0.005	2.151	0.775	0.006
Branch Road	-11.921	1.248	0.000	-11.775	1.255	0.000
Turns	-4.384	0.498	0.000	-5.503	0.503	0.000
Travel distance	-0.008	0.001	0.000	-0.010	0.001	0.000
Tolls	0.004	0.001	0.000	0.005	0.001	0.000
Ln(Path Size)	-0.600	0.227	0.000			
Observations		7709			7709	
Adjusted rho square		0.164			0.152	
Final log-likelihood		-3731.0			-1894.2	
Short-haul						
Constant	6.474	0.379	0.000	5.885	0.381	0.000
Motorway	-2.427	0.375	0.000	-3.007	0.381	0.000
Arterial Road	-3.306	0.361	0.000	-3.823	0.369	0.000
Sub-Arterial Road	-1.582	0.366	0.000	-1.946	0.374	0.000
Branch Road	-7.373	0.407	0.000	-7.534	0.412	0.000
Turns	-4.011	0.145	0.000	-3.651	0.137	0.000
Travel distance	-0.080	0.003	0.000	-0.068	0.003	0.000
Tolls	0.026	0.002	0.000	0.021	0.002	0.000
Ln(Path Size)	0.684	0.051	0.000			
Observations		9621			9621	
Adjusted rho square		0.273			0.256	
Final log-likelihood		-2631.8			-2669.4	

5.2.3 Marginal effects

To assess the comparative sensitivity of variables across the three scenarios, we calculate the marginal effects of variables with significant effects in each scenario, as delineated in Table 4.

First, it shows that the presence of branch roads has the largest influence on the route choice in each scenario. Specifically, 1 unit (1%) increase in the proportion of branch roads, the probability of choosing this route decreases by 4.691% in long-haul trips, 1.920% in medium-haul trips, and 1.143% in short-haul trips, respectively. Additionally, the marginal effect of branch roads is pronounced in long-haul trips, followed by medium-haul and the least in short-haul trips, suggesting that trucks' avoidance of branch roads increases with longer trip distances.

Second, the marginal effect of the turns ranks second for both medium-haul and short-haul trips. This indicates that convenience of operation and safety significantly affect route preference for both distance scenarios. Specifically, when the number of turns increases by 1 per kilometer, the probabilities of choosing this route decrease by 0.706% and 0.622% for medium-haul and short-haul trips, respectively.

Third, the route choices of long-haul and medium-haul trips are also sensitive to the variables of motorway and sub-arterial road. However, we find that long-haul trips exhibit greater sensitivity to motorway and sub-arterial roads compared to medium-haul trips. Specifically, a 1% increase in the proportion of motorways leads to a 0.358% increase in the probability of selecting this route for long-haul trips, whereas it results in a 0.272% increase for medium-haul trips. Similarly, a 1% increase in the proportion of sub-arterial roads results in a 0.470% increase in the likelihood of choosing this route for long-haul trips, but only a 0.341% increase for medium-haul trips. These findings suggest that longer-distance travel may prioritize faster routes provided by motorways. Simultaneously, it uses the sub-arterial roads to complete the terminal transportation.

Furthermore, the marginal effect of travel distance and tolls are relatively small, but they also exhibit variability across these three scenarios. Specifically, when the travel distance increases 1 unit (1 kilometer), the probability of choosing this route decreases by 0.001% in both long-haul and medium-haul trips, and 0.012% in short-haul trips, respectively. However, this marginal effect in short-haul trips is more pronounced compared to this in long-haul and medium-haul trips, meaning that short-haul trips demonstrate the highest sensitivity to changes in travel distance when compared to long-haul and medium-haul trips, and more tend to the shortest distance route. In addition, the marginal effect of tolls on long-haul and medium-haul trips are less pronounced compared to this in short-haul trips, suggesting that long-distance travel is comparatively insensitive to tolls change.

Table 4 Marginal effects of significant variables across three scenarios

Variables	Long-haul	Medium-haul	Short-haul
Motorway	0.358	0.272	-0.376
Arterial Road	/	/	-0.513
Sub-Arterial Road	0.470	0.341	-0.245
Branch Road	-4.691	-1.920	-1.143
Turns	/	-0.706	-0.622
Travel distance	-0.001	-0.001	-0.012
Tolls	0.001	0.001	0.004
Path Size	-0.086	-0.096	0.106

5.3 Route choice mechanism

We find that while the combination of motorways and sub-arterial roads is preferred for both long-haul and medium-haul trips, long-haul trips exhibit a higher sensitivity to motorways and sub-arterial roads compared to medium-haul trips. These findings suggest that longer-distance travel may prioritize faster and more accessible routes provided by motorways and sub-arterial roads. Given that long-distance travel typically entails greater uncertainty as the travel distance increase (Cantillo et al., 2021; Hu et al., 2018; Zhu et al., 2023), route decision-makers may pay more attention to the efficiency and reliability of the route. Hence, decision-makers with long-distance travel usually select routes with high-grade roads, characterized by fewer interference, faster speeds, and enhanced safety. Moreover, long-haul and medium-haul trips also exhibit less sensitivity to changes in tolls. On the one hand, higher travel costs make it less sensitive to tolls (Toledo et al., 2020; Wang and Goodchild, 2014; Wood, 2012; Zhou et al., 2009). On the other hand, they tend to prefer some motorways offering faster speeds despite higher toll charges. This observation further confirms that longer-distance travel places greater emphasis on travel efficiency while somewhat reducing the attention on travel economics. In addition, given the value of goods in long-haul and medium-haul trips is higher than that in short-haul trips, the preferred route with high-grade road and higher tolls can be understood.

In the context of short-haul trips, the preferred route characteristics also underscore their emphasis on travel safety, efficiency, and reliability. Specifically, their preferences incline towards routes with fewer turns, more direct, and shorter travel distances. Short-haul trips commonly favor local low-grade roads, such as sub-arterial roads, which typically feature multiple intersections. Therefore, opting for such routes facilitates the avoidance of congestion, and promotes ease of driving and reliability, all while improving driving safety concurrently. Additionally, short-haul trips exhibit the highest sensitivity to changes in travel distance compared to long-haul and medium-haul trips. On one hand, the decrease in travel distance leads to an increase in sensitivity to travel distance, which is similar to the previous studies (Łukawska et al., 2023; Toledo et al., 2020). On the other hand, short-distance delivery demands frequently include essential items such as daily necessities, food, and fast-moving consumer goods, which often necessitate urgent and timely delivery (Giuliano et al., 2020; Zhu et al., 2023).

Consequently, any increase in travel distance can result in extended delivery times, presenting a heightened sensitivity to travel distance for delivering these goods (Hess et al., 2015; Knorring et al., 2005; Quattrone and Vitetta, 2011).

6. Policy implications

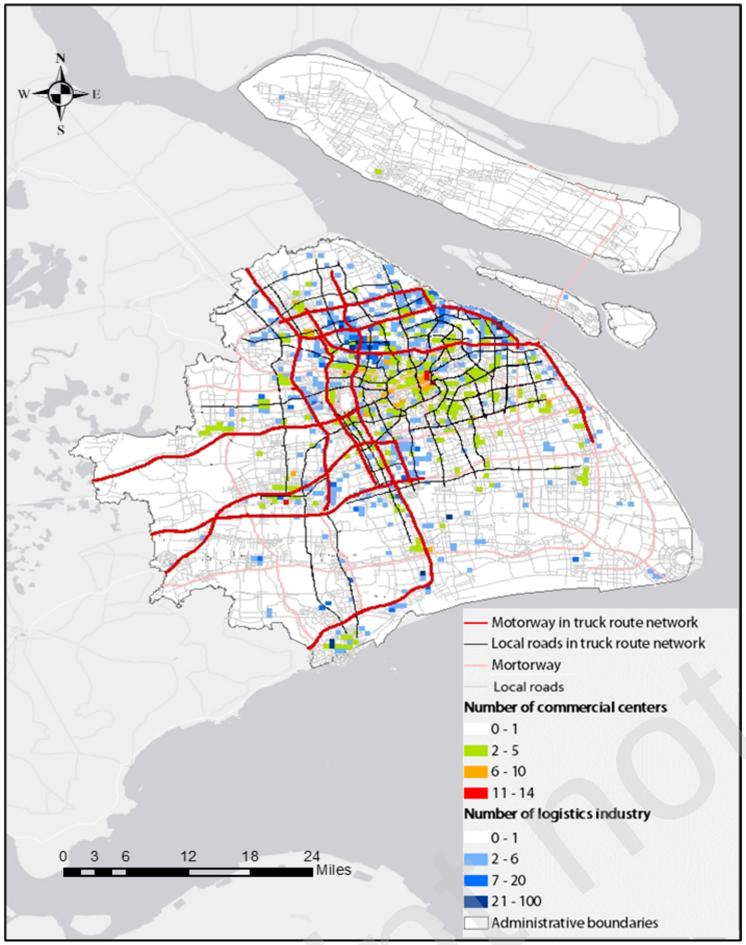
Based on these findings, we propose a few strategies for designing an urban truck route network to accommodate diverse freight demand types with varying travel distances. Specifically, this network can be categorized into two main segments: (1) interregional trunk routes that primarily accommodate long-haul and medium-haul trucking and (2) local routes that mainly serve short-haul trucking. Specific trucks are recommended to follow truck routes to the greatest extent possible; going off the routes to avoid traffic could lead to traffic fines subject to certain regulated zones and time periods. The real-time navigation system on smartphones could incorporate the truck route network when providing navigation suggestions to truck drivers so that violations can be further reduced. Specific considerations on designing the truck route network are shown as follows.

When designing the interregional trunk routes, planners may consider placing emphasis on prioritizing freeways linking regions with significant freight connections, so as to construct the main skeleton for the truck route network. The selected motorways should be able to provide the most time-saving route options. In this way, long-haul and medium-haul truck drivers could make the best use of the truck route network through interregional corridors, thus avoiding the serious congestion in the high-density urban areas.

With regard to the local routes, attention should be paid to arterials and secondary roads between zones with high concentrations of freight related establishments including fulfillment centers, warehouses, and retail stores. Planners may consider establishing a grid-like sub-network with intervals twice or three times as the existing road network. Such sub-network would provide short-haul urban delivery trucks conveniences to travel within the central areas. After all, the central areas are filled with freight demand and delivery trucks deserve more access to accommodate such demand.

In order to better illustrate the design principles, we again utilize Shanghai city as the case study. Renowned as a global trade hub, Shanghai has witnessed the proliferation of freight establishments in recent years (Qin et al., 2023; Yang et al., 2022b). We focus on the areas with massive freight demand and try to formulate a truck route network serving both long-haul and short-haul truck movement. It is intuitive to designate the major inter-province motorway as the trunk freight corridors that provide capacities for large-volume interregional truck flows (see the Fig. 5). Long-haul and medium-haul trucks predominantly travel along these designated truck routes (as illustrated in Figure 6), according to the data set we presented above.

For the local truck routes, direct connections between the urban core and a multitude of warehousing facilities are established. These routes radiate from the urban core area, characterized by a high concentration of commercial centers, and typically utilize certain arterials and primary surface roads, as illustrated in Fig. 5. Along these truck routes, short-haul trucks can efficiently reach their destinations via the most direct and fewer turns. The selected short-haul trucking (as presented in Fig. 6) exactly relies on this network to complete the main trip.



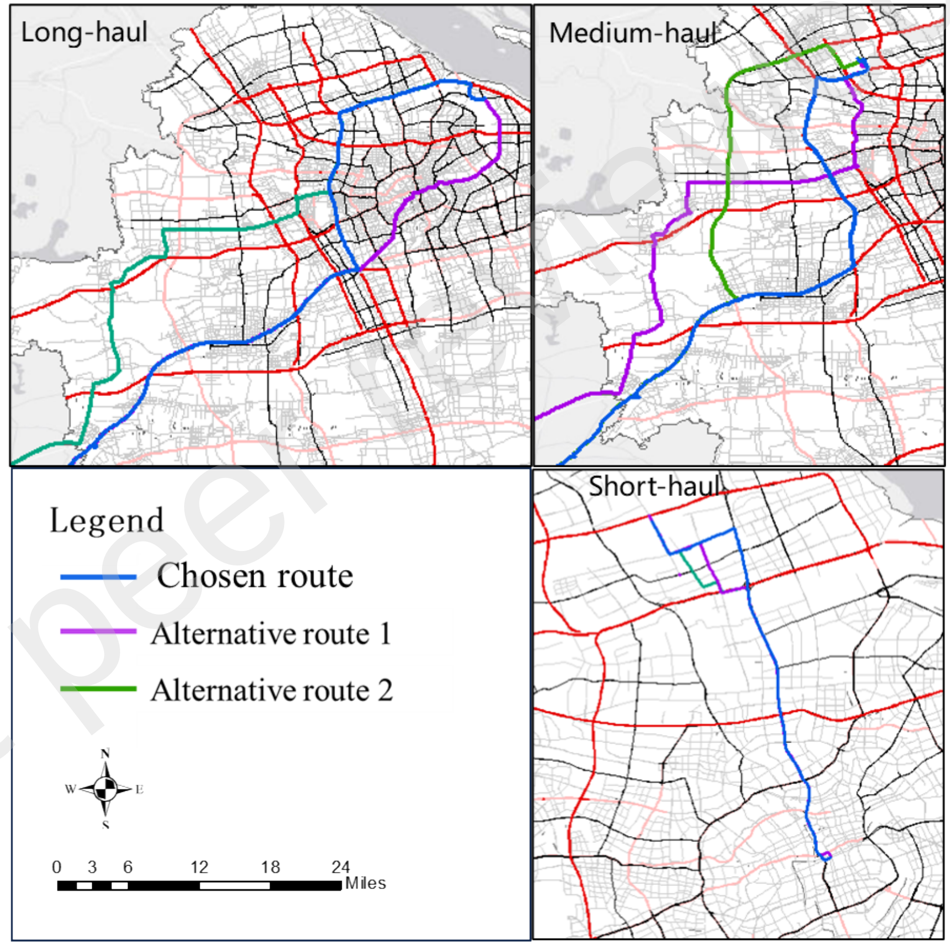


Fig. 5. Truck route network in Shanghai City

Fig.6. Samples for Long-haul, medium-haul, and short-haul

In addition, the proposed design principles for the truck route network resemble those found in the New York City's truck route map, as shown in Fig. 7. Specifically, the truck route networks in New York are divided into local truck routes and through truck routes. Among these, the local truck route network permits trucks with origins or destinations for delivery, loading, or servicing within the respective borough to utilize. Through truck route networks allow trucks without origins or destinations within the borough to use the routes (NYC, Department of Transportation, 2022). We observe that the local truck route network (blue lines) offers the shortest and least convoluted routes for trucks to navigate safely and efficiently. In addition, the report indicates that nearly one-third of all serious injury and fatality crashes involving trucks happened on non-truck routes (NYC, Department of Transportation, 2022). Therefore, these designated truck route networks play a pivotal role in enhancing urban traffic safety. Concurrently, our findings validate the rationale behind the design of these truck route networks.

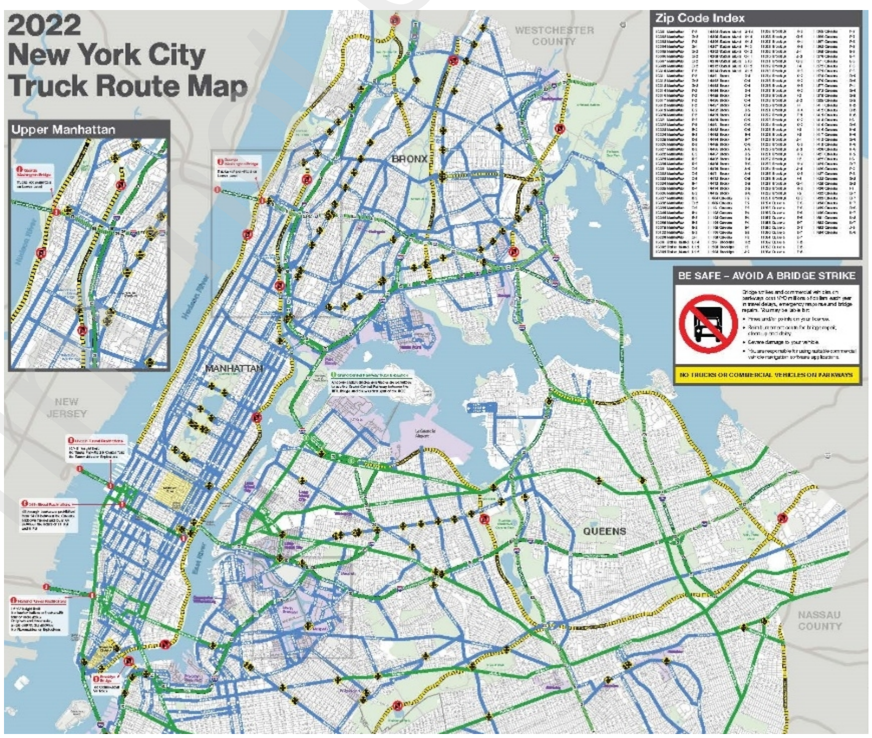


Fig. 7. New York City Truck Route Map

7. Conclusions

This paper aims to investigate the variations and commonalities in route choice preferences among trucks undertaking short-haul, medium-haul, and long-haul, and uncover the underlying mechanisms governing route choice behavior. Considering the overlapping of available routes, we use the Path Size Logit model to explore the route choice preference, and utilize truck GPS data to conduct empirical analysis within the framework of route decision mechanisms. The significant contributions of this research are threefold. Firstly, it provides a novel understanding the distinctions and commonalities in truck route preferences across long-haul, medium-haul, and short-haul, thereby shedding light on a previously overlooked research area. Second, it offers a systematic framework for analyzing truck route choice preferences, which is helpful to reveal the mechanism of truck route choice behavior. Third, the discoveries gleaned from this research can offer insights into designing a tailored truck route network for long-haul, medium-haul, and short-haul trips. This tailored approach is pivotal for efficiently managing truck traffic flows and alleviating their impact on the urban transportation system.

We find that while the characteristics of preferred routes vary across long-haul, medium-haul, and short-haul trips, they collectively reflect the consideration of travel efficiency, safety, and reliability in the decision-making process. Specifically, all these freight demands incline to the short distance routes, while short-haul trips exhibit the highest sensitivity to the travel distance. In addition, long-haul and medium-haul trips tend to favor routes that combine motorways and sub-arterial roads, while long-haul trips present higher sensitivity. However, short-haul trips prefer the route characterized by few turns, and a tendency towards sub-arterial roads as the last-mile delivery ways. Finally, we propose different truck route network design principles appropriating for long-haul, medium-haul, and short-haul trips to better manage truck travel routes.

There are some shortcomings in this paper. First, we assume that decision-makers are rational and their choices are driven by utility maximization. However, it's important to acknowledge that route decision-makers may also be influenced by bounded rationality and individual psychological perceptions, such as attitudes and habits, which were not measured in this study. Future research could explore route preferences under the influence of habit to gain a more comprehensive understanding of route choice preference. Second, the lack of certain information about route decision-makers in the route choice model, which is inherent to the limitations of GPS data. In future studies, integrating survey data with large-scale GPS data could compensate for these deficiencies and provide a more comprehensive understanding of route preferences. Third, the truck travel dataset in this paper primarily focuses on the Yangtze River Delta region, where goods of high value are predominant. Consequently, route decision-makers tend to allocate less attention to economic factors. In future research, it would be beneficial to utilize more comprehensive datasets encompassing a broader range of goods to enhance the understanding of route choice mechanisms.

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