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Modeling the economic cost of congestion in Addis Ababa City, Ethiopia

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Abstract

Road traffic which results in significant time lags, increased fuel consumption, and financial losses, remains a noteworthy challenge in developed and developing countries. As a result, the Ethiopian Government and the City Administration of Addis Ababa have built extensive road networks and imposed restrictions on driving, vehicle acquisition and parking. However, despite all these efforts, drivers and passengers waste significant time on long traffic queues, resulting in unpredictable and delayed travel. The current study investigated the cost of travel time delay, vehicle operating costs, time reliability, and the factors influencing these variables. The study used questionnaires, measurements, and traffic counting techniques to collect data from nine road segments. The sample comprised 3240 participants. The cost functions of both drivers and passengers were examined using a multiple linear regression model, with estimation performed using ordinary least squares. According to the findings, the economic costs of congestion depend on the number of lanes, the length of the road segment, the volume of traffic, and the respondents' income level. The study also revealed that travel, vehicle operation, and unreliability costs account for 74%, 6%, and 20%, respectively, of the total congestion costs.

Keywords Congestion, Economic cost, Free flow, Travel time, Unreliability, Vehicle operating cost

Background

The phenomenon of urbanization is occurring globally, as Farrell (2017) noted. Approximately 50% of the global populace resides in urban areas, with projections indicating a surge in this statistic, particularly in emerging economies. According to the United Nations (2018), it is projected that by 2050, the urban population agglomeration will be predominantly concentrated in Asian and African cities, constituting 90% of the total population. This will result in the addition of 2.5 billion individuals to the global urban population. Similarly, according to the United Nations (2019), the urban population in sub-Saharan and East African nations experienced a growth rate of 4% and 4.5% from 2015 to 2020, and this population is anticipated to grow at a rate of 3.7% and 4.2% from 2025 to 2030 respectively. Such a population growth along with the rapid urbanization and a strong propensity for automobile ownership leads to the spread of motorization in emerging economies (Minalu and Tekilu 2014). On the other hand, poor infrastructure and poor maintenance of it aggravate the growing volume of traffic, leading to congestion, pollution, and a low standard of road safety (Yilma 2014).

As identified by different studies, traffic congestion incurs substantial economic costs in the majority of nations. For example, Afrin and Yodo (2020) reported that in 2018, the United States incurred $87 billion in lost productivity due to congestion. According to Gabr et al. (2018), the annual total traffic cost on the primary

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four routes in Mansoura city, Egypt, was estimated to be 184.5 million Egyptian pounds (EGPs). In addition, traffic congestion has been prevalent in numerous metropolitan areas in sub-Saharan Africa (Gabr et al. 2018; Oluwaseyi 2017; Vencataya et al. 2018).There are different factors that contribute to the presence of congestion in road segments or on different routes. These include traffic volume, the capacity of the segment, the number of lanes, segment length, and modal choice (Arnott 2001). It also includes the time of the day, rain, occupancy (Feng et al.2011), number of pedestrian crossings, percentage of heavy vehicles, average travel speed, number of crosswalks, and average headway time (Addison and Fosu 2016) & duration of day, travel direction, and number of road accidents (Charlotte et al. 2017). Ethiopia has begun a period of swift urbanization, predominantly in the metropolis of Addis Ababa. According to the United Nations Human Settlements Program (UN-HABITAT) report of 2017, the city has already encountered notable challenges regarding traffic congestion and road safety. Consequently, the daily transportation of individuals and goods within cities has become progressively intricate and arduous, leading to increased travel time and vehicular operational expenses.

In Addis Ababa, more than 600,000 vehicles, accounting for 56% of the whole vehicle fleet, are responsible for significant local air pollution and traffic congestion. Although Addis Ababa boasts an extensive network of roads, spanning around 5,000 km and consisting of asphalted, gravel and cobblestone surfaces, these roads are insufficient to accommodate the increasing transportation needs of the city, especially along the primary routes. Davis (2022) identified a total of 124 routes for Anbessa buses, 2 routes for Light Rail Transit (LRT), 1529 routes for minibus taxis, and 37 routes for Higer buses. A significant majority of the routes are located in the core areas. Approximately 70% of taxi routes are located in inner sub-cities such as Lideta, Addis Ketema, Arada, and Kirkos. Since 2014, RIDE cab and other metered taxis have been transitioning to become online door-to-door services.

In 2008, the Addis Ababa transport bureau implemented a zoning taxi system to ensure equitable transport services across various route segments and mitigate traffic congestion and related challenges. Although Addis Ababa has fewer vehicles compared to other developing cities, transit is still impacted by several factors, such as infrastructure and architectural categories. Pedestrians frequently exhibit incorrect walking behavior on road networks, leading to inefficiency and necessitating urbanization and urban development to address transportation issues. As per the Addis Ababa transport bureau, 65% of the roads lack pedestrian infrastructure. All of these factors highlight the distinctive characteristics of the transportation environment in Addis Ababa. As stated above, one of the urbanization challenges in Addis Ababa city in connection to transportation system is traffic congestion.

Sitotaw and Tekilu (2019) conducted a study to determine the overall economic cost of congestion in Addis Ababa. This study focused on the route from Megenagna to the CMC, both of which are located in the city's eastern region. The results indicated that the total congestion cost for this 4.46 km distance was 42,897,752.15 Birr. Consequently, the mean economic loss incurred per kilometer per annum amounted to 9,618,330 Birr (the Ethiopian currency). Andarge and Teklu (2017), estimated the overall congestion costs, encompassing both the delay and wasted fuel costs incurred by passenger and truck vehicles utilizing four distinct road segments, with a total length of 1.18 km, located in the southeastern corridor of the city. The estimated total cost was 213 million Birr. The loss incurred was calculated to be 180 million Birr per kilometer. Sitotaw and Tekilu (2019) employed nonrepresentative sample to estimate the temporal value of passengers, while Andarge and Teklu (2017) accounted for full vehicle occupancy across all vehicle types when estimating the economic value, potentially inflating the overall economic cost.

Although the cost of congestion is an existing reality, the road segments considered in previous studies in Ethiopia did not go through the congestion criteria to determine the presence of congestion in the identified segments. Mohan Rao and Ramachandra Rao (2012) and Afrin and Yodo(2020) identified speed reduction index, travel rate, delay rate, volume to capacity ratio, and relative congestion index as a criteria to identify the presence of congestion in road segments. The criteria have the minimum value to classify the road segments as congested or noncongested before going to any cost estimation. For example a road segment with its speed reduction index value of greater than 5 can be labeled as congested road.

There is also very little evidence in statistical modeling of the economic cost of congestion by taking into consideration explanatory variables such as volume, segment width and length, trip frequency, and modal choice that all influence the impact in some way. In addition, the socioeconomic characteristics of the respondents were not included as explanatory variables for the cost of congestion in any study to determine how individual characteristics impact economic costs. Furthermore, most studies looked at the dependability of time data(they took time delayed as dependent variable), which is part of the overall cost component, to see how different traffic variables/parameters interact with time (Addison and Fosu 2016; Charlotte et al. 2017; Feng et al. 2011). Moreover, there has been no research conducted that has constructed a statistical model that establishes a relationship between the economic cost of traffic congestion and the transportation and road factors mentioned as explanatory variables in Ethiopia.

Therefore, this study aims to identify the total economic cost of congestion and model the cost per the identified explanatory variables by considering one of its subcity (Kolfe keraniyo subcity). Specifically, the following questions were answered : (1) What are the travel time, vehicle operation, and unreliability costs of traffic congestion in the study area? (2) What is the statistical relationship between the drivers' cost of traffic congestion and the traffic volume of the segment, modal choice, trip frequency, segment length and width, and socioeconomic characteristics of the respondents as explanatory variables? (3) What is the statistical relationship between the passengers' cost of traffic congestion and the traffic volume of the segment, the modal choice, trip frequency, segment length and width, and socioeconomic characteristics of the respondents as explanatory variables?

In answering the research question described above, the city administration will be able to know the cost of congestion in the city and compare any policy measures that can be applied thereafter. For example the city administration is recently applied different policy measures including demolishing of most of the roundabout and replacing it with traffic stops, construction of pedestrian infrastructures along the primary roads, and provision of rapid bus transit services. The city administration can also use the statistical relationships to decide the best variable that can reduce traffic congestion.

Study sites and methods

Description of the study site

Addis Ababa, the political and administrative center of Ethiopia, was founded in 1886. The municipal jurisdiction encompasses an area of 540 square kilometers, which is divided into 11 subcities and 118 woredas for administrative convenience (refer to Fig. 1). Geographically speaking, Addis Ababa is situated within the latitudinal range of 8°50' to 9°06'N and the longitudinal range of 38°39' to 38°55'E. According to a report by the transport authority of Ethiopia, the cumulative number of registered vehicles in the nation, encompassing motorbikes,

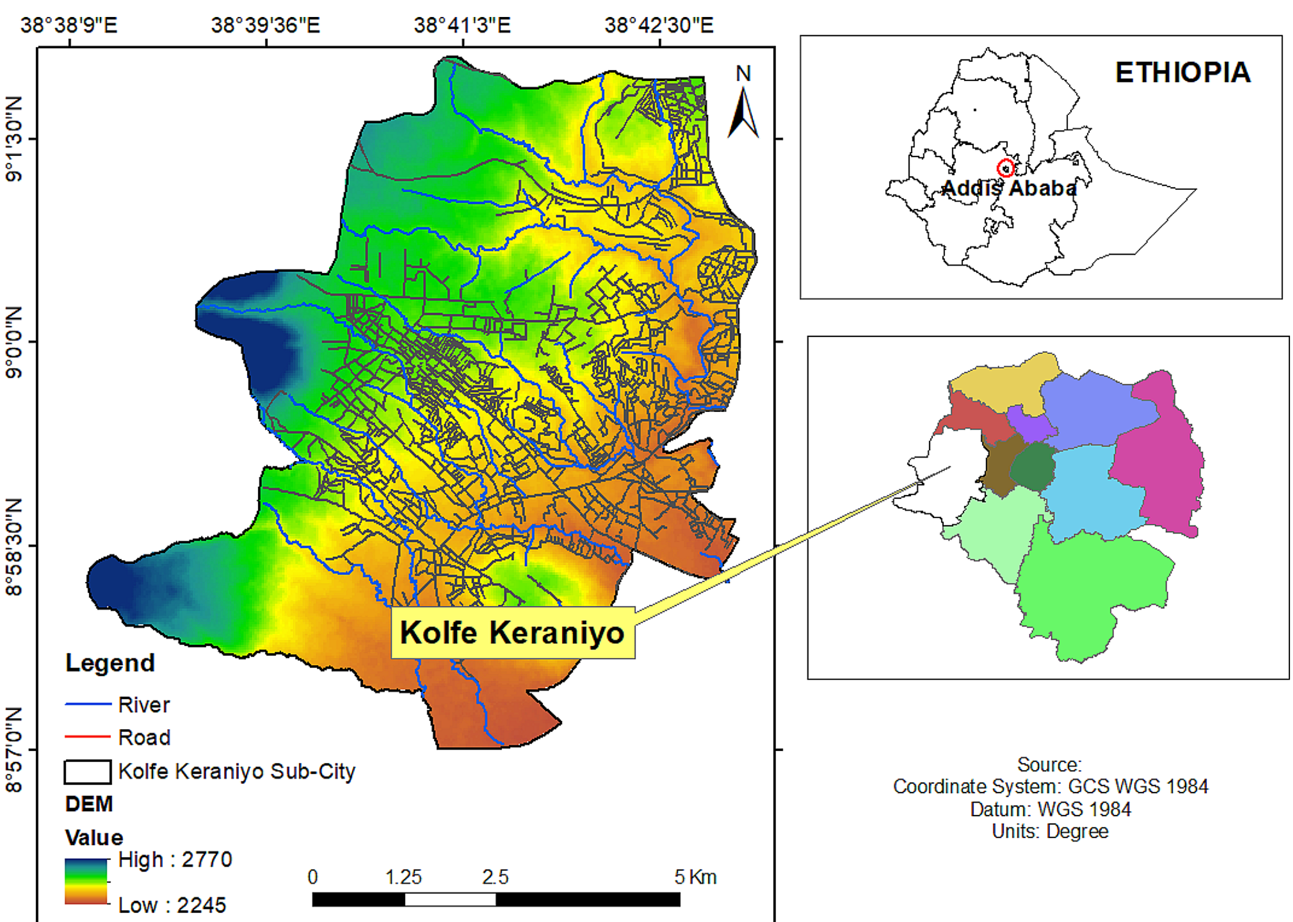

Fig. 1 Location map of Addis Ababa city

was 1,071,345 in 2019. The city accounted for more than 50% of the total number of registrations in the country.

Kolfe Keraniyo is one of the eleven subcities. According to the data provided by the Addis Ababa city administration, the aforementioned subcity encompasses an area of 61.25 square kilometer and is inhabited by a population of 546,219 individuals, comprising 220,859 males and 235,360 females. The subcity is equipped with three primary entrances that facilitate the ingress of vehicles from neighboring towns.

Methodology

Sampling technique and sample size determination

a) Sampling technique.

The study area included four distinct population groups that were interconnected to estimate the economic cost of traffic congestion. The pertinent elements in this context are the various road segments or routes, the vehicles utilized for transportation, the drivers responsible for operating these vehicles, and the passengers being transported. The study area was found to contain a total of 14 routes, consisting of 7 for outbound travel and 7 for inbound travel, for a total of 36 segments. The identification of routes was subsequently conducted through a preliminary observation of the thoroughfares accessible within the subcity. The routes facilitate the transportation of commuters from the periphery of the subcity to commercial hubs, specifically the Addis subcity, Lideta subcity, Nifasilik lafto subcity, and Gulele subcity. Furthermore, they can function as a means of accessing the surrounding residential areas, namely, Woletie, Ashewa Meda, and Burayu, to the urban center of Addis Ababa.

A preliminary study was conducted to identify the segments that exhibited acceptable levels of congestion, as determined by a speed reduction index (SRI) greater than 5 from 7:00 AM to 8:00 PM (Mohan Rao and Ramachandra Rao 2012; Afrin and Yodo 2020). Census data pertaining to the identified segments revealed that a total of nine segments met the criteria for congestion. Seven of the aforementioned segments meet the criteria solely during the morning hours from 7:00 AM to 11:00 AM, while two of the segments satisfy the conditions exclusively in the evening hours from 4:00 PM to 8:00 PM. The study area did not exhibit any acceptable levels of congestion during the time period from 11 AM to 4 PM. The segments that have been identified to represent subcity traffic congestion are presented in Figs. 2 and 3, as well as in Table 1.

After identifying the qualified road segment, two distinct data types were gathered utilizing the segments and traffic points located at the destination site as the designated units for data collection. The initial aspect pertained to the duration necessary to traverse the entirety of the segment, while the latter was employed to enumerate and classify vehicles that traversed the endpoints within half-hour increments during peak periods, specifically from 7 to 11 AM and 4 PM to 8 PM. Vehicle occupancy rates by vehicle categories were also identified. The above procedures helped to estimate the population size at each segment which ultimately allow to select the samples.

This research employed both stratified and simple random sampling techniques to collect information from respondents. The specified segment or traffic point is utilized by two distinct groups, namely, the drivers and the passengers, who can be classified into separate strata. After establishing the appropriate sample size for each stratum, a sampling distribution was conducted to encompass drivers and passengers across all vehicle categories, with both strata being given equal consideration. The inclusion of additional drivers in the sample is imperative for addressing inquiries pertaining to the vehicle's classification, as well as associated details such as year of production, fuel category, and fuel efficiency per kilometer.

b) Sample size determination.

As can be seen in Table 1, a distinct population is associated with each of the nine segments, and as such, a representative sample was selected for each segment. The study's sample size was determined based on Yamane (1967). According to Yamane (1967), the sample size of the population is calculated using the following formula

$$n = N/(1 + N(e)2.$$

Where N=population size n=desired sample size e=the margin error in the calculation.

Therefore, the sample size of the study is given in the Table 1.

c) Data collection instruments.

The study used questionnaires, measurements, and counting techniques to collect data from nine road segments.Survey questionnaires were administered to both drivers and passengers who were traveling in diverse modes of transportation. The first part of the questionnaire contains the demographic characteristics of the respondents while the second part includes information about the travel behavior and the third part contains information about the vehicle characteristics. In addition the duration required to traverse the segment was recorded on multiple occasions throughout a week, encompassing Monday to Saturday. Additionally, a tally

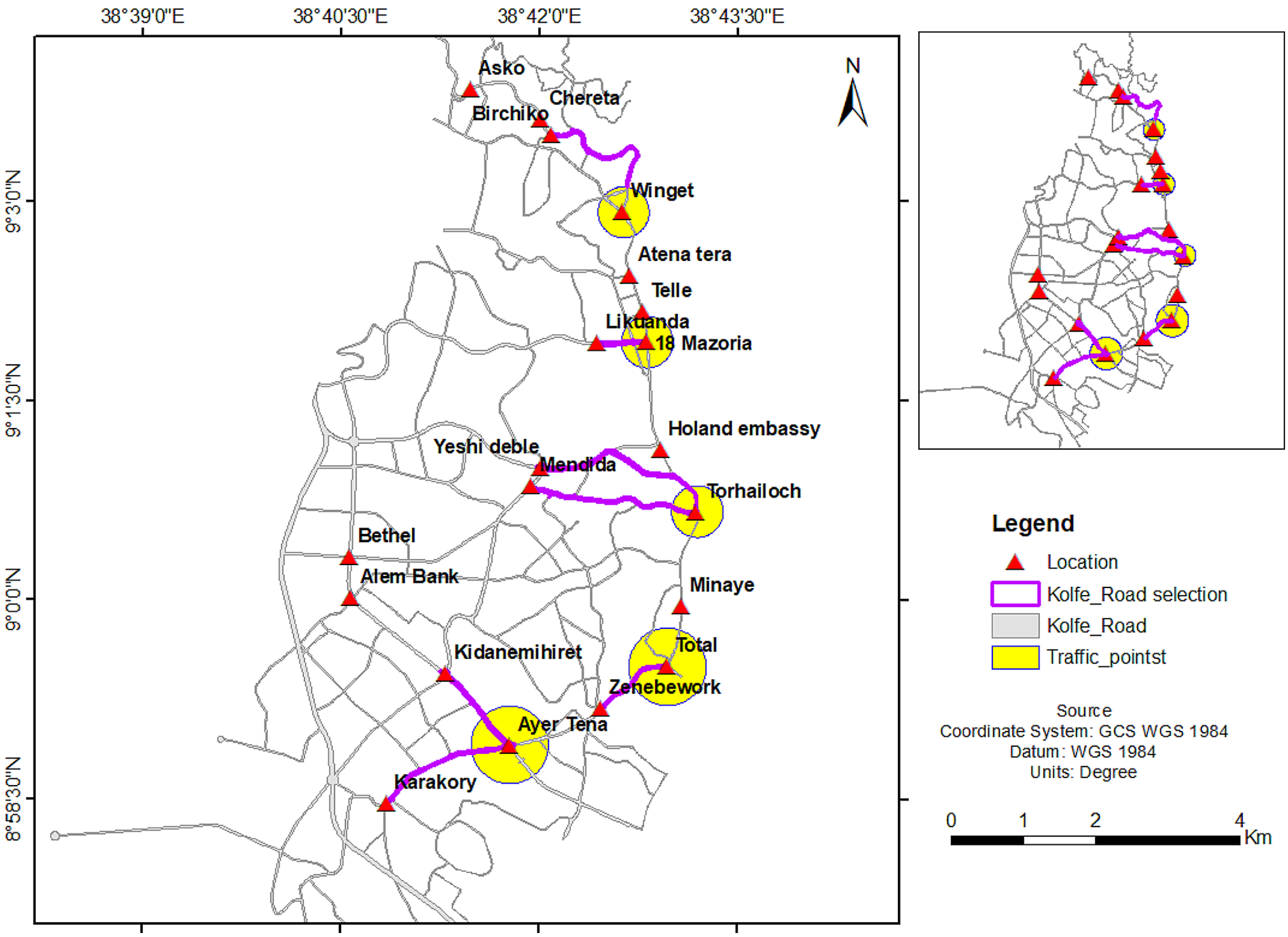

Fig. 2 Qualified segments and traffic points in the study area (morning)

of the vehicular traffic passing through the designated points was conducted. The study was conducted over a period of three weeks and was distributed across three distinct months of the calendar year (specifically, April 4–9/2022, May 2–7/2022, and June 6–11/2022).

Estimation of the economic cost of traffic congestion

Economic costs can be objectively measured through three distinct components: travel time, vehicle operation, and unreliability costs.

i) *Travel Time Cost*:

The amount of time forfeited due to traffic congestion can be calculated by determining the disparity between the duration of travel speed when there is congestion and the speed at which traffic flows freely in the absence of congestion. The value attributed to time is subsequently utilized to calculate the value of the time lost due to traffic congestion.

The quantification of the value of individual travel can be derived from the income section of the survey formulated and disseminated among commuters and drivers. Furthermore, data about the hourly income rate of commercial vehicles and trucks were gathered.

Therefore, the annual vehicle delay cost for passengers = daily passenger vehicle hours of delay × value of person time × vehicle occupancy × annual factor (52 weeks x 6 days-holidays) (Andarge and Tekilu 2017; Eisele et al. 2013).

Similarly, the annual delay cost for commercial vehicles = daily commercial vehicle hours of delay × value of commercial vehicle time × annual factor (52 weeks x 6 days-holidays) (Andarge and Tekilu 2017; Eisele et al. 2013).

ii) Vehicle operating cost (VOC).

The present research utilized multiple data sources to establish usage rates for vehicle operating costs in a congested state. Then, these rates are subsequently compared with those in an uncongested system to evaluate the impact of traffic congestion on vehicle operating costs. The initial instrument employed for data collection

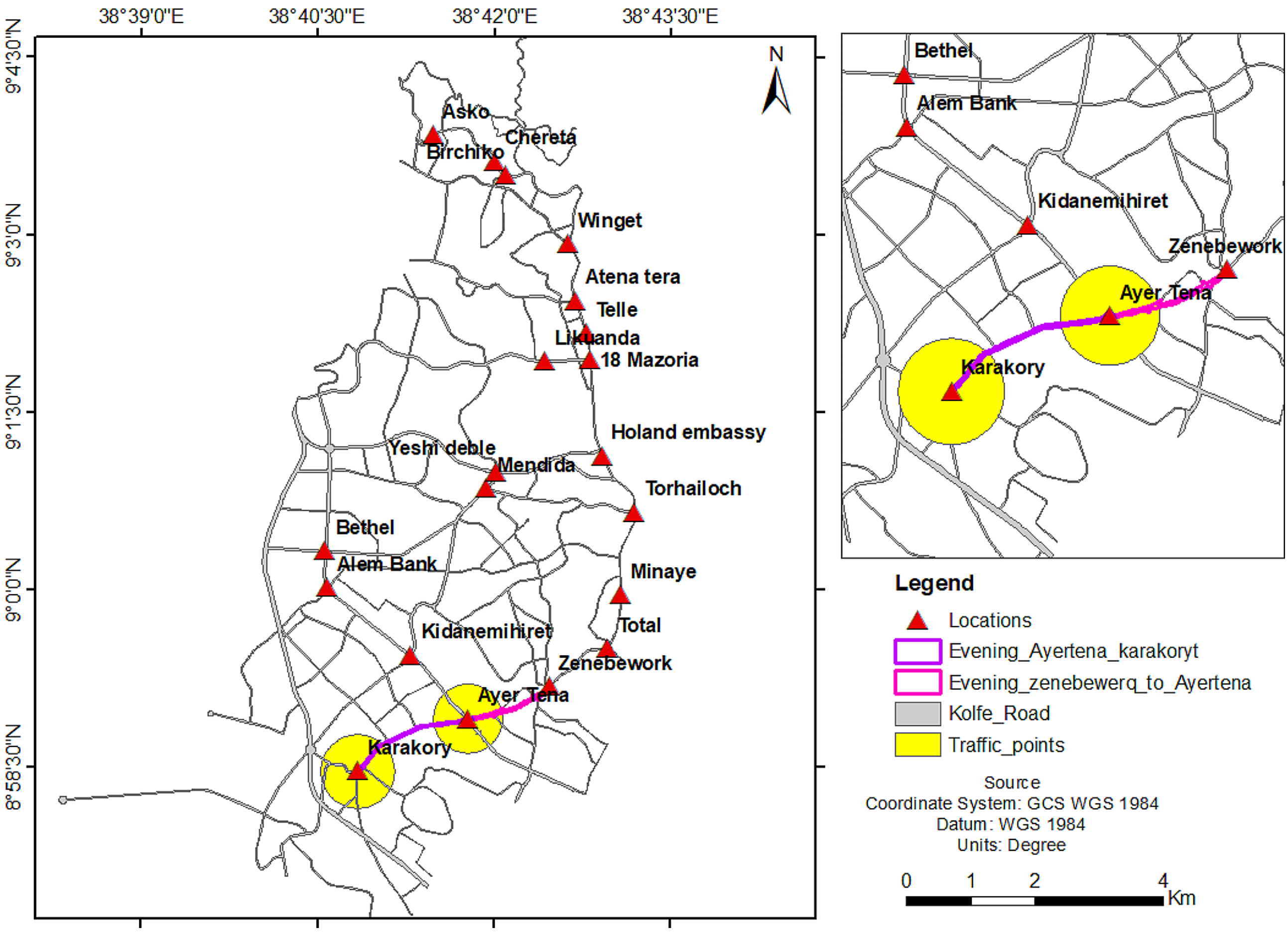

Fig. 3 Qualified segments and traffic points in the study area (evening)

Table 1 Population and sample size of the study population

SN	Segment Name	Traffic point	Total population	sample size	sample size(driver)	sample size(passenger)
	Morning (7AM -11AM)					
A1	Kara-Ayertena	Ayertena crossings	44,533	396	198	198
A2	Kidanemihiret-Ayertena	Ayertena crossings	20,947	393	197	197
A3	Zenebwork-Total	Total roundabout	36,917	396	198	198
A4	Mendida-TorHailoch	Torhailoch roundabout	44,774	396	198	198
A5	Holland-Torhailoch	Torhailoch roundabout	34,999	395	198	198
A6	Lukanda-18mazoriya	18 mazoriya crossings	43,567	396	198	198
A7	Birchiko -Winget	Winget roundabout	39,033	396	198	198
	Evening (4PM -8PM)					
B1	Ayertena-Kara	Karakore taxi mazoriya	43,014	396	198	198
B2	Zenebwork-Ayertena	Ayertena crossings	35,236	396	198	198
Total			343,020	3,560	1,780	1,780

Source: Field survey, May/2022

involved examining of the knowledge and experience of drivers operating on various types of vehicles. This was done to ascertain the rate of fuel consumption per kilometer under both free-flowing and congested traffic conditions. This was accomplished through the administration of a field survey questionnaire. Next, the calculation of the consumption component was performed across various vehicle categories. Accordingly,

Annual vehicle fuel cost = Daily fuel wasted × vehicle's category × gasoline/benzene cost × annual conversion factor (Andarge and Tekilu 2017; Eisele et al. 2013).

An alternative method of addressing the VOC involved calibrating data derived from prior investigations.

Various authors have identified inefficiencies in vehicles of varying types. For example, according to the findings of the Royal Automobile Club of Queensland (RACQ) on Greener Monitoring, the average fuel consumption of vehicles under congested conditions was 30% greater than that under free-flow conditions.

The overall fuel-related operational cost can be estimated by multiplying the fuel consumption rate by the number of cars, the roadway length, and the fuel price.

iii) Unreliability Cost:

Traffic congestion can increase travel time uncertainty, which can compel travelers to allocate more time. Several tools exist to measure reliability. These indices include the percent variation and travel time window method, 95th or other percentile travel time, as well as the buffer index (BI) and planning time index (PTI) (Chen and Fan 2019). The present study assessed reliability by quantifying the reliability as the standard deviation of travel time.

The total cost of variability = 1 standard deviation (STD) ×VOT ×value of reliability (VOR) × peak congested vehicle kilometer traveled.

Modeling of the economic cost of congestion

In addition to assessing the overall cost of congestion in the examined segments, this study endeavored to construct a statistical model that quantifies the economic cost of traffic congestion considering several factors, including volume, volume squared, segment capacity, frequency of trips, modal selection, segment width and length. According to the urban economic theory proposed by Richard (2001), the model to be estimated is nonlinear, posing a challenge to estimate using a multiple linear regression model. As a way out, one can change the nonlinear to linear model by substituting the quadratic part (q^2 with q^*) and running a multiple linear regression model. i.e.

$$C = \beta_1 q + \beta_2 q^* + \beta_3 \tau + \beta_4 \omega + \beta_5 MC + \beta_6 RC$$

The reduced model is therefore.

$$\begin{aligned} CP_i = & \alpha_1 q + \alpha_2 q_i^* + \alpha_3 \omega_i \\ & + \alpha_4 TF_i + \alpha_5 MC_i + \alpha_6 NL_i + \alpha_7 SL_i \\ & + \alpha_8 INC_i + \alpha_9 AGE + \alpha_{10} HS + \alpha_{11} WEX + u_i \end{aligned}$$

$$\begin{aligned} CD_i = & \theta_1 q + \theta_2 q_i^* + \theta_3 \omega_i \\ & + \theta_4 TF_i + \theta_5 MC_i + \theta_6 NL_i \\ & + \theta_7 SL_i + \theta_8 INC_i + \theta_9 AGE \\ & + \theta_{10} HS + \theta_{11} WEXP + \varepsilon_i \\ & \mathrm{i} = 1 \ldots \mathrm{n} \end{aligned}$$

where CP and CD are the individual congestion costs (Birr per km) for passengers and drivers, respectively; q is the traffic volume of the segment (number of vehicles passing per hour per lane); q* is the traffic volume squared of the segment (the same unit as q); w is the capacity of the segment; TF is the trip frequency of the individual using the segment (number); MC is a modal choice of the individual (for passenger: Bus, City Bus, Minibus, Midbus, Meter Taxi; for drivers: Auto, Utility, Mass, and Truck); NL is the number of the lane of the segment in which the individual was considered as a sample; SL is the segment length at which the individual was considered as a sample; INC is the income of the respondent; AGE is the age of the respondents; HS is the household size of the respondents; WEXP is the work experience of the respondents; and n is the sample size.

The assumptions of linear regression models, such as the normality and independence of the error, the inclusion of the uncorrelated predictors (no multicollinearity), constant variance (homoscedasticity), and uncorrelated errors (no autocorrelation), were tested. The ordinary least squares method was used for the estimation of the model.

Results and discussion

Descriptive statistics of the respondents

The study planned to incorporate 3560 samples using the survey method. However, due to the methodology employed for data collection, which involved administering questionnaires to respondents on the streets and collecting completed forms on subsequent days, the response rate was 91%. A total of 3240 drivers and passengers responded to the study questionnaire. Table 2 displays the results of the characteristics of the respondents.

Segment characteristics of sampled route

The characteristics of the segments are presented in Table 3. The segments have a minimum length of 0.88 km and a maximum length of 2.623 km.

Economic cost of traffic congestion

Travel time cost

As shown in Table 4, the study revealed that the mean daily time loss in the observed segments varied between 38,687 and 49,011,considering free-flow speeds of 30, 40, and 60 km/hr. However, the above scenario suggests that the per-kilometer losses fall within 2,418 to 3,063 h.

The data pertaining to the income levels of the respondents were gathered to convert unproductive hours into a monetary value. These data served as a proxy measure for the wages of the respondents and were analyzed for specific segments within the designated time frame, revealing a significant loss. Accordingly, the average

Table 2 Descriptive statistics of the respondents

Characteristics of the respondents		Frequency	%
Response rate			91
Gender of the respondents	Male	2510	77.5
	Female	730	22.5
	Total	3240	100.0
Age by groups	1–25	523	16.1
	26–35	1556	48.0
	36–45	790	24.4
	46–55	289	8.9
	>=56	82	2.5
	Total	3240	100.0
Education levels of the respondents	Below eight grades	183	5.6
	9–12	1177	36.3
	Diploma	1237	38.2
	Degree	535	16.5
	Master's Degree and above	108	3.3
	Total	3240	100.0
Marital Status of the Respondents	Single	1215	37.5
	Married	1966	60.7
	Divorce	59	1.8
	Total	3240	100.0
Income by groups	<=2000	263	8.1
	2001–5000	794	24.5
	5001–10,000	1850	57.1
	10,001–15,000	180	5.6
	15,001–20,000	74	2.3
	>=20,001	79	2.4
Occupation of the respondents	Working as an employee in a government office	512	15.8
	Working as an employee in a private office	1449	44.7
	Working my private job	1279	39.5
	Total	3240	100.0
Work experience by a group	<=1	132	4.1
	2–5	846	26.1
	6–10	1689	52.1
	11–15	268	8.3
	16–20	136	4.2
	> 21	169	5.2
	Total	3240	100.0

daily incomes of drivers and passengers were 35 and 33 Birr, respectively (Table 5). A similar analysis conducted by Sitotaw and Tekilu (2019) estimated that the average income of respondents (drivers and passengers) in the city (Gurdsholla to CMC) was 32 Birr per hour, while European academic research (2015) estimated the average value of time in Ethiopia for business trips to be 19 Birr per hour. Therefore, the total economic loss in the segments was calculated by combining the waste time and the average income of the drivers and passengers. The results indicate that drivers incurred losses of 45.4, 51.2, and 65.3 million Birr due to time wastage at 30, 40, and 60 km/hr speeds, respectively. Similarly 353.4, 398.7, and 414.4 million Birr have been expended as a result of passenger traffic congestion, with the same speed scenarios of 30, 40, and 60 km/hr taken into account, as indicated in Table 5.

Another cost element linked to travel time pertains to the expenses incurred during a business trip. The estimation identified this component, which involved segregating vehicles by license plate number filtration. Accordingly, following the Ethiopian Transport and Logistics Authority plate number assignments, in this research taxis, private vehicles (predominantly automobiles), business vehicles, government-owned vehicles and nongovernmental organization (NGO) vehicles are assigned plate code numbers 1, 2, 3, 4 and 35, respectively. Additionally, other code numbers are allocated for diplomats. The present analysis, which exclusively focuses on commercial vehicles estimated an annual loss of Birr 102.6 to 131.4 million (Table 6).

Considering the mean remuneration and assuming speeds of 30, 40, and 60 km/hour, the estimated annual losses due to time delays amount to Birr 501.4 million, 566.9 million, and 611.1 million, respectively.

Vehicle operating cost (VOC)

The survey and field counting results given in Table 7 show that the mean fuel consumption in liters per kilometer varies between 0.09 for automobiles and 0.27 for heavy trucks. The study segments exhibit a range of fuel consumption rates from 433 to 2247 L per day, resulting in a cumulative daily consumption of 8220 L. After daily consumption is extrapolated to a yearly basis, the total fuel consumption amounts to 2,465,959 L. Notably, 40% of the vehicles utilize diesel, while the remaining 60% use benzene.

Given the challenges in objectively measuring fuel loss during congestion, this study relied on drivers' estimates of fuel loss while in traffic. Therefore, the data about driver approximations, which were gathered through a questionnaire survey, revealed an average fuel loss of 26%. Similarly, as per the report by RACQ, approximately 30% of the fuel is estimated to be wasted due to traffic congestion. Furthermore, traffic congestion accounts for 40% of the fuel cost in Dhaka city, Bangladesh (Khan and Islam 2013).

Considering an estimated fuel loss of 26% attributable to traffic congestion, the study segments experienced a loss of 44.9 million Birr. This translates to an annual loss of 2.450 million Birr per kilometer of driving in the segments mentioned in the study.

Unreliability cost

After determining the travel time cost, as described in the above section, the next step is to determine the cost of unreliability for each subset of the population (drivers,

Table 3 Characteristics of the segments' average time taken under traffic congestion

Segment Code	Number of lanes	Actual				SRI (Speed Reduction Index)		
		Time in Hr (Average) in Hr	Standard deviation in Hr	Distance in km	Speed km/hr	30	40	60
A1	1	0.2167	0.100	1.958	9	7.0	7.8	8.5
A2	2	0.1333	0.049	1.334	10	6.7	7.5	8.3
A3	3	0.2500	0.059	1.139	5	8.3	8.8	9.2
A4	2	0.2000	0.045	2.383	12	6.0	7.0	8.0
A5	2	0.1639	0.055	2.623	16	4.7	6.0	7.3
A6	1	0.0833	0.039	0.881	11	6.3	7.3	8.2
A7	2	0.1434	0.066	2.295	16	5.0	6.3	7.5
B1	1	0.2000	0.062	1.958	10	6.7	7.5	8.3
B2	3	0.1333	0.026	1.413	11	6.3	7.3	8.2

Table 4 Time taken under free flow in Hr under different speed scenarios

Segment code	Time taken under free flow (different speed)			Time wasted for different speed scenario			Total time wasted in hr/ day		
	30	40	60	30	40	60	30	40	60
A1	0.065	0.049	0.033	0.151	0.168	0.184	6742	7469	8196
A2	0.044	0.033	0.022	0.089	0.100	0.111	1861	2094	2327
A3	0.038	0.028	0.019	0.212	0.222	0.231	7828	8178	8528
A4	0.079	0.060	0.040	0.121	0.140	0.160	5398	6287	7177
A5	0.087	0.066	0.044	0.046	0.068	0.090	1606	2371	3137
A6	0.029	0.022	0.015	0.054	0.061	0.069	2351	2671	2991
A7	0.077	0.057	0.038	0.057	0.076	0.095	2218	2965	3711
B1	0.065	0.049	0.033	0.135	0.151	0.167	5795	6497	7199
B2	0.047	0.035	0.024	0.086	0.098	0.110	3039	3453	3868
Total wasted time in HR per day							38,687	43,844	49,011
Wasted time Hr/km./day							2418	2740	3063

passengers, and commercial vehicles). According to the findings, the total unreliability cost for drivers, considering a variation of one standard deviation from the mean, was 13.6 million Birr. In a similar vein, the unreliability cost associated with the passenger was 105.7 million Birr (See Table 8). Finally, the cost of unreliability for commercial vehicles is 31 million Birr, bringing the total cost of uncertainty in the study segment up to 150.3 million Birr (See Table 9).

As shown in Table 10, the total economic cost of traffic congestion in the study area ranged between 696.5 million and 806.3 million Birr per year, considering the three economic cost components. As expected, most of the cost components were accounted for by travel time (74%), followed by unreliability cost (20%). Finally, fuel costs make up 6% of the total congestion costs. The structure of congestion cost components varies depending on the methodology used, data availability, coverage, and the country's or citizens' per capita income (Andarge and Teklu 2017; Gabr et al. 2018; Sitotaw and Tekilu 2019; United Nations 2018). For example, the HDR for the Office of Economic and Strategic Analysis (2009) estimated that the overall cost of congestion in all urban areas in the U.S. was $85.4 billion. The most significant category of this cost was travel time, which accounted for $60.6 billion or approximately 71% of the total. The expenses associated with operating vehicles were identified as the second major factor contributing to the total cost of congestion, which was estimated to be $11.3 billion. Specifically, these costs accounted for 13% of the fuel cost component, while the remaining cost component represented 16%.

In a similar vein, Gabr et al. (2018) reported that the aggregate yearly cost associated with traffic congestion on the examined routes was 184.5 million EGP. The predominant component of the total yearly cost associated with traffic congestion in the research area was waiting time delays, accounting for 55% of the overall expenditure. The maintenance cost accounting for 28% of the overall yearly expenditure is mostly attributed to the substantial operation expenses associated with microbuses and minibuses. The cost associated with reliability accounted for approximately 6% of the overall annual expenditure, but the remaining expenditures, including fuel consumption, pollution, and the productivity loss

Table 5 Economic loss of drivers and passengers

Segment name	Average wage per hr(deriver)	Average wage per hr(passenger)	Driver population	Passenger population	Economic loss of drivers ('000)			Economic loss of passenger ('000)		
					30 km/hr	40 km/hr	60 km/hr	30 km/hr	40 km/hr	60 km/hr
A1	41	32	3,644	40,889	7,525	8,258	58,773	65,108	71,442	7,525
A2	32	29	2,851	18,096	2,767	3,900	13,989	15,739	19,087	2,767
A3	38	40	5,086	31,831	12,701	14,468	80,343	83,939	69,814	12,701
A4	29	26	4,044	40,730	5,020	7,981	37,581	43,770	61,980	5,020
A5	28	22	3,720	31,279	3,108	5,632	16,187	20,653	36,511	3,108
A6	34	34	5,120	38,447	3,185	4,328	20,888	23,729	25,058	3,185
A7	42	43	4,884	34,149	5,749	6,720	32,557	41,029	36,230	5,749
B1	36	41	3,608	39,406	5,962	7,436	65,746	73,708	62,615	5,962
B2	36	35	4,900	30,336	5,165	6,624	27,290	31,016	31,619	5,165
Total time delayance cost					45,383	51,182	65,346	353,354	398,691	414,357

resulting from injuries, constituted a similar proportion of approximately 6%.

In Ethiopia, particularly in Addis Ababa, Sitotaw and Tekilu (2019) reported that the total economic cost of congestion from Megenagna to CMC (Eastern parts of the city), which is approximately 4.46 km, was 42,897752.15 Birr. The average loss per km/year was 9,618,330 Birr, and the average speed of vehicles throughout the segment was 16.6 km/hr. This average decreased to 10.6 km/hr during the pick hours, while the findings of this study indicated that the average loss per km/per year was 41,042,133 Birr and that the average speed was 10.5 km/hr. Keeping the spatiotemporal issues constant, the traffic speeds identified for the segments in this study look similar. In addition, the average incomes of the respondents in the two studies were also nearly similar (the average income per hour in the present study was 35 and 33 Birr for passengers and drivers, respectively, while it was 32 Birr in the previous study). In relation to this, Andarge and Teklu (2017) estimated the total congestion costs, including delay costs and wasted fuel costs of passenger and truck vehicles. By using four road segments with a total segment length of 1.18 km in the southeastern corridor of the city, they estimated 213 million Birr, which is equivalent to 180 million Birr per km. The cost per km found by that study seems exaggerated compared to the findings of the current study. The main reason for this discrepancy could be the vehicle occupancy rate. A previous study considered the scenario of full vehicle occupancy, which was deemed impracticable, as demonstrated in the present study.

Regression model for the economic cost of congestion

Following the specified model in Sect. 3.2.3 and using SPSS, separate multiple linear regression models were applied for drivers and passengers. A commonly used method for standardizing datasets that display skewed variables is to implement logarithmic transformation of the data. All continuous variables were logarithmically transformed as per standard practice. Accordingly, Tables 11, 12, 13 and 14 show the econometric model results. Regarding the assumptions of the linear regression model, the collinearity statistics show that the data on traffic volume and traffic volume squared have a multicollinearity problem; hence, correction is needed. Accordingly, based on the importance of each variable in the model, the variable with respect to the square of the traffic volume was removed from both models, and new models were constructed, excluding this variable. For cross-sectional data, serial correlation was not a problem and was not considered in this study. Furthermore, a test of heteroscedasticity revealed that the data had no such problem as the error had no relation with the independent variables. We also conducted normality tests for the

Table 6 Time wasted for business vehicles in Birr

Vehicle category	Plate number		Total	Daily rent value	Time wasted for different speed scenario in Birr per day		
	1	3			30	40	60
Automobile		2,925	2,925	571.6	22,072	25,167	28,260
Automobile Taxi	1,256	1,055	2,311	561	17,115	19,515	21,914
Utility		3,376	3,376	975.7	43,485	49,583	55,677
minibus	1,224	3,797	5,021	688.4	45,630	52,029	58,424
Mid bus		770	770	811.1	8,245	9,401	10,557
Bus		2,008	2,008	4000	106,034	120,904	135,763
Minitruck		2,019	2,019	1117.9	29,796	33,975	38,150
Truck		1,323	1,323	2087.7	36,463	41,576	46,686
Heavy truck		720	720	3500	33,268	37,933	42,595
Total Loss in for business vehicles per day(birr)					342,107	390,084	438,026
Total Loss in for business vehicles per year(birr)					102,631,959.49	117,025,268.48	131,407,779.80

Table 7 Total fuel consumption in liter and Birr in the identified segments

Vehicle type	Fuel consumption per km	A1	A2	A3	A4	A5	A6	A7	B1	B2	Total Fuel consumption in liter per day
Automobile	0.093	204	136	179	347	377	161	429	202	212	2,247
Automobile taxi	0.098	48	19	22	86	88	22	72	50	25	433
Utility	0.127	38	117	182	86	74	31	235	37	216	1,015
Mini bus	0.123	239	96	159	269	290	154	334	246	199	1,986
Mid bus	0.143	27	14	24	27	16	5	33	13	28	188
bus	0.179	130	22	34	144	108	40	100	130	38	747
Mini truck	0.187	66	32	77	107	108	76	73	66	90	694
truck	0.189	91	11	25	77	75	53	17	93	32	472
Heavy truck	0.267	126	3	9	62	60	35	16	121	7	438
Total Fuel consumption per day (Liter)		970	450	711	1,204	1,194	577	1,310	957	848	8,220
Total Fuel consumption per Year ('000)		291	135	213	361	358	173	393	287	254.4	2,466.0
Total Fuel loss per Year in Liter ('000)		75.6	35.1	55.5	93.9	93.1	45	102.2	74.7	66.1	641.1
Total Fuel LOSS per Year In Birr ('000000)		5.3	2.5	3.9	6.6	6.5	3.1	7.2	5.2	4.6	44.9

Table 8 Unreliability cost for drivers & passengers

Segment Code	Mean	1Standard deviation (STD)	Unreliability cost	
			Driver	Passenger
A1	13	2.521	1,885,278	16,310,849
A2	8	2.917	1,345,331	7,652,256
A3	15	3.517	3,360,325	22,208,692
A4	12	2.717	1,618,657	14,112,999
A5	10	3.283	1,682,239	11,179,491
A6	5	2.317	2,005,698	14,944,454
A7	9	3.983	4,120,865	29,407,355
B1	12	3.700	2,434,097	30,091,516
B2	8	1.583	1,390,645	8,351,266
For the whole population			19,843,135	154,258,879
68.5% of the population			13,592,547.57	105,667,332.28

Table 9 Unreliability cost for business vehicles

Vehicle category	Plate number		Total	Daily rent value	Unreliability Cost assuming for 1 STD
	1	3			
Automobile		2,925	2,925	571.6	3,081,189
Automobile TAXI	1,256	1,055	2,311	561	2,389,258
Utility		3,376	3,376	975.7	6,070,423
minibus	1,224	3,797	5,021	688.4	6,369,881
Mid bus		770	770	811.1	1,150,974
Bus		2,008	2,008	4000	14,802,121
Minitruck		2,019	2,019	1117.9	4,159,485
Truck		1,323	1,323	2087.7	5,090,122
Heavy truck		720	720	3500	4,644,092
For the whole business population					47,757,544
68.5% of the business population					31,042,403.55

error using the Kolmogorov-Smirnov test and the Shapiri-Wilk test and found that there is no problem with it.

For the first model (driver model), depicted in Table 11, the coefficient of determination (R-square) value of 0.927 indicates that 92.7% of the variation in the dependent variable (economic cost of congestion) was accounted for by the independent variables. With respect to the second model (passenger model), the coefficient of determination (R-square) of 00.976 indicates 97.6% variation in the dependent variable (economic cost of congestion), which accounts for independent variables and indicates a strong relationship between the predictors and the dependent

Table 10 Summary of economic cost

SN	Economic cost components	population unit	Birr (30 km/hr speed)	Birr (40 km/hr speed)	Birr (60 km/hr speed)	Share
1	Time cost	Driver	45,383,186	51,182,064	65,346,150	
2	Time cost	Passenger	353,353,972	398,691,449	414,356,761	
3	Time cost	Business	102,631,959.49	117,025,268	131,407,779.80	
Travel Time			501,369,117	566,898,781	611,110,691	74
4	Vehicle operating cost		44,880,456.9	44,880,456.9	44,880,456.9	6
5	Unreliability cost	Driver	13,592,547.57	13,592,547.57	13,592,547.57	
6	Unreliability cost	Passenger	105,667,332.28	105,667,332.2	105,667,332.28	
7	Unreliability cost	Business	31,042,403.55	31,042,403.55	31,042,403.55	
Total Unreliability cost			150,302,283.40	150,302,283.40	150,302,283.40	20
Total Economic cost			696,551,857	762,081,521	806,293,431	100

Table 11 Overall significance of the models

Model	*R*	*R* Square	Adjusted *R* Square	Std. Error of the Estimate
Driver	.963[a]	0.927	0.926	0.51347
Passenger	.988[a]	0.976	0.976	0.51756

variables. Therefore, the overall significance test results for both models in Table 12 also showed that the model fit well (at $P=000$).

Tables 13 and 14 show significant positive correlations between the dependent variable and the respondent income and traffic volume. On the other hand, segment length and number of lanes exhibit a significant and negative correlation with the individual congestion cost. According to both models, the analysis revealed the expected signs of the significant predictors. Although the study was performed on time reliability, which is a component of congestion, Assen and Quezon (2019) also identified volume and segment length as predictors. The direction of the relationship is the same for segment length, while the opposite is true for volume compared to the current study. An increase in the volume of vehicles traversing a specific location within an hour is suggestive of a surplus of vehicles in a queue, thereby leading to an increase in travel expenses. These points can be illustrated by two frequently occurring traffic scenarios. The first is the current traffic jam, where there are many cars but they move slowly. When these two factors are combined, the flow rate is very low. The second situation is when there is very little traffic on the road, so drivers can go as fast as they want without being bothered by other

Table 13 OLS estimates of the coefficients for the driver model

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
LNL	−0.815	0.054	−0.304	-15.197	0.000
LSL	-1.016	0.051	−0.342	-19.885	0.000
LQ	0.947	0.049	2.866	19.376	0.000
LAGE	−0.056	0.082	−0.105	−0.686	0.493
LHS	0.016	0.029	0.011	0.545	0.586
LINCOM	0.537	0.028	2.522	19.350	0.000
LWEXP	0.022	0.030	0.024	0.733	0.464

Table 14 OLS estimates of the coefficients for the passenger model

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
LNL	-1.063	0.047	−0.221	-22.509	0.000
LSL	-1.044	0.041	−0.203	-25.495	0.000
LQ	1.247	0.039	2.127	31.977	0.000
LAGE	−0.029	0.055	−0.030	−0.533	0.594
LHS	0.029	0.026	0.012	1.100	0.271
LINCOM	0.580	0.024	1.517	23.886	0.000
LWEXP	0.012	0.023	0.008	0.506	0.613

Table 12 Overall significance of the models

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
Driver	Regression	3212.614	7	458.945	1740.713	.000[c]
	Residual	254.425	965	0.264		
	Total	3467.039[d]	972			
Passenger	Regression	15321.567	7	2188.795	8171.166	.000[c]
	Residual	376.891	1407	0.268		
	Total	15698.458[d]	1414			

[a]Dependent Variable: Congestion cost

cars. The fast speeds are balanced by the very low density, which means that the flow is very low (Arnott 2001). In both models, the number of lanes negatively correlates with the individual congestion cost. This finding is in line with microscopic transport theory which states that as more lanes are built, drivers tend to use these alternative lanes to smooth travel and hence reduce the cost of congestion (Feng et al. 2011). The number of cars travelling through a certain segment also relies on how many cars travel through the opposite segment (in this study, certain traffic junctions, such as roundabouts, are staffed by traffic personnel who facilitate the flow of traffic). That is, if thereare few cars using the opposite segments, there is a steady flow in the segment, as long as other things stay the same, such as the shape of the roundabout, the number of traffic cops, the driver's experience, and the quality of the car. The variable Income was also found significant. As income increases, so does the individual cost of congestion, as the opportunity cost of remaining in traffic increases. The segment length is negatively correlated with the individual cost of congestion. As the segment length increases, there is a stable traffic flow, as evidenced in the model. The other variables such as work experience and household size were found to be insignificant in this study.

Conclusion

In this study, we examined the economic cost of congestion and tried to model it at the individual level. Thus, we identified the costs of travel time, fuel, and unreliability for drivers and passengers in different groups. We also examined the relationships between the economic costs of congestion and traffic volume, the number of lanes, segment length, age, household size, work experience and income for drivers and passengers. The study's findings indicated that a total of 696.6 to 806.3 million Birr per year were lost as an economic cost of congestion. The travel time, unreliability costs and fuel costs account for 74%, 20% and 6%, respectively. The volume, number of lanes, segment length, and income determine the individual congestion cost.

The study also have some limitation in terms of estimating the overall cost of congestion as some economic cost components such as the health cost, social cost, safety costs, environmental costs are not included in this study. In addition, we only considered the vehicle operating costs from the fuel point of view though other costs connected with it such as maintenance cost, depreciation costs, start and stop costs were not included. Though the data was collected repeatedly for three weeks in different months of the year, the result would be more accurate if we had the chance to include more weeks. There is also a limitation to incorporate some additional transport, road and traffic variables because of the resource and technology needed to trace them. Nevertheless, the study followed a strict methodology that covered the design of the survey, identification of the population, and sample selection. This methodology fosters trust in the validity of the research outcomes. Accordingly, the finding of the study aligned with the microscopic theory proposed by Richard (2001).

The identification of the economic costs can help the city administration to bench mark the present cost and compare the outcome of any policy measures by the city administration in the selected routes or road segments in the future. It also gives the chance to evaluate the impact of the mass transport service provision and the transport infrastructure provision which the government considered as a policy direction. Furthermore, the significant variables identified in the statistical modeling part dictates the policy direction to develop timely strategies for transport planning and traffic management. In addition, this work will make a small contribution in terms of addressing the lack of literature on the subject, modeling the congestion cost. This model can be further enriched by incorporating additional traffic, transport, and road variables.

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Author contributions
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The majority of the data we use for the analysis is in the manuscript. For others, we will provide them on request.

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