TRB

TRANSPORTATION RESEARCH RECORD

Journal of the Transportation Research Board, No. 2478

Freight Systems

Urban Freight and Trucking

VOLUME 2

The National Academies of
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Foreword

The 2015 series of the *Transportation Research Record: Journal of the Transportation Research Board* consists of approximately 970 papers selected from more than 4,500 submissions after rigorous peer review. The peer review for each paper published in this volume was coordinated by the committee acknowledged at the end of the text; members of the reviewing committees for the papers in this volume are listed on page ii.

Additional information about the *Transportation Research Record: Journal of the Transportation Research Board* series and the peer review process appears on the inside back cover. TRB appreciates the interest shown by authors in offering their papers, and the Board looks forward to future submissions.

Note: Many of the photographs, figures, and tables in this volume have been converted from color to grayscale for printing. The electronic files of the papers, posted on the web at **www.TRB.org/TRROnline**, retain the color versions of photographs, figures, and tables as originally submitted for publication.

Measurement Conversion Factors

To convert from the unit in the first column to the unit in the second column, multiply by the factor in the third column.

Customary Unit	*SI Unit*	*Factor*
Length		
inches	millimeters	25.4
inches	centimeters	2.54
feet	meters	0.305
yards	meters	0.914
miles	kilometers	1.61
Area		
square inches	square millimeters	645.1
square feet	square meters	0.093
square yards	square meters	0.836
acres	hectares	0.405
square miles	square kilometers	2.59
Volume		
gallons	liters	3.785
cubic feet	cubic meters	0.028
cubic yards	cubic meters	0.765
Mass		
ounces	grams	28.35
pounds	kilograms	0.454
short tons	megagrams	0.907
Illumination		
footcandles	lux	10.76
footlamberts	candelas per square meter	3.426
Force and Pressure or Stress		
poundforce	newtons	4.45
poundforce per square inch	kilopascals	6.89

Temperature

To convert Fahrenheit temperature (°F) to Celsius temperature (°C), use the following formula:
°C = (°F – 32)/1.8

SI Unit	*Customary Unit*	*Factor*
Length		
millimeters	inches	0.039
centimeters	inches	0.394
meters	feet	3.281
meters	yards	1.094
kilometers	miles	0.621
Area		
square millimeters	square inches	0.00155
square meters	square feet	10.764
square meters	square yards	1.196
hectares	acres	2.471
square kilometers	square miles	0.386
Volume		
liters	gallons	0.264
cubic meters	cubic feet	35.314
cubic meters	cubic yards	1.308
Mass		
grams	ounces	0.035
kilograms	pounds	2.205
megagrams	short tons	1.102
Illumination		
lux	footcandles	0.093
candelas per square meter	footlamberts	0.292
Force and Pressure or Stress		
newtons	poundforce	0.225
kilopascals	poundforce per square inch	0.145

Temperature

To convert Celsius temperature (°C) to Fahrenheit temperature (°F), use the following formula:
°F = (°C × 1.8) + 32

Abbreviations Used Without Definitions

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACRP	Airport Cooperative Research Program
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials (known by abbreviation only)
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SHRP	Strategic Highway Research Program
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board

Sustainable Freight

Impacts of the London Congestion Charge and Low Emissions Zones

Andrea Broaddus, Michael Browne, and Julian Allen

Assessments were made of the impacts on freight traffic and operations of two sustainability policies currently in effect in London, a congestion charge zone (CCZ) and a low emissions zone (LEZ). Responses by freight operators, including retiming, rerouting, reducing the number of trips and kilometers traveled, and replacing vehicles, was investigated. Trends from 1994 to 2012 were identified with the use of road traffic estimates, cordon counts, and vehicle speed data, supplemented by interviews with freight industry experts and operators. In this time frame, goods traffic increased throughout London but declined in the central CCZ. Findings indicate that freight traffic was largely insensitive to the congestion charge. Price elasticity of demand was estimated as −.04 to −.06 for light goods vehicles and as perfectly inelastic for medium and heavy goods vehicles in the long run. The congestion charge may have time-shifted some light goods vehicle trips. No evidence was found of rerouting of freight traffic or avoidance traffic around the CCZ. Freight operators likely benefited from travel time reductions and journey reliability improvements throughout Inner London, a wider area than the CCZ. Operational efficiencies may have been achieved through greater vehicle load consolidation but offset by the relocation of logistics depots and warehouses priced out of central London. The LEZ was effective at spurring vehicle replacement, including some substitution to smaller vehicles. Discussion recounts freight operators' perceptions of these policies and how their concerns have been addressed.

Sustainable transport policies fall into three main policy mechanisms for reducing emissions: setting vehicle standards requiring low-emissions vehicles, creating incentives encouraging conversion to low-emissions fuels, and using pricing to reduce vehicle kilometers traveled (VKT). Over the past two decades, London has taken bold steps implementing policies of all three types. This paper considers two policies currently in effect: a congestion charge zone [(CCZ) (pricing)] and low emissions zone [(LEZ) (vehicle standard)]. Both policies were first-of-a-kind in the United Kingdom and among the largest in scope of their kind in the world.

Specific responses from the freight sector have been required because goods vehicles are major contributors to particulate and smog emissions. Road freight in London accounts for about 240 million tonnes (28% of London total) of PM_{10} (particulate matter), 5,500 million tonnes (17%) of nitrogen dioxide (NO_2), and 250 million tonnes (4%) of carbon dioxide (CO_2) emissions (*1*). Freight is a derived demand that increases with population growth and follows the economic cycle. Thus, while London has experienced a long-term decline in private automobile traffic since 1999, the picture is more complicated for freight, with differing patterns for light and heavy goods traffic (Figure 1).

The LEZ was targeted at the freight sector to encourage replacement of the most polluting heavy vehicles, and it affects all goods vehicles (except the smallest vans) operating in Greater London (area of 600 mi^2). The CCZ affects only vehicles circulating within an area of central London defined by a cordon (area of 8 mi^2). Both policies are enforced using an automated number plate recognition system. Their boundaries are shown in Figure 2.

This paper investigates potential ways that freight operators could have adjusted their operations in response to the CCZ and LEZ. The aim is not to contrast and compare these policies as competing approaches, but to consider their combined impact on a particular road user group and assess progress toward sustainability goals. Freight represents a baseline of vehicle emissions that must be addressed by sustainable transport policies, but it is a somewhat captive user group with many types of constraints, and so results may not be as expected. Much of the freight data presented in this paper have not been previously published, but they were provided to the researchers by Transport for London (TfL).

GEOGRAPHY OF LONDON

Greater London has approximately 8.4 million residents and 4.3 million jobs. The CCZ roughly defines London's central business district, containing 1.3 million jobs and only 175,000 residents (*4, 5*). It encompasses most of London's most popular historic, cultural, and shopping destinations; they are visited by more than 15 million international tourists annually (*6*). The CCZ contains over half of Greater London's office space (15 million ft^2), 15% of retail space (2 million ft^2), and 2% of warehouse space (200,000 ft^2) (*7*).

This paper refers to Inner and Outer London, defined geographies used in statistical reporting. Inner London consists of the 13 innermost boroughs, and Outer London the remaining 20 boroughs. Inner London has a much higher density (26,000 people per square mile) than does Outer London (10,000 people per square mile). Central London may be defined differently depending on the context; in this paper, it refers to the CCZ.

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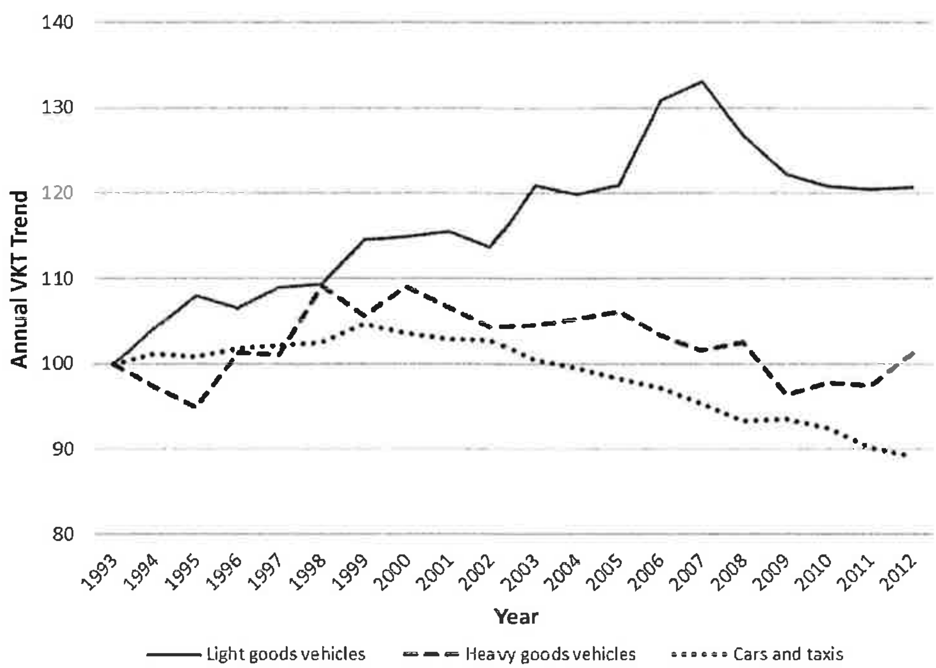

FIGURE 1 Annual VKT trend in London, all roads (1993 = 100) (2).

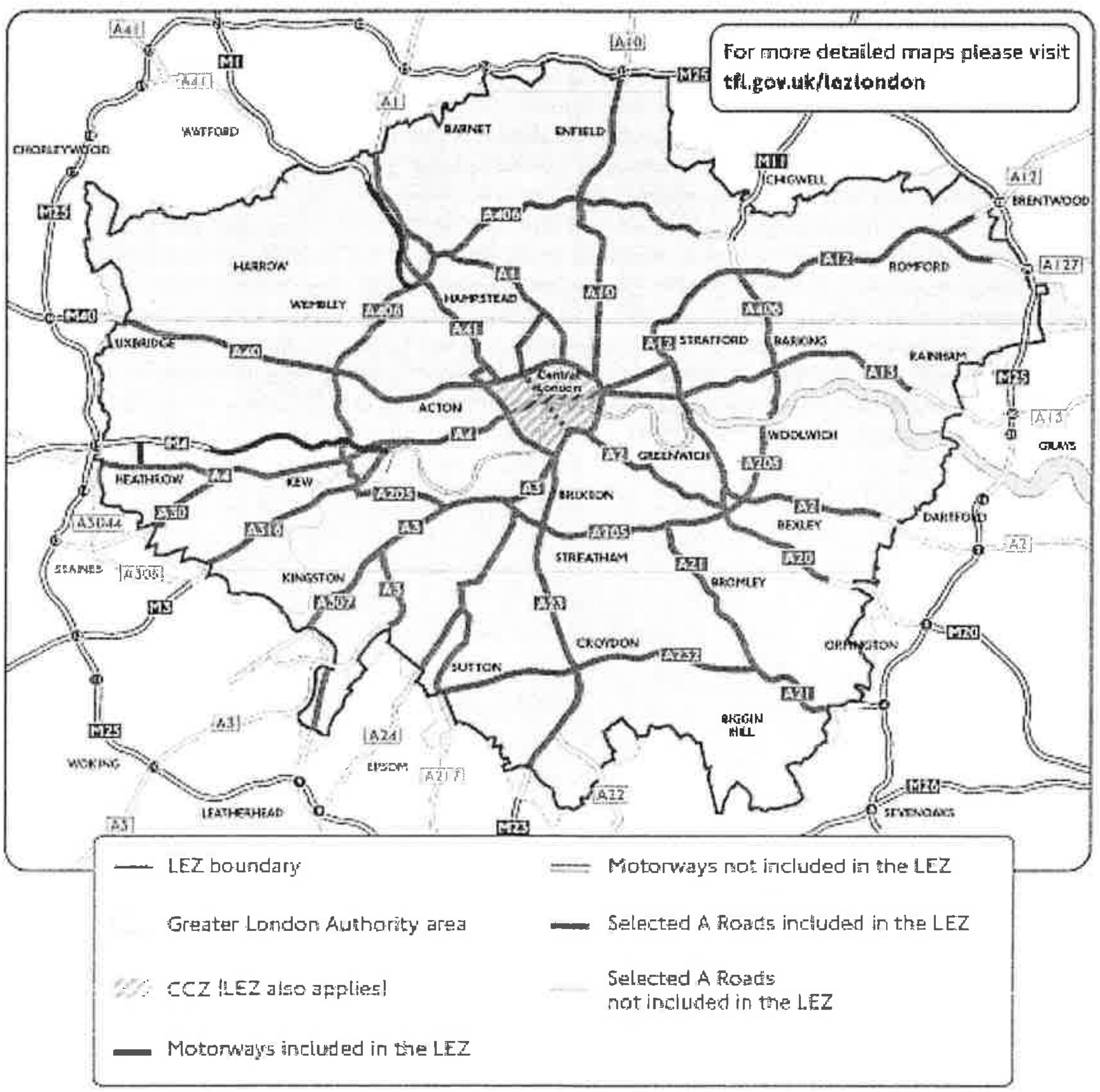

FIGURE 2 Boundaries of the CCZ, LEZ, and traffic count cordons (3).

CCZ PRICING

Introduced in February 2003, the CCZ covers London's central business district, an area of 8 square mi. All vehicles entering the zone are required to pay a daily fee during business hours on weekdays (07:00 to 18:00). When it was introduced, the fee was £5, but it is currently £11.50 (£1 = US$1.71 in June 2014). There is an exemption for vehicles that emit 75g/km or less of CO_2, the Euro V standard for air quality (the European Union sets vehicle emissions standards for vehicles sold within member states, referred to by the iteration of revision with Roman numerals for goods vehicles). Freight operators with more than six vehicles are eligible for a fleet discount of £1 per vehicle per day. The CCZ was expanded in 2008 to include a western extension area, but this was removed in response to residents' complaints in 2011. No further expansion or differentiated pricing is under consideration at this time.

Traffic volumes fell by an estimated 20% within the CCZ immediately on its introduction, and they have remained stable over the decade (*8*). Vehicle travel speeds increased in the early years but gradually declined over time resulting from road works and road space reallocation, such that average traffic speeds in the zone today are approximately equivalent to what they were ten years ago (*8*). Road work entailed maintenance and repair of key utilities located beneath London's road network, including gas, electricity, telephones, water supply, and sewage. Road space reallocation in the CCZ included the expansion of exclusive bus and cycle lanes, as well as pavement widening. Dedicated bus lanes in the zone grew from 24.5 mi in 2003 to 26.5 in 2007 (J. Barry, head of Bus Network Development, Transport for London, personal communication, April 7, 2014). Bus and cycle traffic priority measures and intersection redesign for safety purposes also contributed to reduced traffic speeds. These measures contributed to an estimated 30% decrease in network capacity in central London between 1993 and 2009, despite travel speeds increasing after the initial introduction of the CCZ (*8*). Whether the freight sector was differentially affected by these changes to the street network is unclear, for care was taken to preserve curbside access for freight vehicles.

LEZ STANDARDS

Introduced in February 2008, the LEZ sets minimum emissions standards for heavy vehicles operating throughout Greater London (600 mi^2), and it is in force 24 h a day, every day of the year (*9*). Noncompliant vehicles must pay a fee of £200 per day for vehicles 3.5 tonnes and heavier, and £100 per day for 1.2-tonne vehicles. The LEZ had a phased introduction of increasingly tough emissions standards and inclusion of vehicles. The Phase 1 emissions standard was Euro III for heavy goods vehicles (HGVs) over 12 tonnes. In July 2008, Phase 2 extended this standard to 3.5-tonne vehicles, buses, and coaches. Approximately 90% of the existing goods vehicle fleet was compliant at that point (*10*). Older vehicles could be retrofitted with a filter or converted to natural gas, but no government assistance was offered to assist with equipment purchases or truck replacement.

Phase 3 of the LEZ was originally planned for introduction in October 2010, but it was deferred until January 2012 by a newly elected mayor in response to stakeholder concerns about the economic recession (*11*). Phase 3 extended the Euro III standard for particulate matter to all diesel-powered vehicles in London, including light goods vehicles (LGVs) and a range of other commercial, civic, and personal vehicles: minibuses up to 5 tonnes; ambulances, fire trucks, garbage trucks, and motorhomes over 2.5 tonnes; large vans, pickup trucks, and 4 × 4 utility vehicles over 1.2 tonnes. Vehicles registered as new after January 1, 2002, automatically met this standard, as that was the date for manufacturer compliance. Since it was pushed back, the introduction of Phase 3 coincided with the planned date for LEZ Phase 4 requirements, which raised the emissions standard for HGVs over 3.5 tonnes to Euro IV. Vehicles registered as new after October 1, 2006, automatically met this standard. LEZ vehicle compliance rates have risen over time, and by March 2014, compliance rates were 99% for Phase 3 vehicles and 97% for Phase 4 vehicles (*12*).

METHODOLOGY

The research questions are as follows. Have the CCZ and LEZ policies spurred changes toward more sustainable freight operations in regard to types of vehicles, routes, number of trips, and ultimately VKT? Have operators been able to realize operating efficiencies, such as time and fuel cost savings, that offset costs of compliance? Table 1 summarizes the list of expected responses to the CCZ and LEZ, based on both explicit policy goals and anticipated changes owing to indirect effects. Evidence was sought as to whether these expected responses have transpired in publicly available data and reports, supplemented by personal interviews with freight industry experts and operators. CCZ price changes were used to calculate the price elasticity of demand for freight traffic, and travel speed changes resulting from the CCZ to calculate potential time savings benefits to freight operators.

Traffic trends over time were identified using road traffic estimates produced by the UK Department for Transport and TfL. Traffic flow data are collected continuously on a network of automated counters on motorways and major roads (A roads), supplemented by manual counts (from 7:00 to 19:00) to identify vehicle type. VKT estimates are calculated for each link of the network by multiplying average daily traffic flow by the length of the road link, and then by 365 days per year. To compare VKT consistently across the network, trends were calculated and mapped as annual VKT per road kilometer. In these data, an LGV has a gross weight of 3.5 tonnes or less, while an HGV is over 3.5 tonnes.

Cordon crossing counts are conducted manually at three concentric cordons in London: a central cordon slightly outside the congestion charge boundary; an inner cordon approximately 10 mi from the center; and a boundary cordon on the administrative edge of London, roughly equivalent to the M25 orbital motorway (these are visible in Figure 2). Historically, these counts were not conducted at each cordon every year, but they were rotated such that counts were taken at each cordon once in 3 years. Since 2001, central cordon counts have been conducted annually. To compare cordon counts with each other, missing years were imputed. In these data, goods vehicles are

TABLE 1 Expected Responses to CCZ and LEZ Policies

Expected Response	CCZ	LEZ
Retime trips	X	
Reroute trips	X	
Reduce number of trips (traffic counts)	X	
Reduce vehicle kilometers traveled	X	X
Replace or redeploy most polluting vehicles		X

NOTE: X = expected response to that policy; blank cell = not an expected response to that policy.

reported as light, medium, and heavy. LGVs have two axles, four wheels, and a gross weight of 3.5 tonnes or less; medium goods vehicles (MGVs) have two axles, six wheels, and a gross weight over 3.5 tonnes; and HGVs have more than two axles and a gross weight over 12 tonnes.

To assess how companies handled the compliance cost of these fees and adjusted their operations, interviews were conducted with representatives of major parcel delivery companies. Interviewees were asked how significant the costs are, whether they can be passed along to customers explicitly, and what types of operational changes were made as a direct result of these policies. The number of interviews was limited by time and resource constraints, as well as the availability of an appropriate company representative, so interviews involved only large parcel companies.

DATA ANALYSIS

Freight transport is used to meet the demand for goods. Freight is a derived demand: the demand is for goods supply, not freight transport in itself. Therefore, goods demand and the extent of freight transport activity are not the same thing and do not necessarily have to move in the same direction or by the same magnitude. Many goods vehicles are not full when operated, so there is excess capacity to carry more goods without necessarily adding vehicle journeys. The percentage of freight capacity that is used is called the load factor. While demand for goods normally increases with population growth, there could be more or fewer freight trips, depending on the size of vehicles used and their load factor. There was no publicly available data for the amount of freight moving around London that would have allowed the researchers to calculate load factor trends.

Freight operators normally pass along operating costs to customers, who in turn pass along the cost of goods supply to the public. In theory, compliance with the CCZ and LEZ could raise freight prices to the extent that they would affect demand for goods. Yet these fees are quite modest compared with the major freight cost drivers: labor and fuel. Given the relatively small proportion of vehicle operating costs and total distribution costs that the CCZ and LEZ accounts for, such a change in the demand for goods and services is unlikely.

Price Elasticity

Because freight is a derived demand, and customers set delivery times, operators are expected to have limited sensitivity to pricing measures like congestion charging. The congestion charge was raised from £5 to £8 in July 2005 (60% change in price), and then from £8 to £10 in January 2011 (25% change in price). As shown in Figure 3, freight traffic crossing the central cordon remained quite stable after each of these price changes. These price changes and cordon counts were used to calculate the point elasticity of demand (percentage change in quantity/percentage change in price). Results are shown in Table 2.

For 2005 to 2006, when there was a 60% increase in price, a 3% to 10% decrease in goods vehicle traffic was observed and implied a low elasticity of −.06 to −.14. From 2010 to 2011, after a price increase of 25%, LGVs declined slightly, but MGV and HGV traffic increased, implying that they are perfectly inelastic to price. These calculations show that freight traffic had a much lower sensitivity to price than elasticities for personal vehicles calculated by TfL. Elasticity of

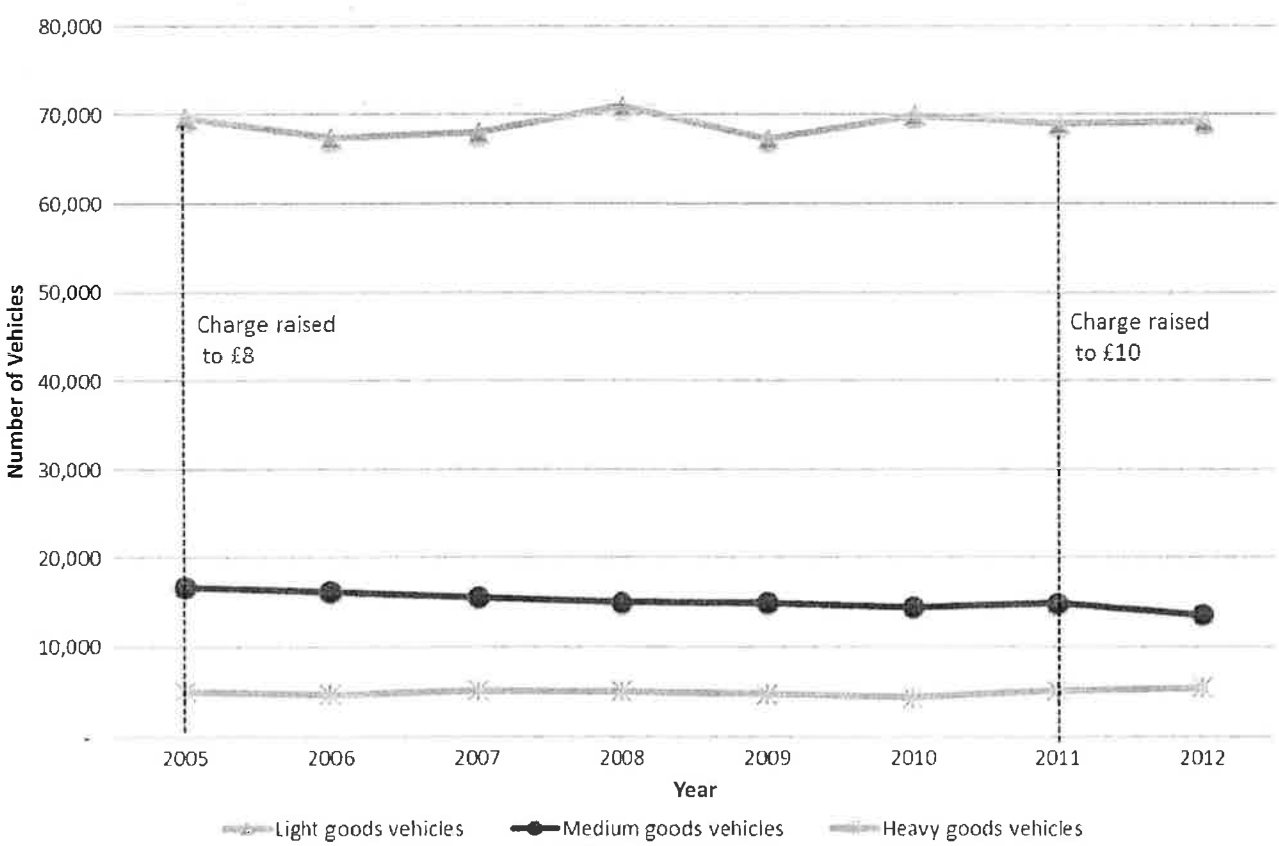

FIGURE 3 Inbound goods vehicles entering CCZ during charging hours (7:00–18:00) (*13*).

TABLE 2 Elasticity Estimates for Goods Vehicles (*17*)

Vehicle Type	Price Change from £5 to £8				Price Change from £8 to £10			
	2005 Count[a]	2006 Count[a]	Percentage Change	Elasticity	2010 Count[a]	2011 Count[a]	Percentage Change	Elasticity
LGV	66,826	64,607	−3	−.06	66,630	65,960	−1	−.04
MGV	16,278	15,675	−4	−.06	14,089	14,565	3	0
HGV	4,880	4,456	−9	−.14	4,226	4,989	18	0
Total	87,984	84,738	4	−.06	84,945	85,514	1	0

NOTE: Estimates are point elasticity of demand (percentage change in quantity/percentage change in price).
[a]Total vehicles crossing the central cordon inbound during charging hours.

demand for car traffic of was estimated as −.55 after the introduction of the congestion charge, and −.16 after it was increased to £8 (*14*). TfL accounted for fuel and time costs, while that was not done in this research.

LGVs were most likely to be able to adjust, and they showed a consistent slight elasticity to these price changes. It could be that any trips that could be diverted by route or time were adjusted in the first few years, leaving a base level of the most essential trips in the long run. This base level of demand is driven by the economic cycle and is insensitive to pricing. Another possible explanation for stable traffic volumes in the face of rising prices is that operators have been consolidating loads, increasing load factors, and improving efficiency over time. However, data were lacking toward exploring these possibilities.

Travel Speeds

By pricing discretionary traffic off the roads, the CCZ was expected to benefit the freight sector in two main ways: travel time savings and journey reliability. Average travel speeds in Central, Inner, and Outer London were examined for evidence. As shown in Figure 4, vehicle speeds increased in Inner London from about 11 mph in the early 2000s to 12.5 mph in the period 2006 to 2009 (*8, 15*). Meanwhile, speeds within Central London fell from 10.6 mph in 2003 to 2006 to 9.3 mph in 2006 to 2009. LGV traffic increased throughout Inner London, indicating that the freight sector likely reaped the benefits of travel time savings and journey reliability over a much larger area than the CCZ.

In 2007, TfL estimated travel time savings benefits for Central, Inner, and Outer London using a model based on observed traffic volumes, a £5 charge, and the changes in travel speeds observed in the first year (*16*). The model did not account for speed reductions attributable to road work or changes to the network, and so it must be considered a maximum estimate. The model estimated time savings per vehicle kilometer to be 35 s for Central, 3.6 s for Inner, and 1 s for Outer London. This means a vehicle would save about one min per mi driven in Central, per 10 mi in Inner, and per 37 mi in Outer London. The model estimated the value of improved journey reliability as

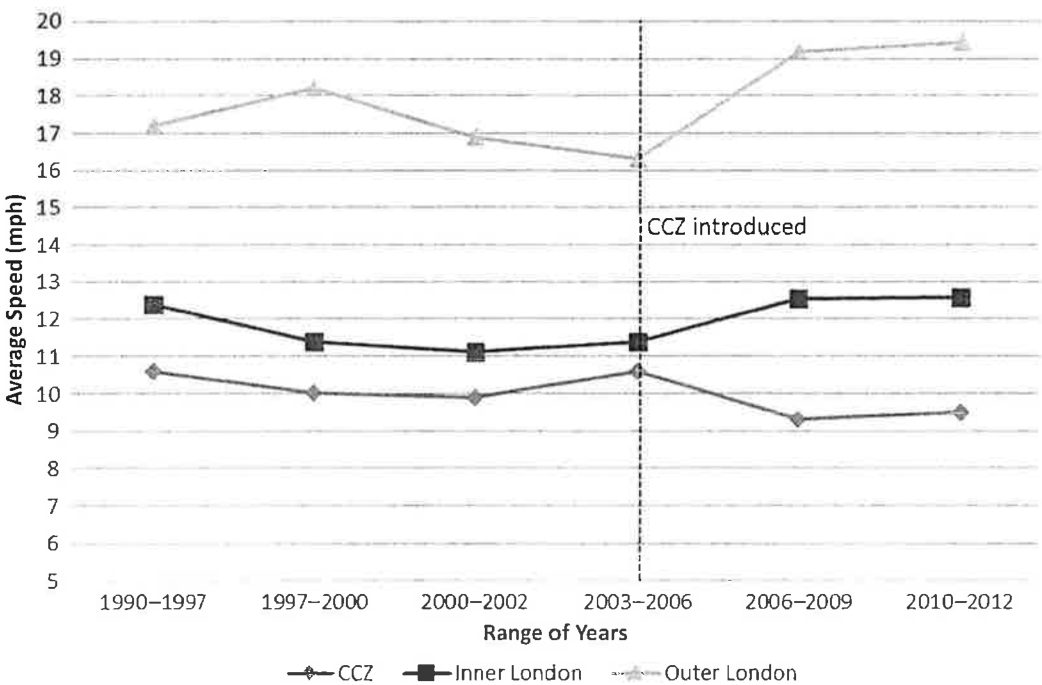

FIGURE 4 Average vehicle speeds on TfL strategic roads (*8, 15*).

30% of travel time savings in the charging zone, but zero elsewhere (explained further in the TfL report). The value of time savings for goods vehicle drivers was estimated as £0.27 per min.

These values were used to estimate potential time savings for a freight operator. For instance, a delivery vehicle traveling 20 mi on a round trip from a depot in Inner London, and traveling an additional 20 mi making deliveries in Central London, would gain a time savings of 22 min per vehicle per day. The value of time savings and improved reliability would equate to about £8 per vehicle driver per day. These amounts would add up quickly for a large fleet. Clearly, even though this is a best-case model, the time and reliability savings resulting from reduced traffic could add up to significant productivity gains for freight operators.

Retiming of Trips

The CCZ was expected to shift some trips from the working day to the evening and night. This was clearly seen in aggregate traffic at the central cordon, where the proportion of daytime vehicle crossings dropped by 5% (*13*). Disaggregation of the cordon data revealed that goods vehicles follow a different temporal pattern than private automobiles. Figure 5 shows vehicle counts by hour at the central cordon in 2012, as an example, as the patterns at the inner and outer cordons were similar. Private car traffic has two clear daily peaks in the morning and evening. Goods traffic peaks in the morning, but outbound goods traffic trails off gradually throughout the day. LGVs had the most similar pattern to that of private vehicles, showing a tendency toward an evening peak.

A consistent temporal pattern across all cordons suggests that freight operators lack discretion to shift trip times to avoid the congestion charge, for their schedule is driven by customer needs. Drivers of HGVs 3.5 tonnes and above are subject to drivers' hours restrictions, meaning that they must leave Central London to take a break unless they have a place to park. LGVs may show a different pattern because they are less constrained in this regard. Inbound light goods traffic peaked at 7:00, when the congestion charge starts, meaning that many were not able to avoid the charge. Many of these vehicles, especially vans, are likely operated by small business tradespeople (e.g., electricians, plumbers, and builders) whose working hours match those of peak-hour commuters. LGVs (vans) are often parked at residential addresses overnight and used for commuting to work and home.

From the data available, it cannot be concluded that operators responded to the CCZ by retiming trips. This aligns with other research showing that pricing has little influence on freight trip timing, because delivery and pickup times are set by the customer. A recent survey of freight operators found that 69% reported they cannot change their schedule, owing to customer requirements (*18*). Among operators that have been able to shift deliveries to night hours, the CCZ is not likely the driver of change. Large retail operators with staff working during the night (e.g., Sainsbury, John Lewis) are most able to take advantage of these benefits of out-of-hours deliveries, and they are best able to avoid the congestion charge, because their sites receive full vehicle loads and are subject to dedicated logistics operations.

Rerouting of Trips

The congestion charge was expected to shift some trips onto alternate routes, such as going around rather than through Central London during charged hours. TfL reported that inbound goods traffic decreased by about 10% when the congestion charge was first introduced, with commensurate increases on a diversion route, the Inner Ring Road (*19*). Yet orbital route traffic counts offer scant evidence that freight operators have been skirting the CCZ, over the long run. Orbital traffic flow counts showed a broadly similar pattern to cordon counts.

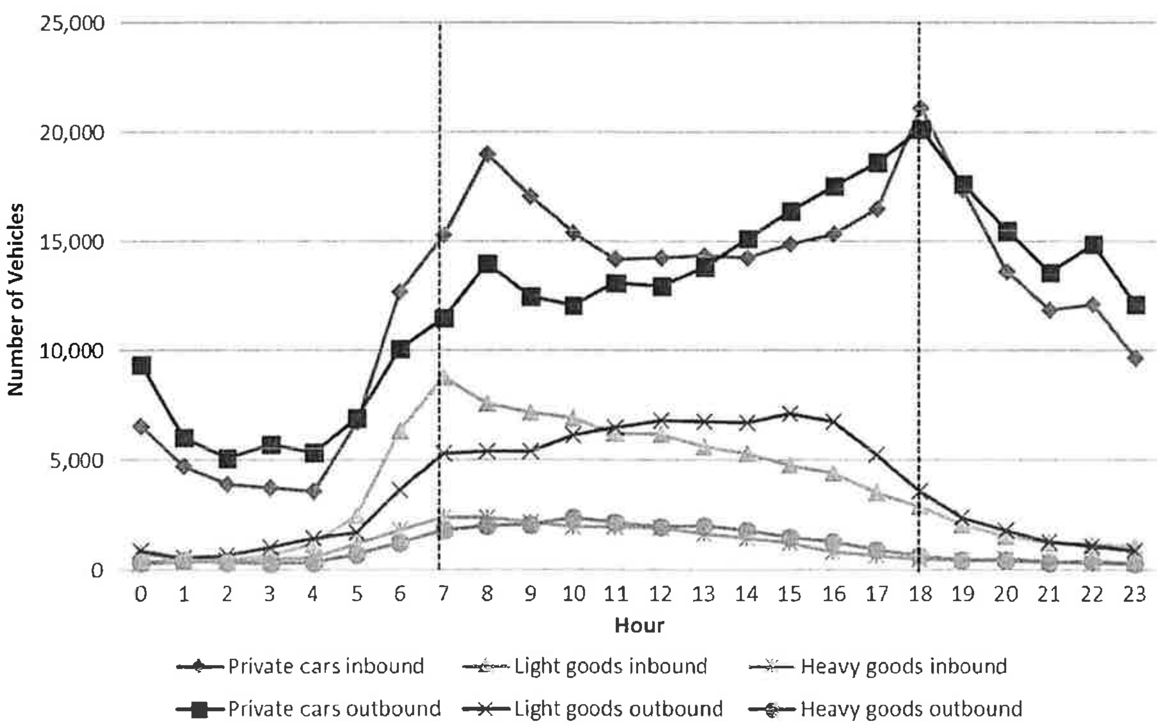

FIGURE 5 Vehicles crossing the central cordon in London, by hour (2012) (congestion charge in effect 7:00–18:00) (*17*).

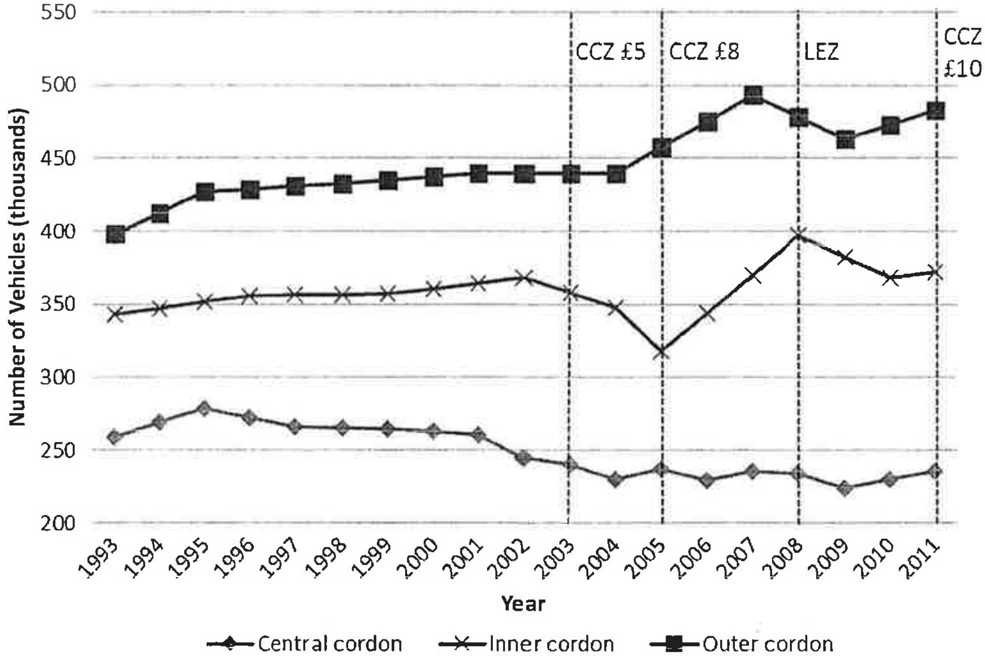

FIGURE 6 Goods vehicles crossing London cordons, 24-h counts (*13*).

As shown in Figure 6, goods vehicles crossing the central cordon peaked in 1995 and then declined until 2004, hovering around 240,000 vehicles per day on average after the CCZ took effect. By contrast, goods vehicles crossing the inner and outer cordons have been gradually increasing since the 1990s, with a higher rate of increase since the CCZ. The inner cordon showed an unexpected downturn around the 2005 data point and imputed values for the 2 years before and after, perhaps because of road work in a critical area for these cordon counts.

A differential impact at the central cordon is unexpected, for the congestion charge was expected to deter discretionary trips but not freight. The CCZ may have accelerated an existing trend of declining goods traffic entering Central London. It may have stabilized goods vehicle trips into central London, in spite of increasing population and employment density there. Declining goods vehicle traffic is likely related to the relocation of logistics depots and warehouses to Outer London, resulting from high land values. The available data are inadequate to clearly conclude that freight operators have rerouted trips to avoid the CCZ.

Reduced Number of Trips

The CCZ was expected to reduce the number of goods vehicle trips by encouraging operational efficiencies and consolidation, yet it was not focused on key factors driving demand for freight trips. Industry experts named population growth and rising demand for home delivery from online shopping as the most important drivers of freight demand (Personal communications: A. Bolitho, property, energy, and transport policy advisor, Retail Consortium, Nov. 21, 2013; P. Barrett, public affairs manager, London Chamber of Commerce, Nov. 29, 2013; and N. Chapman, head of policy for London, Freight Transport Association, Oct. 27, 2013). Changes in the construction industry and tax incentives for small businesses have driven growth of light goods vehicle registrations, particularly vans (M. Browne, professor, Westminster University, personal communication, April 20, 2014). Absolute reductions in goods vehicle traffic in Central London commenced in 2001, before congestion charging (see Figure 6). It is possible, although publicly available data are lacking to show evidence, that this is a result of greater load consolidation. Interviewees commented that operating cost pressures from fuel, labor, and parking violations were of greater importance to improving operational efficiency than the costs of the CCZ and LEZ (Personal communications: R. Currie, director of Public Affairs, UPS Europe, April 25, 2014; M. Schulz, city logistics and public affairs manager, TNT Express, April 9, 2014).

Since car traffic declined while goods traffic increased (see Figure 1), goods vehicles are becoming a more prevalent proportion of traffic throughout London. From the late 1990s to the early 2000s, goods vehicle traffic was stable and formed roughly 17% of traffic at all three cordons (*13*). Starting in 2003, the proportion of goods traffic began increasing at all three cordons, such that in 2012, goods vehicles were roughly 20% of traffic at the central and inner cordons, and 19% at the outer cordon. The rising proportion of goods traffic likely reflects the reduction in car traffic in Central and Inner London after the CCZ came into effect.

Reduced VKT

LGVs account for more than 3 billion annual VKT in London, and HGVs for approximately 1 billion (2). The CCZ was expected to reduce goods VKT by encouraging operational efficiencies such as freight consolidation, as discussed earlier, and resulting in fewer trips and shorter trips. The LEZ was expected to have a mild VKT reduction effect by deterring noncompliant goods vehicles from passing through London, and by suppressing discretionary trips by other types of noncompliant vehicles. In 2007, TfL estimated that the CCZ had reduced total VKT within the charging area by

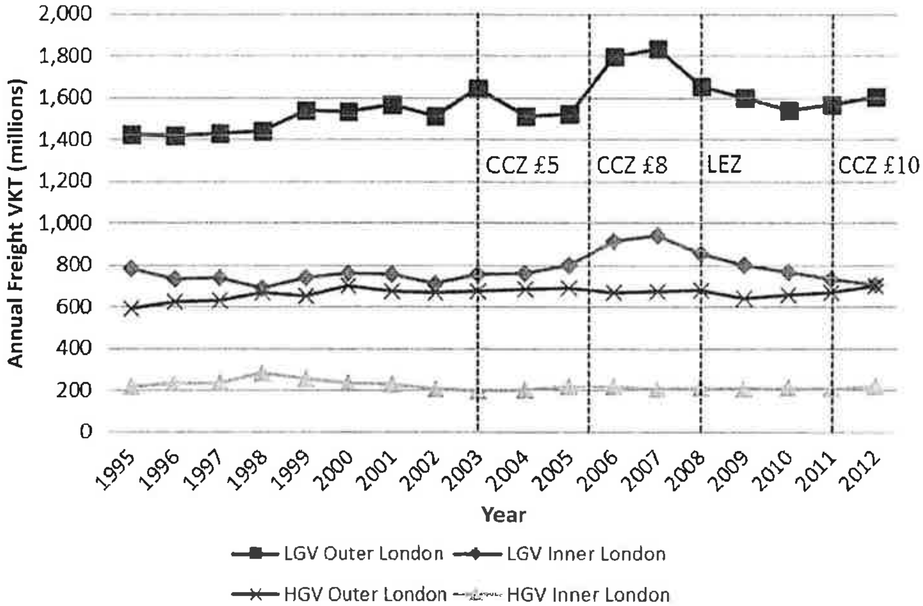

FIGURE 7 Annual freight VKT for Inner and Outer London (2).

17% (255,000 km per day); in Inner London by 2.5% (378,000 km per day); and in Outer London by 1% (221,000 km per day) (*16*).

Freight VKT was disaggregated by Inner and Outer boroughs, as shown in Figure 7. In Inner London, HGV traffic has been stable or declining, and LGV traffic increased less than in Outer boroughs. Yet it remains unclear whether these changing VKT patterns are directly related to the CCZ. They may be the result of several indirect and contradictory impacts, and complicated by industry trends such as substitution of smaller for larger trucks owing to greater driver availability.

Replacing Vehicles

The LEZ was expected to stimulate fleet turnover to less polluting vehicles. Goods vehicles operating in London may be registered inside or outside London. In 2012, there were 225,000 goods vehicles registered at London addresses, the vast majority being LGVs (*12*). A London registration does not mean that the vehicle is kept and used in London; likewise, vehicles kept and used in London may be registered elsewhere. TfL estimated that 725,000 to 860,000 vehicles were driven in the LEZ area in 2007, approximately 20% of which were over 12 tonnes (*10*). A survey of operators undertaken during the LEZ public consultation found that most would purchase new vehicles to comply, while some with larger fleets would redeploy older vehicles outside the zone, and some would switch to smaller vehicles not subject to the regulation (*20*).

A recent study of vehicle registrations found evidence that the LEZ had a substantial effect on the composition of London's goods vehicle fleet (*21*). Ellison et al. compared the replacement rate of goods vehicles in London to other areas of the United Kingdom from 2006 to 2011, and found it was higher in the years the LEZ Phase 1 and Phase 2 went into effect (*22*). In 2007, London's proportion of 12-tonne goods vehicles older than Euro III was about the same as the rest of the United Kingdom in 2007 (47%), but it had fallen to 32% by 2008. Similarly, the replacement rate of LGVs in London jumped by 10% over the rest of the United Kingdom in 2011, the year before Phase 2 LEZ regulations went into effect. The authors concluded the LEZ had spurred a one-time fleet turnover of 20% over the natural replacement rate among London-registered operators. Further, they noted a shift toward smaller vehicles. London's freight fleet remained stable after the LEZ came into effect, but the proportion of LGVs increased by 3.3%, offset by a 3.3% decline in medium and heavy rigid and articulated vehicles. This apparent switching out of vehicle types was attributed to both the LEZ and increased demand for home deliveries from online shopping.

TfL cordon data corroborated a trend of substitution of LGVs for MGVs. As shown in Figure 8, when cordon crossings were disaggregated by type of vehicle, the proportion of HGVs was found to have remained roughly stable since 1990, ranging from 5% to 6% of all traffic at the central cordon, 7% to 8% at the inner cordon, and 13% to 14% at the outer cordon (*13*). Meanwhile, the proportion of MGVs declined, and that of LGVs increased at all three cordons. For example, at the central cordon in 1995, medium vehicles were about 30% of goods traffic, and light vehicles were 65%, but by 2012, the proportions had changed to 17% and 77%, respectively (*13*). Changes in vehicle proportions were similar at the inner and outer cordons, suggesting a long-term industry trend toward smaller vehicles from before the CCZ or LEZ came into effect. Driver regulations may be a contributing factor, for 7.5-tonne vehicles requiring a special license to drive can be replaced by large vans, which do not (M. Browne, personal communication, April 20, 2014).

DISCUSSION OF RESULTS

Responding to Concerns Raised by Freight Operators

The public consultations on the CCZ and LEZ drew a lot of attention, and many companies were actively involved when they were introduced. Despite TfL's assertions that the CCZ would reduce travel times and allow operational efficiency gains, trade associations tended to disagree. The Confederation of British Industry and

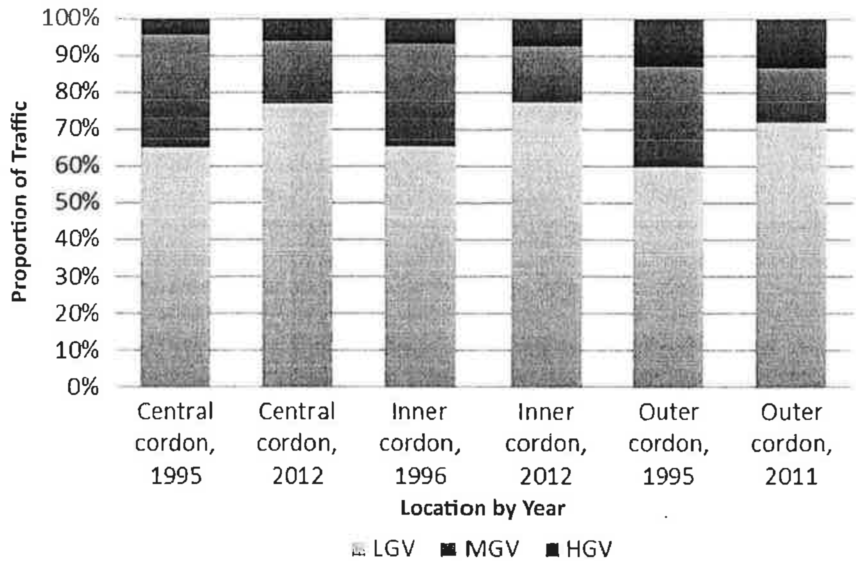

FIGURE 8 Proportion of goods vehicle traffic at each cordon, by vehicle size (*13*).

the Freight Transport Association both argued that any travel time savings would be too small to facilitate additional delivery work on a vehicle journey (M. Browne, personal communication, April 20, 2014). Operators argued for an exemption on the basis that their trips were not discretionary and could not be shifted to a different mode, route, or time of day. They argued their trips are driven by customer demand, making the congestion charge essentially a tax on their business. The operators interviewed saw their role as promoting the economy, like taxis, which were exempted; some argued they provide an essential service, like ambulances, which were also exempted (Personal communications: R. Currie, April 25, 2014; M. Schulz, April 9, 2014). Some operators continued to seek an exemption during the most recent CCZ public consultation in spring 2014, while others declined to participate, seeing it as entrenched.

TfL has never altered its position on a freight exemption, considering taxis part of the public transportation system and essential services as public sector, but its responses to other concerns have been well received. When the CCZ was first introduced, operators had to make individual payments. Since 2008, a new automated system allows freight operators to register vehicles and make bulk payments, and that has greatly reduced the administrative burden. Initially, only operators with 25 or more vehicles qualified for the £1 per vehicle fleet discount, but it was reduced to nine vehicles in 2008 and six vehicles in 2014.

In recognition of increasing regulatory complexity, TfL developed a voluntary program to assist with compliance, available for free to any freight company operating in London. Launched in 2008, the Freight Operator Recognition Scheme (FORS) helps operators comply with the LEZ, CCZ, and other rapidly changing safety, parking, and loading regulations. The FORS also provides operators with practical advice to help reduce fuel consumption, CO_2 emissions, vehicle collisions, and other penalty charges. It is delivered through company training, workshops, and electronic guides and tools. Three levels of FORS certification are available: bronze, silver, and gold. These are attained through the degree of implementation of FORS-recommended systems, policies and procedures, provision of operational data for benchmarking purposes, and ongoing independent assessment and monitoring. FORS certification is increasingly adopted as a requirement in private- and public-sector procurement contracts. By 2013, approximately 145,000 goods vehicles operating in London were registered in FORS (*12*).

Achieving Operating Efficiencies

As shown in Figure 6, Central London is served by a stable or declining number of goods vehicles even as the number of residents and firms has grown there. The CCZ suppressed private automobile traffic, reduced travel delay, and improved journey reliability within the CCZ and throughout Inner London (*16*). These trends imply that several efficiencies might be in play, allowing operator to serve a similar or growing customer base with less delay or fewer vehicles.

Operators reported that the congestion charge was one of several costs driving efficiency, but not nearly as significant as rising fuel and labor costs; it was characterized as a cost they had learned to live with (R. Currie, April 25, 2014; M. Schulz, April 9, 2014). The level of the charge was considered too low, and the market too competitive, to respond by adding a surcharge on central London deliveries. Industry experts speculated most operators absorbed the charge or passed it to customers, either through higher prices or higher contract charges (N. Chapman, Oct. 27, 2013; M. Browne, April 20, 2014). Concern was expressed that smaller operators might be unable to do either, and so withdraw from the central London market, making it a niche market with higher delivery costs (N. Chapman, Oct. 27, 2013).

Operators said they would prefer to avoid the congestion charge by having more flexibility to make out-of-hours deliveries, for night traffic flows are lower and there is greater availability of curb space, but they are constrained. London boroughs restrict delivery hours and routes with loading time restrictions on local streets and nighttime activity curfews on some supermarkets and offices. Boroughs also control the London Lorry Control Scheme, which restricts HGVs over 18 tonnes without permits to certain main roads during nighttime and weekend hours. TfL has no jurisdiction to adjust these restrictions, but it has been assisting operators by setting up a Quiet Deliveries Consortium to enable dialogue. An agreement was reached for an out-of-hours deliveries trial during the 2012

London Olympics. During the trial, a greater proportion of goods vehicle journeys were made during the evening, night, and early morning compared with that of summer 2011; HGVs did the most time-shifting (*23*). Retiming of goods vehicle operations was most significant in central London, indicating that heavy goods trips might shift to avoid the congestion charge if they were able.

Parking violations were named by operators as a greater cost concern than the CCZ or LEZ. A typical delivery vehicle risks a £65 ticket during each of its dozens of stops per day. Given the complexity of curb space regulations managed by different units of government and enforced with varying intensity, that can add up to six-figure annual fines for large operators. For comparison, one operator estimated the annual CCZ compliance cost was approximately £2,200 per vehicle operating in central London; it would take only 12 days to exceed that amount with LEZ violations (M. Schulz, April 9, 2014).

When asked whether they had realized travel time and reliability benefits from the CCZ, operators were reserved. They reported that time savings were noticeable in the early years but eroded over time (N. Chapman, Oct. 27, 2013; R. Currie, April 25, 2014; M. Schulz, April 9, 2014). Some operators commented that they were not getting value from the charge, and one noted more valuable operating efficiencies had been achieved as a result of internal factors, such as higher load factors and drops per route (R. Currie, April 25, 2014). These perceptions of CCZ benefits reflect the difficulty of comparing against how much worse congestion might have been without the CCZ. They also may not take account of time savings and journey reliability improvements throughout Inner London. Although pedestrian and cyclist priority has slowed traffic in the CCZ, interviewees commented that they supported these safety measures, for HGVs are responsible for a disproportionate share of pedestrian and cyclist deaths (*2, 20,* R. Currie, April 25, 2014).

In theory, freight operators should be able to achieve operational efficiencies from increasing customer density in Central London. However, when asked, they said no, because of how costs are calculated—on the basis of the number of stops a vehicle can make in a typical workday, rather than on a basis of per delivered item. This measure does not reflect an efficiency gain such as increased parcels delivered per stop. It is more sensitive to constraints on the delivery window, such as nighttime curfews, because drivers are forced into peak traffic and can make fewer stops per day per vehicle. Operators said the CCZ would be more palatable if it were accompanied by reforms to expand the delivery window.

An indirect effect of the LEZ and CCZ, together sending a strong signal to freight operators about London's commitment to sustainability, was to spur experimentation with electric vehicles (EVs). Both parcel operators we interviewed reported EV pilot programs at their Central London depots using custom-built or custom-modified vehicles, because appropriate freight EVs are not yet commercially available (R. Currie, April 25, 2014; M. Schulz, April 9, 2014). EVs were expected to help reduce fuel and excise duty costs, as well as gain exemption from the LEZ and CCZ.

Improving Spatial Efficiencies

Neither the CCZ or LEZ directly affected factors driving freight VKT, so in this section there is discussion of a missed policy opportunity. VKT could be more effectively reduced by encouraging spatial efficiencies that reduce and shorten trips through the location of logistics centers. Operators reported they would prefer to bring freight into central London in bulk with large vehicles at night, and then deploy small vehicles for short trips, preferably EVs (R. Currie, April 25, 2014; M. Schulz, April 9, 2014). Such bundling and centralization would reduce the number of LGVs on roads throughout London during peak hours, and also VKT and emissions from those vehicles.

The constraint that operators face in this context is availability of suitable warehouse space in central locations where land values are high. Freight depot locations are determined mainly by land market values and local planning permission. In most urban areas, as land values rise in the center, industrial uses are pushed further and further out (*21*). During the period of 1998 to 2008, warehouse floor space was rapidly disappearing in most Inner London boroughs, especially those partly within the CCZ (e.g., 82% in the City of London and 51% in Westminster) (*24*). Meanwhile, warehouse growth was strong in many Outer London boroughs (e.g., 34% in Enfield, and 21% in Havering).

Policies protecting some central urban locations for logistics might be more effective than pricing in reducing VKT. For instance, if a company with a fleet of 100 vehicles relocated from a central location to a suburban depot 10 km, that could add up to 500,000 extra annual VKT (assuming 20 round-trip km × 100 vehicles × 250 working days). Allowing freight depots to be continuously pushed to the periphery of the urban area works against sustainability and VKT reduction policies.

Another way to reduce VKT is improving the spatial efficiency of delivery sites. TfL has supported two pilot projects with this aim: freight consolidation centers and "click-n-collect" services. TfL's construction consolidation center demonstration ran from 2005 to 2008. During the pilot, the number of goods trips delivering to targeted construction sites in the City of London was reduced by 68%, and supplier journey times fell by 2 h (*25*). Participation is an issue; consolidation centers have been most successful in locations like Heathrow Airport where the landlord makes participation mandatory (N. Chapman, Oct. 27, 2013; M. Schulz, April 2014). In 2013, TfL launched a click-n-collect demonstration in which customers could opt to have goods delivered to secure lockers at Underground stations. Operators saw this option as an ideal solution for small and low-value parcels, but they expressed skepticism about consumers' willingness to use it (R. Currie, April 25, 2014; M. Schulz, April 9, 2014). Yet it has proved popular, with more than 10,000 orders delivered in the first 10 months (*26*).

CONCLUSIONS

The LEZ appeared to spur higher levels of operational change than the CCZ. This might be expected, for the fee level was sufficiently high to create economic pressure, it was applied at all times throughout Greater London, and compliance could be achieved by a one-time action. It was noncontroversial with operators, for a measure linked directly to air quality and applied to all large vehicles equally, even personal and civic vehicles.

The CCZ daily fee was low enough to be absorbed or passed along by freight operators, even as it was raised over time. Despite seeming to benefit freight operators, it was resisted when introduced and is still perceived as an unfair burden. It may have been less controversial if steps to ease compliance, such as an automated payment system, were introduced right away. Rather than a fleet discount, giving an additional advantage to large operators, discounts should be directly aligned with the goals of the CCZ.

HGV traffic was stable over time and inelastic to pricing, but sensitive to delivery time constraints, meaning there is greater potential to time-shift this traffic through changes to nighttime delivery curfews. LGV traffic was more sensitive to pricing, but also to the economic cycle, driver regulations, and tax incentives for small businesses. LGV traffic appears to be growing for many reasons, meaning that there may be more potential to reduce emissions through vehicle standards than through VKT reduction measures.

The CCZ may have time-shifted some trips by LGVs owned by small businesses, but it was insufficient on its own to shift the timing of freight trips with delivery window constraints. The CCZ would be more palatable to freight operators if accompanied by flexibility for out-of-hours deliveries, which would require the cooperation of local governments. Data were insufficient for determining whether operators were rerouting trips to avoid the CCZ, but there was a trend of declining freight VKT in Central London. There was no evidence of avoidance traffic on orbital routes. Neither the CCZ nor LEZ had any effect on a key driver of VKT: the dispersion of logistics centers to suburban sites that increase driving distances between the freight depot and the first delivery site. A policy protecting freight sites in central areas could be more effective.

Increasing freight VKT in Inner London suggests that operators' perceptions of CCZ benefits may not take account of time savings and journey reliability improvements beyond the charging area. Operators can be highly cooperative engaging with policy makers on initiatives that help solve persistent issues that affect their business, such as delivery window constraints and keeping up with rapidly changing loading and parking restrictions. Such initiatives can help offset discontent over lack of exemptions and discounts from policies like the CCZ and LEZ.

ACKNOWLEDGMENTS

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The Standing Committee on Urban Freight Transportation peer-reviewed this paper.

TRANSPORTATION RESEARCH RECORD: JOURNAL OF THE TRANSPORTATION RESEARCH BOARD

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Papers may be submitted to TRB at any time. However, most authors use the TRB web-based electronic submission process available between June 1 and August 1, for publication in the following year's Record series.

Initial Review: August 15–November 15

TRB staff assigns each paper by technical content to a committee that administers the peer review. The committee chair assigns at least three knowledgeable reviewers to each paper. The initial review is completed by mid-September.

By October 1, committee chairs make a preliminary recommendation, placing each paper in one of the following categories:

1. Publish as submitted or with minor revisions;
2. Reconsider for publication, pending author changes and rereview; or
3. Reject for publication.

By late October, TRB communicates the results of the initial review to the corresponding author. Corresponding authors communicate the information to coauthors.

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- Authors of papers in Category 2 (above) must submit a revised version by November 15 addressing all reviewer comments, along with an explanation of how the comments have been addressed.

Rereview: November 20–January 25

The committee chair sends the Category 2 revised papers to the initial reviewers for rereview. After rereview, the chair makes the final recommendation on papers in Category 2. If the paper has been revised to the committee's satisfaction and ranks among the best papers, the chair may recommend publication. The chair communicates the results of the rereview to the authors.

Discussions and Closures: February 1–May 15

Discussions may be submitted for papers that will be published. TRB policy is to publish the paper, the discussion, and the author's closure in the same Record.

Many papers considered for publication in the *Transportation Research Record* are also considered for presentation at TRB meetings. Individuals interested in submitting a discussion of any paper presented at a TRB meeting must notify TRB no later than February 1. If the paper has been recommended for publication in the *Transportation Research Record*, the discussion must be submitted to TRB no later than April 15. A copy of this communication is sent to the author and the committee chair.

The committee chair reviews the discussion for appropriateness and asks the author to prepare a closure to be submitted to TRB by May 15. The committee chair reviews the closure for appropriateness. After the committee chair approves both discussion and closure, the paper, the discussion, and the closure are included for publication together in the same Record.

Final Submittal of Revised Manuscripts: March 15

In early February, TRB requests a final manuscript for the Category 2, revised papers that have been accepted for publication; the final manuscripts must be submitted by March 15. TRB also notifies authors whose papers were not accepted for publication. TRB makes a concerted effort to publish all papers by December 31; some volumes, however, are released in January and February.

Paper Awards: April to January

The TRB Executive Committee has authorized annual awards sponsored by Groups in the Technical Activities Division for outstanding published papers:

- Charley V. Wootan Award (Policy and Organization Group);
- Pyke Johnson Award (Planning and Environment Group);
- K. B. Woods Award (Design and Construction Group);
- D. Grant Mickle Award (Operations and Preservation Group);
- John C. Vance Award (Legal Resources Group);
- Patricia F. Waller Award (Safety and System Users Group); and
- William W. Millar Award (Public Transportation Group).

Other Groups also may nominate published papers for any of the awards above. In addition, each Group may present a Fred Burggraf Award to authors 35 years of age or younger.

Peer reviewers are asked to identify papers worthy of award consideration. Each Group reviews all papers nominated for awards and makes a recommendation to TRB by September 1. TRB notifies winners of the awards, which are presented at the following TRB Annual Meeting.

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