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Greenhouse gas from ridership on the Jubilee Line Extension

Shoshanna Saxe (PhD, P.Eng (Ontario, Canada)), corresponding Author,

Centre for Sustainable Development

Department of Engineering

University of Cambridge

Trumpington Street

Cambridge, CB2 1PZ, UK

Current address:

s.saxe@cam.ac.uk

Department of Civil Engineering

University of Toronto

Sandford Fleming Building, Room 3001

10 King's College Road

Toronto, ON, M5S 1A4, Canada

Steve Denman (BSc)

sd560@cam.ac.uk

Centre for Smart Infrastructure and Construction

Department of Architecture

University of Cambridge

1-5 Scroope Terrace

Cambridge, CB2 1PX, U.K.

Abstract

This paper examines changes in travel behaviour associated with ridership on the Jubilee Line Extension in east London and the resulting impacts on greenhouse gas (GHG) emissions. The paper looks at initial changes in mode choice after the line opened in 1999 and on-going mode share trends through to 2011. The initial mode shift is assessed through an analysis of published travel survey data and the annual TfL Rolling Origin Destination Survey. Longitudinal changes in mode share are assessed using the London Travel Demand Survey and the relationship between metro accessibility and mode choice. From 2000 to 2011 the calculated GHG savings are 338 ktCO₂e; approximately equivalent to the annual average GHG emissions of 43,000 UK residents.

Keywords: Metro rail, public transport, ridership, greenhouse gas

1. Introduction

Greenhouse gas (GHG) emissions from operating transport vehicles account for a significant and growing percentage of total GHG emissions. In 2012, the transport sector generated approximately 24% of total UK emissions; passenger cars dominated generating 56% of the total transport emissions (The Green Construction Board, 2013). One key facet of reducing transport GHG emissions is reducing the use of private automobile use. The provision of new rail public transit is popularly proposed to increase public transit use in the place of private automobiles. In general, the operation of metro rail transit is less GHG intensive per passenger kilometre travelled (PKT) than buses and automobiles (US Department of Transportation, 2010; Department for Environment Food and Rural Affairs and Department of Energy and Climate Change, 2011; Saxe, Cruickshank and Miller, 2015). As such, attracting riders from other modes to metro rail leads to reductions in GHG emissions.

Around the world, different metro lines have had varying success in attracting mode share. In reaction to the Copenhagen metro a decrease in automobile traffic of up to 13%, and in bus traffic of up to 40% was observed (Vuk and Ildensborg-Hansen, 2006). In Athens, 24% of the new metro's riders switched from cars and 53% from buses (Golias, 2002). In Los Angeles, 67% of riders on the new Gold Light Rail Line had previously been travelling in private cars (Chester et al., 2012). In California, 46.5% of the Bay Area Rapid Transit's (BART) early users came from automobiles (Lave, 1978). In contrast, the Jubilee Line Extension (JLE) in London saw only an initial 2% mode shift from cars and a 6% shift from buses (The Jubilee Line Impact Study Unit, 2002). In a study of a new metro line in Toronto much of the mode shift was from a very crowded bus system. Initially, the GHG intensity of the metro was higher than the bus it replace, though the system was able to save GHGs based on avoided automobile travel (Saxe, Cruickshank and Miller, 2015).

Governments make the choice as to what travel infrastructure to build but uptake of the new infrastructure is reliant on many individual travel choices.

Mode share decisions include many factors including accessibility at the origin and destination based on the available public transit infrastructure, urban form, individual attitudes and socio-economic factors (Bento, Cropper, Mobarak and Vinha, 2005; Batty, Palacin and González-Gil, 2015; Foth, Manaugh and El-Geneidy, 2014).

The impact of increased accessibility on mode share is often explored in travel research (Foth, Manaugh and El-Geneidy, 2014; Ewing and Cervero, 2010, 2001; Batty, Palacin and González-Gil, 2015; Sung, Choi, Lee and Cheon, 2014). In a meta analysis of published studies, Ewing and Cervero (2010) found that the weighted elasticity of vehicle distance travelled was -0.05 for both distance to nearest transit stop and job accessibility. Similarly, the weighted elasticity of transit use was 0.29 for distance to nearest transit stop (Ewing and Cervero, 2010). From this, some redistribution of mode share to transit is expected following the opening of new rail lines.

This paper looks at initial changes in mode use after the JLE opened in late 1999 and on-going mode share trends through to 2011. Ridership on the JLE is calculated from The Rolling Origin and Destination Survey. Initial mode shift is assessed through published survey results carried out by the Jubilee Line Extension Impact Study Unit (JLEISU). The travel distance saved through the initial mode shift is calculated through a comparison of time based shortest path travel models with and without the JLE. Longitudinal changes in mode share are assessed using transit survey data. The net GHG impact of the JLE is assessed by calculating the GHG impact of PKT travelled, minus the GHG impact of PKT avoided on other lines and modes. The analysis in the paper is based on data from:

- 1) The London Travel Demand Survey (LTDS) 2005 to 2011 (Transport for London, 2011);
- 2) Published schedules for the London Underground, Overground, Docklands Light Rail (DLR) and National Rail (Transport for London, 2007, 2013c; a; National Rail, 2014);
- 3) Transport for London's Rolling Origin and Destination Survey (RODS) (Transport for London, 2013d);

- 4) Travel survey results published by the Jubilee Line Extension Impact Study Unit;
- 5) London traffic counts (Department for Transport, 2015)
- 6) Greenhouse gas (GHG) conversion factors derived from London Undergrounds GHG accounts and distance travelled (Transport for London, 2014);
- 7) GHG conversion factors for National Rail and automobiles published by DEFRA (Department for Environment Food and Rural Affairs, 2015)

The study area for this paper extends 2-miles in all directions from the JLE.

2. The Jubilee Line Extension

The Jubilee Line Extension (JLE) was constructed from 1993 to 1999 and is 15.5 km long. The extension starts at pre-existing Green Park Station in the west and runs 11 stops to Stratford Station in East London. The JLE crosses the line of The River Thames four times providing new connections across the river (Mitchell, 2003).

Upon completion, the JLE became an important transportation corridor in London. It is credited with the rejuvenation of the Greenwich Peninsula and the success of the developments at Canary Warf and on the Isle of Dogs (Mitchell, 2003). The entire Jubilee Line now carries 127.6 million passengers annually (Transport for London, 2013b). FIGURE 1 illustrates the JLE.

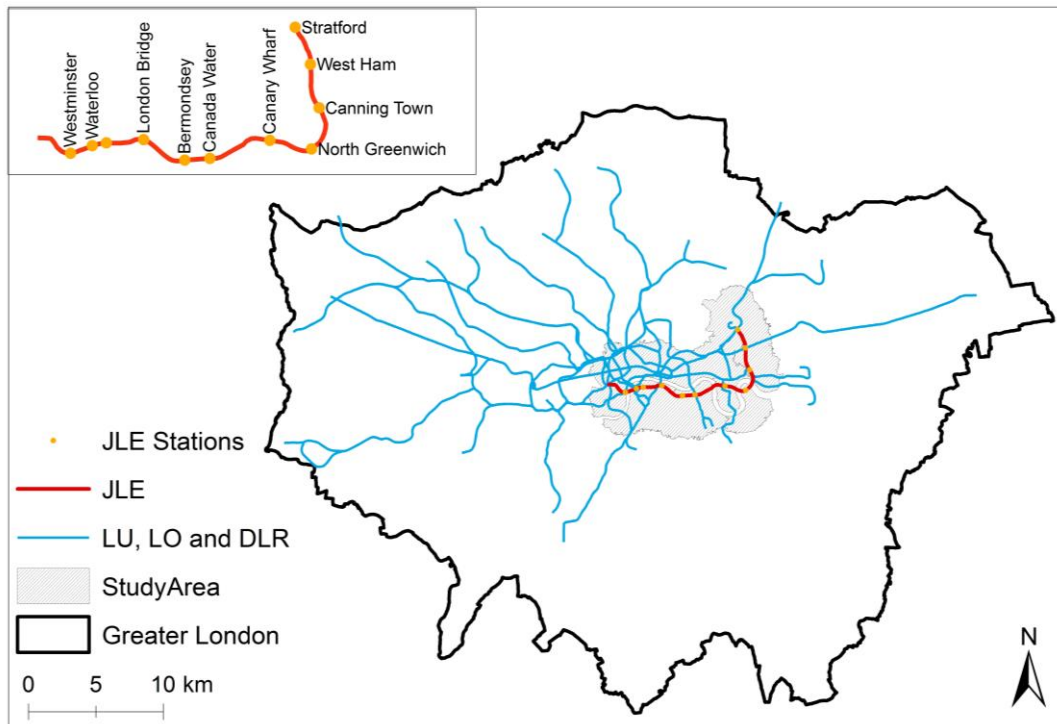


FIGURE 1 The Jubilee Line Extension, 11 new stations (Author's own graphic based on data from © OpenStreetMap contributors, 2015; Doogal, 2013; Ordnance Survey, 2013)

3. GHG Conversion factors

Calculating the GHG savings from mode changes requires an understanding of the GHG intensity for each examined mode and how it has changed with time. It was not possible to gather complete sets of GHG intensity data for the study period for all modes, relevant records were not kept in the early 2000s. FIGURE 2 illustrates the GHG intensity of different modes of travel in London during the study period. Data points are shown for the years for which it was available, for years where data for a given mode was not available linear extrapolation was used for most modes. For National Rail, the GHG intensity was significantly higher in 2012 than in 2013 and 2014, as such linear extrapolation based on the three years was heavily influenced by the 2012 value (Department for Environment Food and Rural Affairs 2015). Instead, a yearly improvement of 2% was assumed and the GHG intensity was back calculated. An average automobile occupancy of 1.6 people/automobile is applied throughout – this is the stable annual average occupancy of automobiles in London (Department for Environment Food and Rural Affairs, 2015). Estimates of energy use per passenger kilometre travelled on the JLE were calculated from an estimate of

the energy used to run the line provided by transport for London and yearly RODS data (Transport for London, 2012).

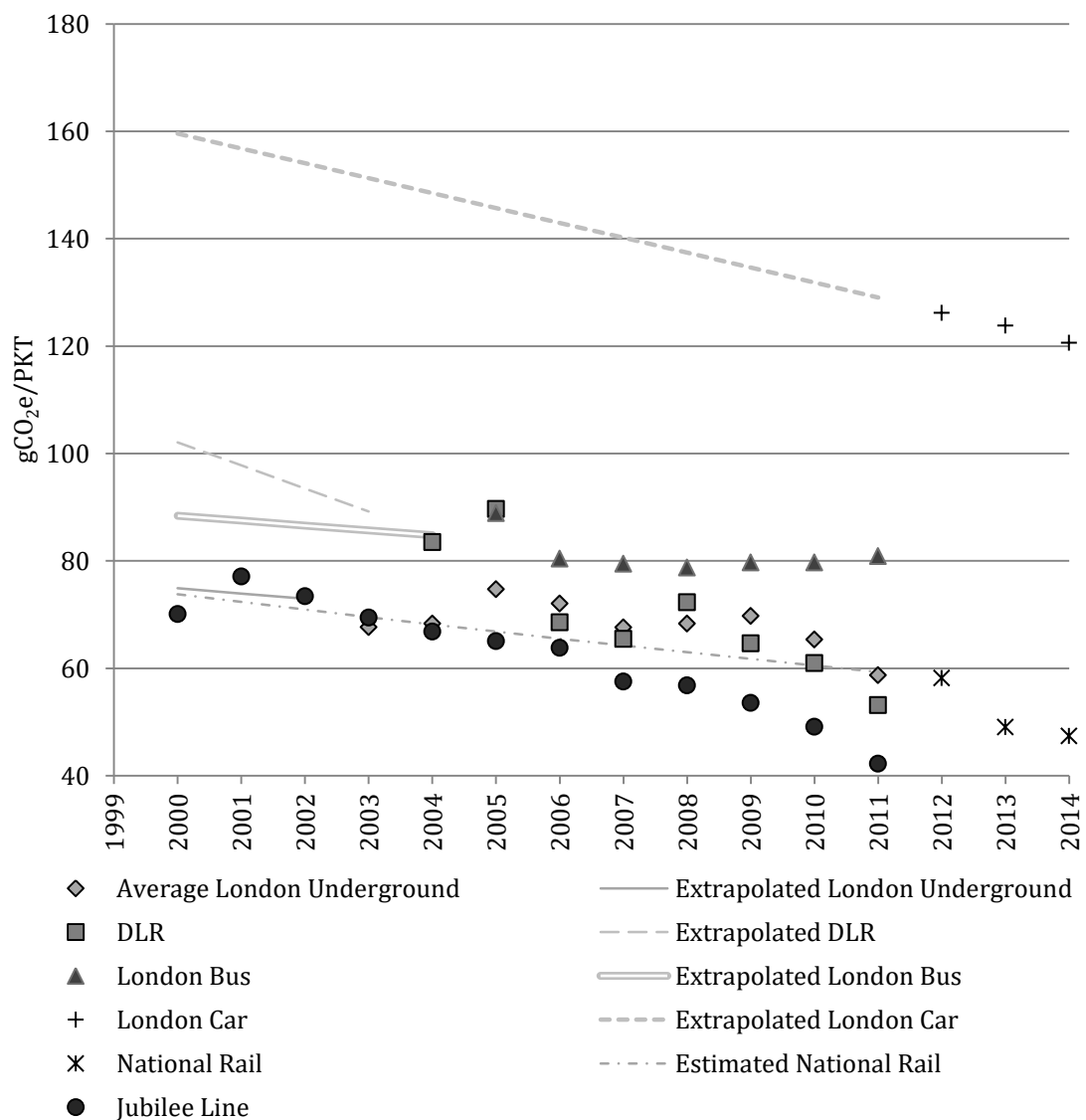


FIGURE 2 GHG intensity of London travel modes (Author's own graphic based on data from Transport for London 2012; Department for Environment Food and Rural Affairs 2015; Transport for London 2014)

4. Initial Mode Shift

In this analysis PKT travelled on the JLE are separated into two groups: (1) the initial mode shift set at the initial ridership in 2000 and (2) the mode share impact with growth in ridership calculated for PKT above the initial 2000 value. The initial mode shift is calculated using the results of a travel survey carried out by the Jubilee Line Impact Study Unit in 2000 and results of the London

Underground RODS in 2000. Long-term mode share is based on the relationship between metro rail accessibility and rail use, which will be discussed in Section 5. For the purposes of this paper the patterns of initial ridership observed in the first year of operation are assumed to hold through 2011 for the magnitude of riders observed in 2000. The mode share analysis is applied only to the growth in ridership.

In its first year more than 486 million passenger kilometres (PKT) were travelled on the JLE (Transport for London, 2013d). The Jubilee Line Impact Study Unit (JLEISU) completed a small survey of passengers in 2000; they investigated how trips made on the JLE had previously been completed (Transport Studies Group University of Westminster, 2004). They found that the vast majority of JLE users had switched from other rail: 54% underground; 21% DLR; 14% rail; 7% bus and 2% private automobiles. For this work the PKT shifted from each mode was calculated based on the station-by-station results of the JLEISU survey combined with the boarding stations of trips reported in RODS. The GHG intensity of each mode was then applied to calculate the GHG savings in 2000.

In 2000, there were 1.8 million trips per day on the underground network of those only 3000 would not have been travelled without the JLE (The Jubilee Line Impact Study Unit, 2002). As such, the induced demand onto the JLE was considered to be negligible and was ignored in this work.

Through mode shift in the year 2000, the JLE ridership resulted in a GHG savings of 5.52 ktCO₂e. The mode shift patterns observed in 2000 were assumed to hold steady for the magnitude of travel in 2000 and propagated through 2011 to calculate the on-going impacts of the initial mode shift. The GHG saving due to the initial mode shift from 2001 to 2011 are shown in FIGURE 3. As shown in FIGURE 2, the GHG intensity of the JLE has declined faster than the average GHG intensity of other parts of the rail network, particularly since 2006. As such the GHG savings due to the initial mode shift have increased with time. This is due, in part, to the rapid increase in ridership on the JLE, from 2004 to 2011 ridership on the London Underground grew by 17%, at the same time ridership on the Jubilee Line grew by 32% (Transport for

London, 2013d). The yearly GHG savings from mode shift have not grown linearly; drops in savings are most prominent from 2000 to 2001 and 2005 to 2006. This is due to changes in the relative GHG intensity of different travel modes in London and the drop in ridership from 2000 to 2001 before recovering in 2002.

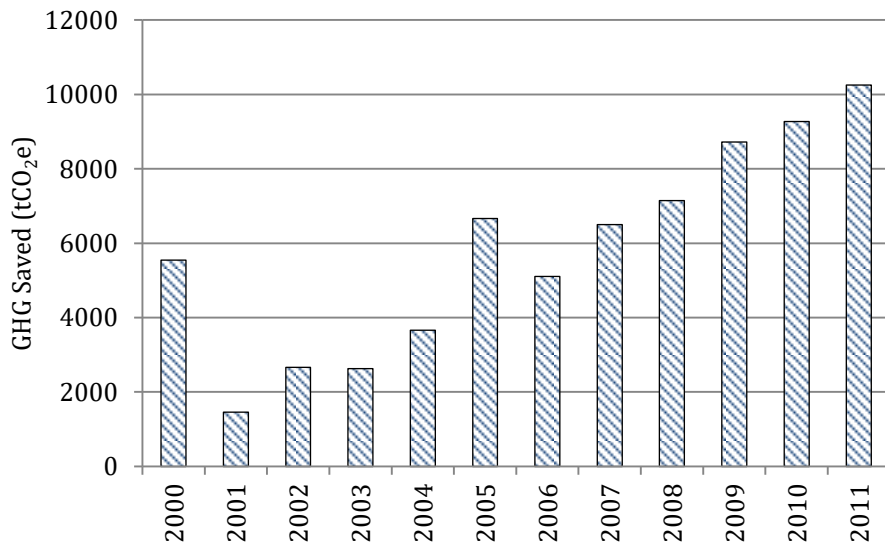


FIGURE 3 GHG saved by mode shift, initial mode shift only

4.1. Relative travel distance of rail trips – mode shift

The JLE provided a new path from central London to the east through the Isle of Dogs and North to Stratford. The Jubilee Line Impact Study Unit (JLEISU) found that the main reason for switching to the JLE was that it was faster than the pre-existing alternatives (The Jubilee Line Impact Study Unit, 2002). In order to complete the assessment of the GHG impact of the initial mode shift to the JLE, we compare the relative distance of travel to make the same trips using the JLE versus other rail modes available prior to JLE construction.

Trips using the JLE reported in the London Travel Demand Survey (LTDS) from 2005 to 2011 were modelled to calculate the change in travel distance facilitated by the line. The LTDS provides detailed origin to destination trip information, including mode and location of transfers. Of the 297,430 trips reported in the LTDS, 2,590 (0.87% of the survey) were reported to use the JLE and were modelled in this study. A detailed walking and rail travel network was

developed and qualifying trips were modelled using time minimized shortest path with and without the JLE.

Model 1) A time minimized shortest path model of the entire trip from origin to destination as reported in the LTDS with the JLE.

Model 2) A time minimized shortest path model from origin to destination as reported in the LTDS on a network without the JLE.

In order to reduce unnecessary processing costs, only trip stages that started or finished within a ten km buffer of the JLE were modelled. In general this applied to the initial ingress or final egress stage of the model trip such as walking to a National Rail station. These trip stages generally would not have been influenced by the JLE. The trips were modelled on identical National and London Rail networks, with the removal of the JLE the only change between model 1 and 2.

The Geographic Information System (GIS) software ArcGIS by ESRI was used for the spatial analysis in this work (ESRI, 2013). Walking path data was developed from Open Street Map vector road layer downloaded on April 13, 2013 (© OpenStreetMap contributors, 2015). A walking speed of 5 km/h was assumed for all walking elements (Shephard, 2008; Transport for London, 2007). The transit network was developed from Open Street Map with station entrance locations from NaPTAN (NAPTAN, 2013) and station locations modified from Doogal (© OpenStreetMap contributors, 2015; Department for Transport, 2013a; Doogal, 2013). Train speed for London Underground was estimated from 2007 data provided by Transport for London (Transport for London, 2007). Train speeds for the Docklands Light Rail (DRL) and London Overground (LO) were calculated from published schedules for 2013 (Transport for London, 2013c; a). Train speeds for National Rail were calculated from published schedules in 2014 and a uniform average speed of 35 km/hr was applied across the network (National Rail, 2014). TABLE 1 lists the assumed impedance times at stations. The waits to first board and transfer impedance times were held constant throughout the analysis; the former based on half the observed head time from published schedules. For National Rail transfers the

impedance time was based on the walking distance between station nodes. The model is London centric, with the majority of trips using the London rail network where headway and transfer times are generally low. It was the intention to keep networks simplistic with the aim of estimating the potential for reductions in trip distances post JLE construction.

TABLE 1 Impedance times in shortest path model

	London Underground	London Overground	DLR	National Rail
Boarding wait time at all stations (minutes)	2	4	4	5
Additional transfer time at junctions (minutes)	2			n/a

Of the 2590 trips that used the JLE as reported in the LTDS stages, 1135 (44%) used the JLE in the model. This reveals the error in capturing true behaviour in the time minimized shortest path model as constructed. The results presented here should be considered in light of the difference between real world behaviour and time minimized shortest path. The variation in the travel routes chosen between the reported stages and the trip models could have many factors, these include:

- 1) The models are perhaps too simplistic to accurately capture true travel time. Assumptions were made for simplicity and for lack of available data (i.e. the head time between trains is constant throughout the day and based on morning travels times). The use of more station specific head time and transfer times would provide better estimations of route choice.
- 2) People are making travel choices based on values other than the shortest time. These can include fewer transfers, avoidance of stairs (Marshall et al., 2009), financial cost (in choosing London Underground over National Rail) and weather (Mackett, 2001).
- 3) People are often inefficient at choosing the shortest route (Guo, 2011)

As shown in TABLE 2, a comparison of the two models revealed only a small saving in total rail travel distance when using the JLE. Without the JLE the total rail distance travelled was increased by 380 km. Compared to the 5,539 km calculated in JLE travel this represents a 7% saving in travel distance for each kilometre travelled on the JLE. In addition, without the JLE an 11% increase in walking is observed.

FIGURE 4 illustrates the different distances travelled by mode.

TABLE 2 Comparison of trips models: with and without the JLE

Model	Distance Travelled (km)						
	JLE	Other London Underground	DLR	National Rail	London Overground	Pedestrian	Rail total
Trips with JLE	5539	27144	4654	19932	390	3649	57657
Trips without JLE	0	29418	6993	21023	604	4052	58038

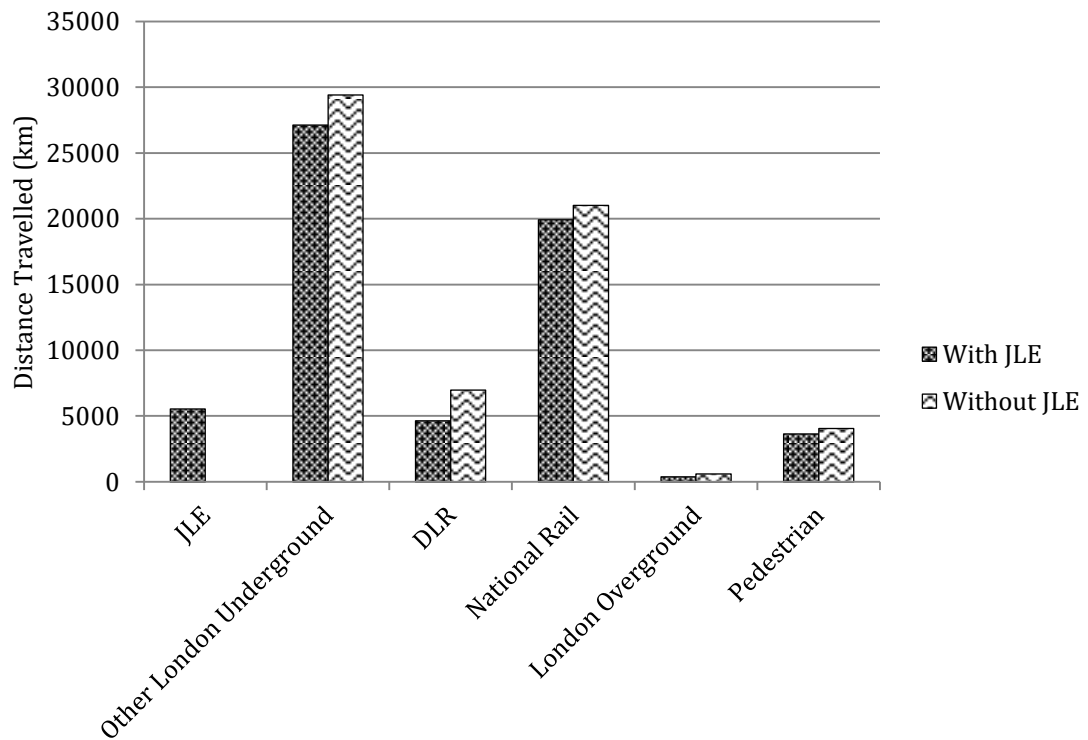


FIGURE 4 Comparison of trip distance by mode for stage model, trips with JLE model and trips without JLE model (Author's own graphic based on data from Ordnance Survey 2013; © OpenStreetMap contributors 2015; Department for Transport 2013b; Department for Transport 2013a)

4.2. GHG impact of relative rail trip distance

For the initial mode shift, a 7% saving in distance travelled accounts for a 33,386,761 km reduction PKT in the year 2000. The reduction in travel was 38% from other underground lines, 40% from the DLR, 18% from National Rail and 4% from the London Overground. These avoided kilometres account for a GHG savings of 2.9 ktCO_{2e} in 2000. As the GHG impact of all travel modes has decreased the savings from path efficiency has reduced. By 2011, the same avoided kilometres accounted for a GHG saving of 1.9 ktCO_{2e}, as illustrated in FIGURE 5.

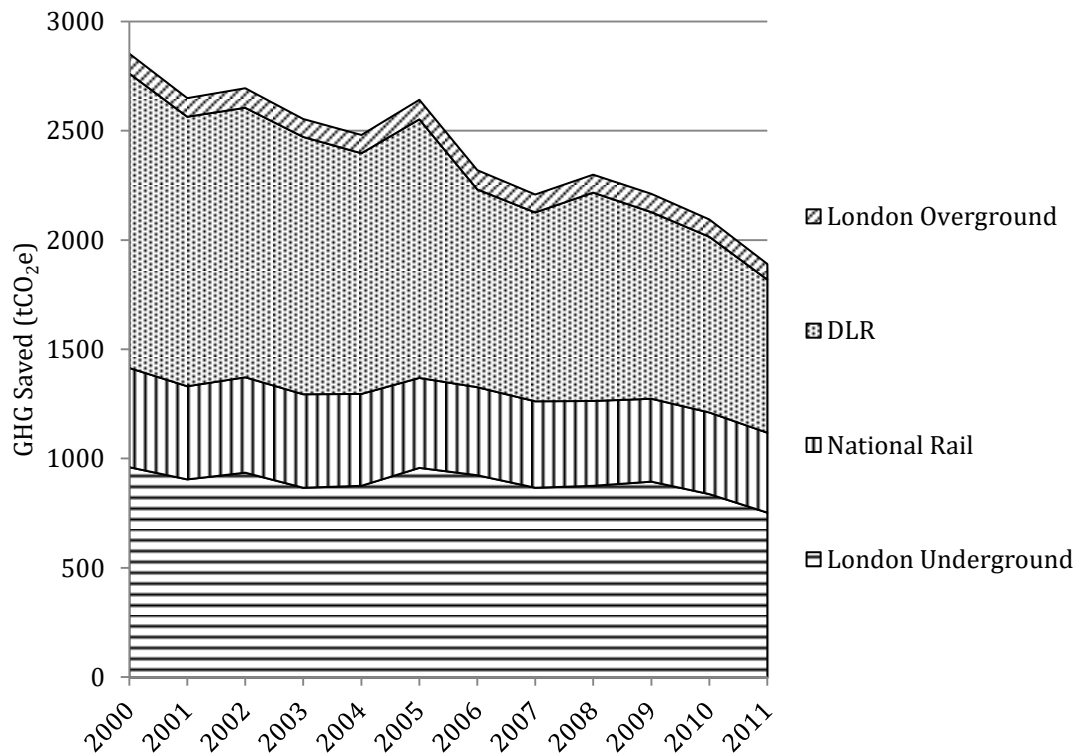


FIGURE 5 GHG saved through path efficiency associated with initial mode shift

5. Mode Share

With time and increased ridership the initial mode shift represents a decreasing fraction of the GHG impact of the JLE ridership. From 2000 to 2011, after a brief dip in 2001, the ridership on the JLE more than doubled. By 2011 there were 514,350,100 travelled on the JLE not explained by the initial mode shift. As these new users have taken up the JLE, the calculated GHG savings associated with the increase in ridership are from trips avoided by other modes. The initial shift mode shift is assumed constant through future years. Under these assumptions, a growing number of PKT remain unaccounted for in measured switches from other modes. The next section investigates how the trips associated with the growth in ridership would have been travelled without the JLE.

5.1. Mode share methodology

The London Travel Demand (LTDS) survey is used to examine the relationship between metro accessibility and mode choice. For this assessment, all trips

between 2005 and 2011 are analysed together. Trip lengths have been taken as the linear distance between the origin and destination recorded in the LTDS. While the authors acknowledge that the use of true trip distances would have been more accurate the data was not available. Due to challenges in accurately modelling travel path using a shortest path network distance, for cars especially, was thought to add spurious detail. For the calculation of GHG emissions savings the use of straight-line distance is conservative.

The LTDS trips are aggregated into 7 macro mode categories:

- 1) Active transportation trips: Bicycle, walking;
- 2) Car trips: Automobile driver, automobile passenger, motorcycle, taxi, small van, dial-a-ride;
- 3) Bus trips: Public transit (bus), school bus;
- 4) Lorry trips: Driver or passenger;
- 5) Urban rail: London Underground, London Overground, DLR;
- 6) Train trips: National Rail;
- 7) Other: Other, plane, boat, unknown

Trips are defined by their main mode by distance; the full distance of the trip is assigned to the main mode.

Accessibility was defined as the isochrone area accessible to the centroid of the Lower Super Output Area (LSOA) within 30-minutes of walking and metro travel and is measured in m^2 (Miller, 1991; Owen and Levinson, 2015). Thirty minutes has been chosen as globally, people prefer to commute 30 minutes in one direction (Rodrigue, 2013), In London, 44% of people commute 30 minutes or less to work (Office for National Statistics, 2011). **Error! Reference source not found.** illustrates the isochrone areas for OA E00020314 located just southwest of Canada Water Station in London. The accessibility of this location increased by 38% through the construction of the JLE.

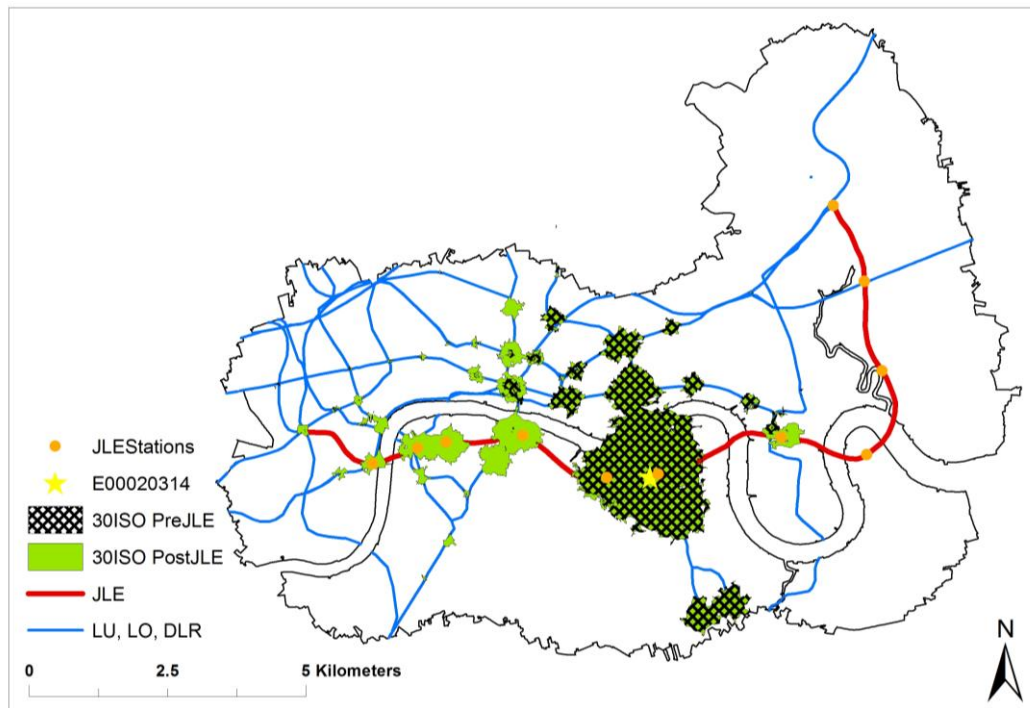


FIGURE 6 Isochrone areas for OA E00020314 (Author's own graphic based on data from © OpenStreetMap contributors 2013; Doogal 2013; Office for National Statistics 2011b)

The total distance travelled by mode compared to accessibility was evaluated for all trips with their origin or destination in the study area. Lorry trips and other accounted for a small fraction of all trips and distances travelled and are excluded. Active transportation accounted for a significant share of the trips but on average less than 10% of the distance travelled. In addition active transportation trips were not correlated to accessibility and, thus, are excluded from here on. Linear regression was used to evaluate the strength of the relationship between mode share and accessibility. Mode share was analysed in two ways: (1) share of total trips; and (2) share of total distance travelled in kilometres. Accessibility proved to be a weak to moderate predictor of mode share for urban and national rail use and car use, and a weak predictor of bus mode choice. The strength of the statistical relationship between accessibility and trip share are summarized in TABLE 3. The relationships between mode share and accessibility were stronger for trip share than distance share. Accessibility was a stronger predictor of trip share than distance share, which is logical given the reduction in mode choice for many long trips makes automobile the default choice in many cases. Given the many factors that influence mode choice from income, car owner ship, the influence of land use

personal preference and mobility to name a few the weak to moderate findings shown in TABLE 3 are not surprising.

PKT are needed to calculate GHG emissions - for this paper the calculations are based on distance-based mode share. Accordingly, for the rest of this section distance-based mode share results are presented. The effect of changes in accessibility on mode use is calculated from a mean relationship between the relationship found for trips starting and finishing in the study area.

EQUATION 1 to EQUATION 4 describe the relationship between accessibility and mode choice for urban rail, bus, car and national rail and are the results of linear regression between accessibility and mode share described in TABLE 3. At the lowest metro accessibility, car transport is the dominant mode choice followed by bus. With increasing accessibility, the mode share of urban rail and national rail increase. The increase in national rail use associated with an increase in metro and walking accessibility was not anticipated but is logical on reflection. Once connected to the rail network people are better able to access National Rail for intercity and regional trips.

The following formulae describe the mean relationships:

EQUATION 1: JLE - Accessibility and urban rail mode share

$$\text{Urban Rail Mode Share} = 17.901 + 4.380 \times 10^{-7}(\text{Accessibility})$$

EQUATION 2: JLE - Accessibility and car mode share

$$\text{Car Mode Share} = 40.847 - 5.508 \times 10^{-7}(\text{Accessibility})$$

EQUATION 3: JLE - Accessibility and bus mode share

$$\text{Bus Mode Share} = 21.700 - 2.936 \times 10^{-7}(\text{Accessibility})$$

EQUATION 4: JLE - Accessibility and National Rail mode share

$$\text{National Rail Mode Share} = 8.109 + 5.084 \times 10^{-7}(\text{Accessibility})$$

5.2. Mode share impacts

The total change in accessibility in the study area was calculated to assess the predicted change in mode share due to the JLE and its associated GHG impacts. In 2001 the residential population of the study area was 786,963 and the employment population was 1,432,109. In the subsequent 10 years the residential population increased by 23% to 967,844 and the employment population by 21% to 1,721,075.

When the JLE opened in 1999 it produced a step change in accessibility. Using the 2001 census population, the total residential accessibility within the study area increased by $7.18\text{E}+11 \text{ m}^2$ (7.2%), where total accessibility is the sum of the population in each OA multiplied by the accessibility of each census Output Area (OA) within the study area.

EQUATION 5: Total population based accessibility for the study area

$$Accessibility_{Total} = \sum Population_{OA} \times Accessibility_{OA}$$

Due to the geospatial concentration of population growth after the opening of the JLE, the total accessibility in the study area grew a further $2.24\text{E}+12 \text{ m}^2$ (20.8%). Using the relationships in EQUATION 1 to EQUATION 4, this further 21% increase accounts for 665,287 km travelled by urban rail per day, or 242,829,755 km in 2011. This residential increase accounts for nearly half of the unaccounted distance travelled on the JLE in 2011 of 514,350,100 km.

In addition to serving the people who live in the study area, the JLE corridor is an important corridor for employment, in particular providing increased access to

Canary Wharf, The City of London and Westminster. Again using the 2001 census, the step increase in total employment related accessibility was $2.24E+12$ m^2 (5.2%). Where total employment accessibility is the sum of the job population in each OA multiplied by the accessibility of each OA within the study area.

EQUATION 6: Total employment based accessibility for the study area

$$\text{Accessibility}_{\text{Total}} = \sum \text{Employment}_{\text{OA}} \times \text{Accessibility}_{\text{OA}}$$

Due to the geospatial concentration of employment growth after opening of the JLE, the total accessibility in the study area grew a further $7.87E+12m^2$ (17.5%). This increase in accessibility works out to a further employment related increase in urban rail use of 2,467,278 km a day. Assuming 250 workdays a year this equates to 616,819,500 km in 2011.

The residential and employment increases, discussed above, together call for an 859,649,255 km increase in urban rail use, this is the same order of magnitude as the observed increase in use of the JLE but is 67% larger. The larger value could be due to a number of factors. Some people who work in the study area would also live in the study area meaning they would be double counted. There are many other rail lines in the study area, which constitute part of the metro accessibility available to local workers and residents. The relationships developed above account also for the accessibility on other lines that would be expected to absorb some of the increase in distance travelled. Given these factors it follows that the growth in residential and workplace population would point to a larger growth in metro use than observed on the JLE. For the purposes of this work the relationships described in EQUATION 1 to EQUATION 4 are satisfactory described the mode share change associated with the JLE. From the equations, for each kilometre travelled on the JLE a reduction in road travel of 1.26 km and bus travel of 0.67 km and an increase in national rail travel of 1.16 km is calculated. An assessment of travel distance compared to

accessibility indicates that increased accessibility does not correlate with more travel overall; accordingly it is assumed that all travel on the JLE replaced travel that would have taken place on other modes.

FIGURE 7 illustrates the calculated GHG emitted and avoided due to the effects of mode share. The growing ridership on the JLE and the yearly fluctuation in GHG intensity for all modes, account for the year on year variation in GHG output.

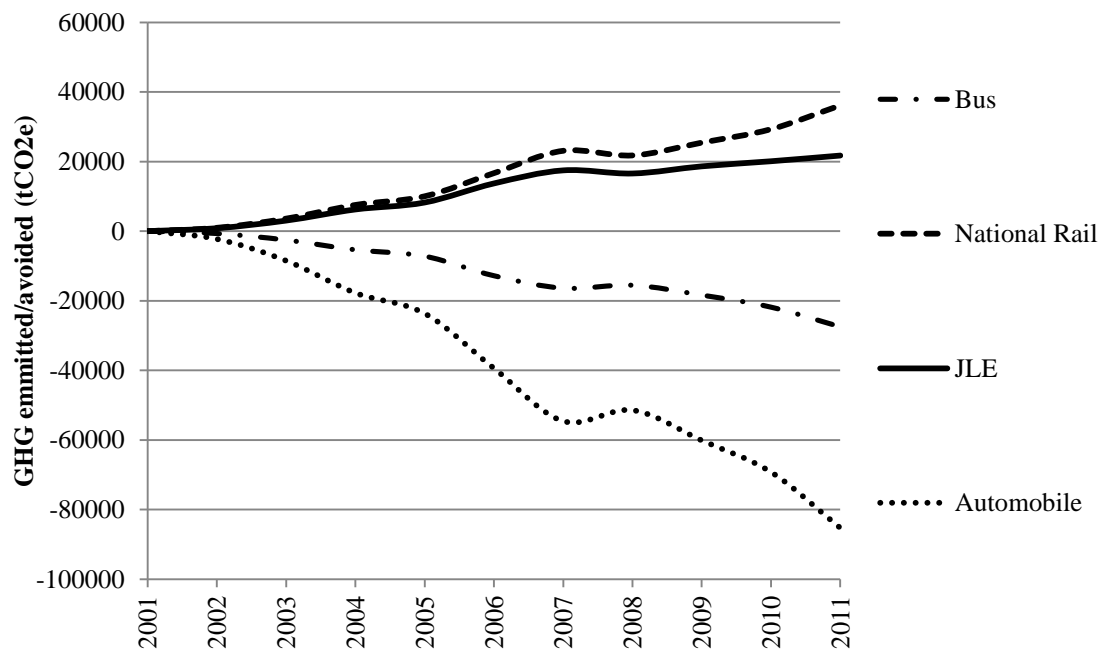


FIGURE 7 GHG emitted and avoided from mode share effects on increased ridership (Author's own graphic based on data from Department for Environment Food and Rural Affairs 2015; Transport for London 2014; Department for Transport 2013b; Transport for London 2013d)

5.2.1. Discussion and conclusions

FIGURE 8 illustrates the calculated GHG savings due to the JLE line ridership. The yearly GHG impact has increased in parallel to increases in the JLE

ridership and decreases in the GHG intensity of electricity in London. As the ridership has grown the impact of the avoided GHG associated with mode share calculation has dominated the calculated savings. From 2000 to 2011 the total calculated savings are 338 ktCO₂e, this is approximately equivalent to the annual average GHG emissions of 43,000 UK residents (The World Bank, 2015). The majority of the calculated GHG savings (59%) come from the mode share impacts in reducing automobile use.

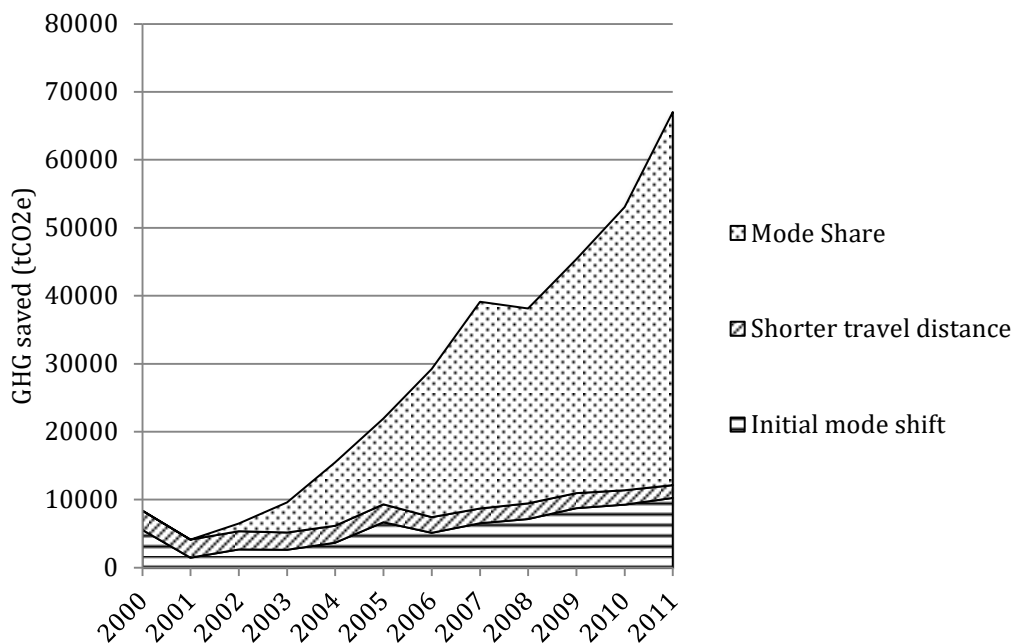


FIGURE 8 Total GHG saved through JLE ridership

The calculated GHG savings are sensitive to the calculated GHG intensity of the Jubilee Line. As shown in FIGURE 2, the conversion factors used for the Jubilee Line are lower than the average London Underground values for 8 out of the 11 years studied. In 2011, the JLE conversion factor is 72% of the average London Underground value. This has a significant impact on all the calculations but in particular changes the impact of kilometres shifted from other Underground Lines, the DLR and National Rail. Especially in the later years of the analysis the JLE conversion factors amount to a saving in GHG for PKT switched from

National Rail and DLR where, if the average London Underground factors were used, the finding would be an increase in GHG in these cases. Using the average London Underground factors, the savings in GHG associated with the JLE ridership are 258 ktCO₂e, 24% smaller than calculated with the JLE factors.

A number of assumptions went into this work, which could benefit from further exploration. The calculation of trip distance from the LTDS survey used in the mode share analysis was based on point-to-point linear distances. This may have a greater effect on some mode types than others, skewing the relative mode share. A more detailed travel survey that tracks used travel routes in detail would reveal real travel distance. Similarly, each trip was assigned to its main mode by distance, whereas in reality many trips are mixed mode. Mixed mode path analysis would give a more complete accounting of distance travelled by mode and associated mode share. The consistent methodology and the large amount of data used here are considered sufficiently accurate for the purposes of this paper.

The effect of increased accessibility on the growing study area population is difficult to quantify and is influenced by many factors outside the scope of this paper. For this work, it is assumed that the new population would otherwise have settled in an area with accessibility reflective of the outer bounds of the study area. The veracity of this assumption has not been tested in this paper. It is possible that the accessibility provided by the JLE attracted people and/or businesses out of the downtown core to an area that was newly metro transit accessible, a likely finding for jobs at Canary Wharf. It is also possible that people would otherwise have settled in an area of much lower accessibility with its associated higher rates of driving. This requires further research.

The influence of induced trips on GHG emissions has not been explored here. Though, analysis of the LTDS shows showed no relationship between increased accessibility and increased personal travel for residents of the study area. The

JLEISU found that the JLE induced a very small number of trips which have been excluded from this analysis (The Jubilee Line Impact Study Unit, 2002).

This research would benefit from an updated accounting of GHG factors for the years analysed. In particular, for National Rail, where extrapolation was required for all studied years, and the relationship between the JLE GHG intensity and other underground lines. Finally, this research was limited to the effects in the JLE corridor; knock-on effects of mode choices were not analysed (i.e. the effects of new trips on other underground lines as space was freed up by people switching to the JLE). Despite these limitations, this work highlighted a number of interesting points to be considered in future metro projects:

- 1) The mode shift onto the JLE was predominantly from other rail lines but the overall savings in PKT is small (7%);
- 2) This small reduction in rail travel distance results in ever smaller GHG savings as all modes become less GHG intensive;
- 3) The increased accessibility associated with the JLE is correlated with increased National Rail use in addition to increased urban rail use;
- 4) The GHG savings are highly dependent on the mode share impact on private road travel. The falling traffic counts in the affected boroughs indicate that PKT diverted to the JLE have not been simply replaced by induced demand on the roads.

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7. References

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