Congestion Reduction in Europe: Advancing Transport Efficiency

MG-5.3-2014
Tackling urban road congestion

D2.1
Urban Congestion and Network Operation: Towards a Broader Set of Metrics for Assessing Performance

WP 2 – Stakeholder Needs and Study Framework

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1. Introduction

The CREATE project is concerned with transport policies and travel patterns in cities, and how these have evolved over time in response to changing circumstances and priorities. It is one of several projects that have been funded through the European Commission's Horizon 2020 programme, under the topic 'Tacking urban road congestion'.

In particular, CREATE explores how cities have responded to the challenges of growing car ownership and use, and the associated increases in traffic congestion. Initially by accommodating this growth through providing increased road capacity, and more recently by reducing reliance on the private car for day-to-day mobility and so containing levels of congestion and ensuring that this affects a decreasing proportion of daily travel.

The project is based around four core propositions:

1. The way in which the "congestion" debate is framed in a city reflects the perceived role of the urban transport systems and how performance is measured: as policy priorities change, so do the appropriate metrics for measuring 'success'.

2. The existence of a 3-stage "Transport Policy Evolution Cycle" spread over 50+ years, which gradually shifts the policy emphasis and investment priorities from catering for road traffic growth [C: Car-oriented city] through extensive road building and increased parking provision ('Stage 1'), through switching the focus to providing high quality public transport [M: Sustainable mobility city] to facilitate person movement ('Stage 2'), to a priority on reducing road traffic and building a liveable and healthy city [P: City of places], through developing streets as 'Places' ('Stage 3').

3. The examination of future mobility options, given the anticipated rapidly growing urban populations (and hence a mobility 'densification') in many larger cities, that will require new policy measures – aided by advances in technology - which can achieve congestion reduction, promote sustainable mobility, while meeting wider policy goals.

4. Promoting the "policy transfer" of understanding gained from investigating the above propositions in several Western European 'Stage 3' cities, to 'Stage 1' cities which are coping with rapid growth in car ownership and currently under pressure to promote 'pro-car' policies. The aim is to provide them with insights into how to short-circuit or speed up the 3-stage historical "Transport Policy Evolution Cycle" that Stage 3 cities have evolved through.

To assist in this analysis, the CREATE consortium includes five Western European 'Stage 3' cities (Berlin, Copenhagen, London, Paris and Vienna) and five Eastern European/Euro-Med 'Stage 1' cities (Adana, Amman, Bucharest, Skopje and Tallinn).

This deliverable addresses four issues:

1. The relationship between urban transport policy framing and the appropriate metrics for measuring transport network performance; for example, the term 'congestion' reflects 'Stage 1' thinking and may have less relevance in later stages – it is not a value-neutral word.

2. A review of how CREATE ‘Stage 1’ and ‘Stage 3’ cities, and commercial service providers such as INRIX, currently capture data about traffic congestion and road network performance and how they present this data – with examples from selected cities.

3. A critique of the limitations of the current indicators of traffic congestion and road network performance.

4. Proposals for a more insightful and comprehensive set of metrics of urban transport network performance, illustrated with data from selected cities.

This deliverable mainly uses data from London to illustrate the application of some of the metrics discussed here. D3.4 presents a comparable set of indicators for the five CREATE ‘Stage 3’ cities, with some examples from the ‘Stage 1’ cities.

2. Relationship between Indicators of Transport Network Performance and Policy Objectives

2.1 An urban transport policy development cycle?

As in all areas of policy, the perception of the problem and the nature of the debate are influenced by the prevailing policy paradigm and the availability of supporting empirical data (Jones, 2012).

For example, when the transport policy paradigm and associated debate is concerned with providing for the projected growth in motor vehicles, then the focus is on ensuring the free movement of vehicles and policy solutions tend to focus on road building and increased parking provision. At this time the importance of pedestrian and cycle movement go unrecognised, partly because they are considered 'old fashioned' modes of transport and also because surveys often only collect data on motorised, longer distance vehicle travel. Conversely, if the policy discourse changes and is about overall quality of urban life, then due consideration is also given to the value of streets as providing a high quality public realm as a backdrop to places which facilitate vibrant economic and social activity.

In city regions, transport perspectives and economic and social priorities are often observed to change over time, as a consequence of changes in policy priorities. Within 'CREATE' this change is described in terms of an evolutionary urban transport policy development process, which is characterised by changing views about providing for car ownership and use, about the role of sustainable transport modes, and more generally about what cities are for (Jones, 2013). This leads to the promotion of different policy objectives and policy measures at different points in time. However, as we shall see, indicators of network performance have not in general kept up with the evolving thinking about the role and delivery of transport services, and the wider role of streets.

This historical, evolutionary process can be observed in the five CREATE Western European cities, but may also be found elsewhere in Europe and in some other parts of the world. To date, we can identify three, largely sequential stages (Jones, 2013, 2016):

Stage One: **Car-oriented city (C)**

Rapid urban economic growth leads to a fast increase in car ownership and use, and general support for policies to cater for this growth (e.g. by new road building, providing extra car parking spaces). This is often linked to strict land use zoning policies that spatially segregate activities and discourage mixed-use development; and street designs which discourage walking and cycling, and may reduce footway width to increase carriageway provision. Investment in public transport may decline, and more of the street space in general is allocated to cars and general traffic.

Stage Two: **Sustainable mobility city (M)**

Problems arising from the growing levels of car use begin to become apparent (e.g. road congestion, air and noise pollution, traffic accidents); resulting in policies which set out to provide better modal alternatives to car use (especially rail-based), to tackle pollution and accidents, and start to limit provision for car use (e.g. by introducing parking restrictions in city centres, or limiting car access to city centres); at this point after a while the rate of growth in car use begins to reduce. Major Chinese cities such as Beijing and Shanghai, are now experiencing Stage 2 conditions.

Stage Three: City of Places (P)

Now there is a much greater policy emphasis on urban quality of life, achieved through: (i) a cutting back in provision for cars and other road traffic by reallocating roadspace to sustainable transport modes and to street activities; and in some cases demolishing elevated highways and multi-story car parks erected during Stage 1, as well as through congestion pricing, etc. (ii) providing enhanced public transport, strong encouragement for walking and cycling, and (iii) promoting a high quality public realm.

This evolutionary process is shown schematically in Figure 1.

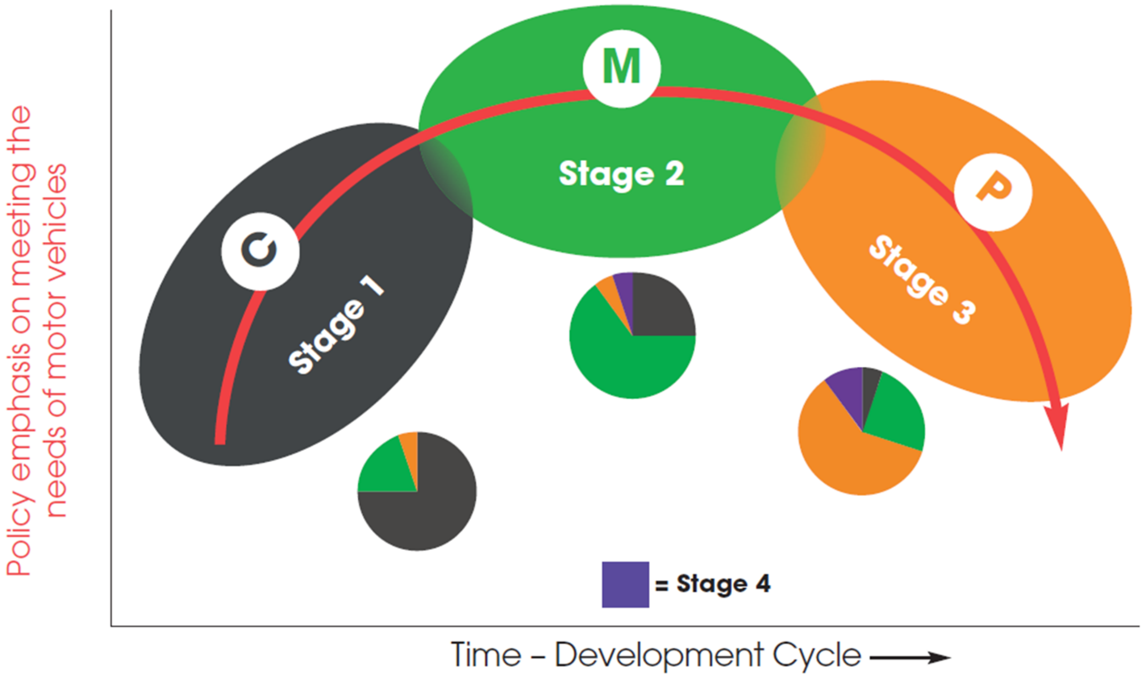


Figure 1: Evolution of city perspectives, with a mix of views at any point in time

The three stages primarily represent an evolution in thinking, on the part of the politicians and the public, about what cities are for and what types of mobility and activity should be encouraged. Sometimes, the order might be different; for example, in Copenhagen the interest in ‘City of Places’ preceded a major investment in ‘Sustainable Urban Mobility’. But, in practice, in all cities the shift from one stage to another is much less clear cut, with overlaps and sometimes short-term reversals of policy following an election. There may be elements of all three stages throughout a city’s development, although the dominant perspective shifts. Elements of ‘Stage 4’ – whatever that turns out to be - are already to be found in city policy debates.

Although cities in less developed economies tend to be in ‘Stage 1’, there are also many cities in advanced economies (e.g. in the USA), which still apply ‘Stage 1’ thinking with transport networks designed to facilitate car travel.

The five Western European CREATE cities are now broadly adopting ‘Stage 3’ policies, although aspects of ‘Stage 1’ perspectives may still be found in their outer urban and peri-urban areas. Outside Europe, cities such a New York, Vancouver and Seoul are also largely experiencing ‘Stage 3’ conditions. On the other hand, the corresponding national transport agencies, which often have a much narrower, more siloed focus, may operate largely within a ‘Stage 1’ or a ‘Stage 2’ paradigm, reflecting their sectoral remit.

A switch in policy perspective (‘Stage 1’ to ‘Stage 2’, or ‘Stage 2’ to ‘Stage 3’) may be associated with the election of a new city mayor (e.g. Auckland, Bogota and London), or another strong political or professional personality; and in the latter case may be accompanied by relative and absolute reductions in car use (and sometimes car ownership), despite increasing incomes, resulting in a decoupling of economic growth from traffic growth. At this point there is now a greater enthusiasm among major property developers to invest in public realm in central city areas rather than in increased car parking provision.

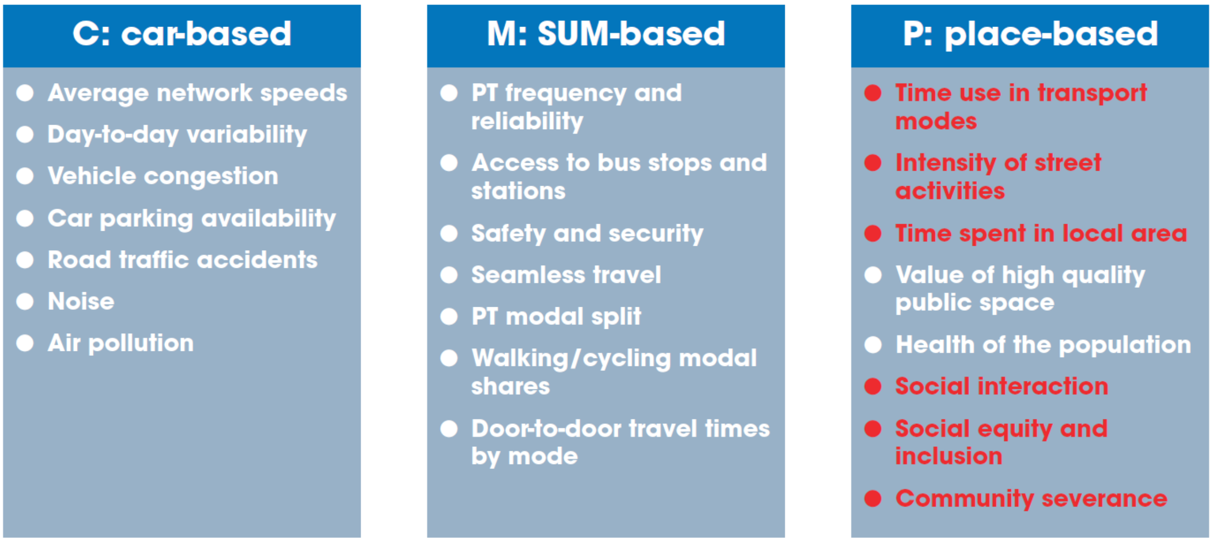
2.2 Changing political priorities among policy objectives and relevant indicators

Associated with these changes in urban transport policy perspectives are corresponding changes in the more operational policy objectives, and in the ways in which the notion of ‘success’ and ‘failure’ is interpreted; which, in turn affects the types and range of network performance metrics and indicators that are used.

For example:

- ‘Stage 1’ desired outcomes: good highway ‘level of service’ and reductions in motorised road traffic delays, with an emphasis on ‘congestion reduction’.
- ‘Stage 2’ desired outcomes: improved public transport provision and performance, high levels of passenger satisfaction, increasing walking and cycling, and stabilisation in car modal share.
- ‘Stage 3’ desired outcomes: improved public realm and greater street activity – resulting in a wider range of performance indicators, reflecting both ‘Movement’ and ‘Place’ considerations.

Figure 2 shows the kinds of ‘measures of success’ that tend to be associated with each policy perspective.



KEY: There are not yet well established means for measuring and valuing these benefits

Figure 2: Indicators associated with each policy perspective

The widely used traditional metrics describing road network performance in terms of traffic congestion and vehicle travel time variability tend to primarily reflect a ‘Stage 1’ policy perspective; and so need to be complemented – and perhaps in some cases replaced - by metrics which are reflections of ‘success’ from the perspectives of ‘Stage 2’ and ‘Stage 3’ policy thinking.

As a consequence of the evolution in urban transport policy thinking, the range of metrics and indicators used to measure ‘success’ is likely to broaden and the importance given to each of them will vary over time. This is evident, for example, in Central London, where road traffic congestion has now returned to its early 2000s levels before congestion charging (road pricing) was introduced, but this is now seen as less of an issue than it was 15 years ago. There are several reasons for this. First, the increased congestion applies to a smaller volume of traffic – overall traffic volumes here have fallen by around one-quarter since 2000 – so it is affecting a smaller proportion of travellers (a ‘Stage 2’ perspective). And second, because of the perceived benefits, from a ‘Stage 3’, perspective that have resulted from taking away capacity for car traffic and reallocating it to pedestrians and cyclists and providing an improved street environment and public realm.

The remainder of this deliverable investigates existing and potential metrics of measuring the ‘success’ of urban transport policies in greater detail.

3. Current Indicators of Traffic Congestion and Transport Network Performance

3.1 Data collection methods

City authorities now have a range of data sources available to them to measure network performance and traffic congestion. These include:

- **Loop detectors**, indicating the percentage of the time that a short section of road (usually on the approach to a junction) is occupied by a motor vehicle; suitably sited detectors can also be used to measure queue lengths
- **Traffic flow** measurement (tubes, loops, sensors) indicating the volume of road traffic crossing a point per unit time period, possibly categorised by vehicle type
- **ANPR** (Automatic Number Plate Recognition), which enables vehicles to be tracked through a network, thereby providing information on average speeds between camera locations (including stop time at junctions) and – potentially – route choices, as well as traffic volume by vehicle type
- **MCO** (Moving Car Observer) method, which involves driving a car at the 'average' speed of traffic, in order to measure travel times between pre-defined points on selected routes, at different times of day
- **GPS** vehicle tracking (in cars, trucks, buses, taxis) reporting back vehicle locations in real time, which enables a wide range of potential performance indicators to be generated, both relating to location and trajectories
- **Mobile phone** tracking data, which has the potential to provide similar information to vehicle-based GPS, but not confined to motorised trips – provided the algorithms can accurately identify travel mode.

Table 1 shows which data sources are routinely used to collect network performance data in each of the ten CREATE cities.

3.2 Measurement of congestion and road network performance

OECD/ECMT (2007, p. 28) notes that it is difficult to come up with a single or simple measure of congestion because:

> *"Congestion is both a physical phenomenon relating to the manner in which vehicles impede each others' progression as demand for limited road space approaches full capacity… as well as a relative phenomenon relating to users' expectations vis-à-vis road system performance."*

Table 1: Methods of collecting network performance data in CREATE cities

		Loop	Flow	ANPR	MCO	GPS	MP	Other
'Stage 3' city	Berlin	X	X			(X)		
	Copenhagen	X	X		X	X	X	
	London	X	X	X	(X)	X		
	Paris/Isle de France	X	X	X		X		
	Vienna	X	X			(X)	(X)	
'Stage 1' city	Adana	X	X					
	Amman	X						Cameras
	Bucharest	X	X			X		
	Skopje	X	X (manual)		X			
	Tallinn	X	X		X	X		
	INRIX					X	(X)	

Falcocchio and Levinson (2015) summarise the various indicators of congestion used by highway authorities in the United States. They identify four dimensions of congestion: (i) Intensity, (ii) Duration, (iii) Extent (spatial) and (iv) Variability. Here we focus on the primary indicators of Intensity and Variability, as Duration and Extent describe the time/space area over which other metrics apply in different cities. Further variations on these indicators are listed in OECD/ECMT (2007) and reproduced in an Appendix to this deliverable.

3.2.1 Intensity of congestion/delay

Excess travel time

The most common indicator of traffic congestion is based on the ratio between the average speed in free-flow conditions (usually based on data recorded in the middle of the night) and those observed at different times of day, converted to an implied increase (absolute or percentage) in average travel time.

This is the basis behind the commercially published indices from INRIX and Tom Traffic which compare congestion levels between cities and countries. For example, the **Travel Time Index (TTI)** , used by INRIX until 2016, was developed using the methodology described in Table 2. This information can either be presented as a ratio (e.g. 1.3) signifying the proportionate increase in journey time, or as the excess amount, which in the US is referred to as the 'travel time tax'.

An example of the INRIX Index applied to data from London is shown in Figure 3.

Figure 3: INRIX Congestion Index for Peak Period Travel in London [dark red = worst]

Excess travel rate

Transport for London (TfL) uses a similar basis for measuring traffic congestion but here it is defined not in terms of differences in speed (km/hr), but the inverse – a difference in 'travel rate' measured in min/km. This is referred to by Falcocchio and Levinson (2015) as the 'congestion delay rate'. Figure 4 shows bi-monthly average values in the Central London congestion charging zone, recording 'excess delay' compared to the free flow conditions found in the early hours of the morning, from 2002 before the scheme was introduced to 2008 when this form of measurement ceased [Note: WEZ = addition of Western Extension Zone].

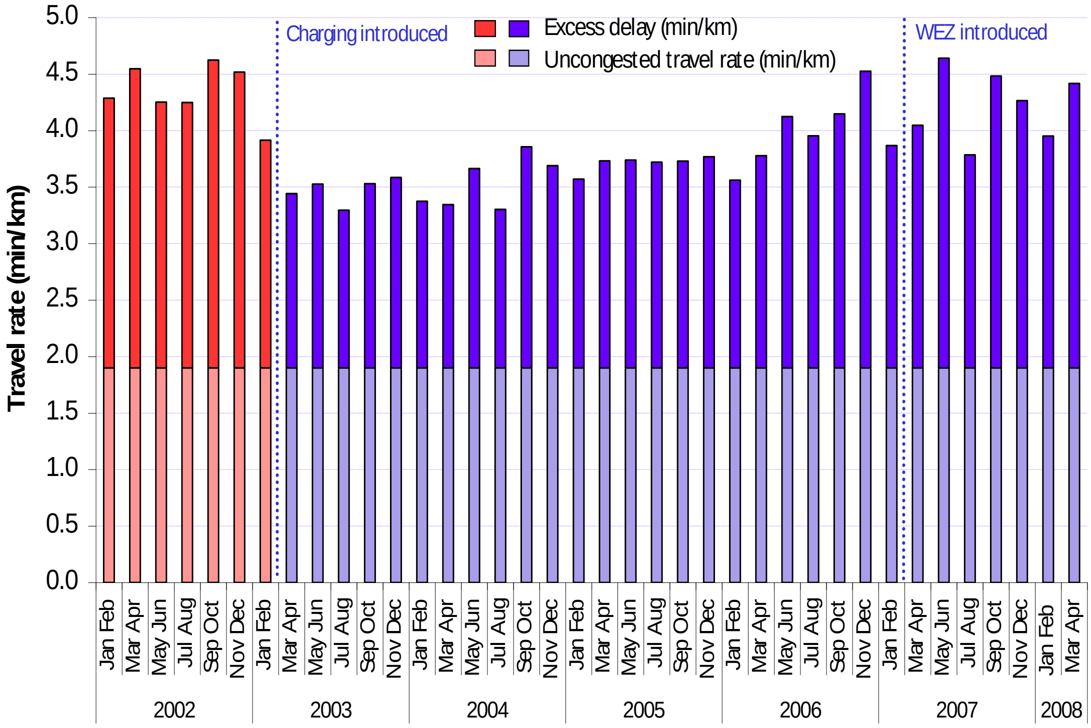


Figure 4: Congestion in the original central London charging zone during charging hours, based on Moving Car Observer (MCO) surveys. Source: TfL.

Table 2: Calculation of the INRIX Travel Time Index (TTI)

"The INRIX Travel Time Index represents the barometer of congestion intensity. For a road segment with no congestion, the TTI would be zero. Each additional point in the TTI represents a percentage point increase in the average travel time of a commute above free-flow conditions during peak hours. A TTI of 30, for example, indicates a 20-minute free-flow trip will take 26 minutes during the peak travel time periods with a 6-minute (30 percent) increase over free-flow. For each road segment, a TTI is calculated for each 1 hour period of the week, using the formula: INRIX Travel Time Index = (Travel Time to cross a segment at Calculated Speed / Travel Time to cross section at Reference Speed) – 1. "Drive Time" Congestion: To assess and compare congestion levels year to year and between metropolitan areas, only "peak hours" are analyzed. Consistent with similar studies, peak hours are defined as the hours from 06:00 to 10:00 and 15:00 to 19:00 of "local time", Monday through Friday – 40 of the 168 hours of a week. For each Metropolitan Area, an overall level of congestion is determined for each of the 40 peak hours by determining the extent and amount of average congestion on the analyzed road network. This is easy to compute once INRIX Indices are calculated for each segment: • **STEP 1:** For each of the 40 peak hours, FRC1, FRC2 and FRC3 road segments [an internationally standardised classification] are analyzed in the Metro Areas and checked. Each segment where the TTI > 0 is contributing congestion, and it is analyzed further. • **STEP 2:** For each segment contributing congestion, the amount the TTI is greater than 1 is multiplied by the length (metric or imperial, based on region) of the segment, resulting in a congestion factor. • **STEP 3:** For each hour period, the overall metropolitan congestion factor is the sum of the congestion factors calculated in STEP 2. • **STEP 4:** To establish the Metropolitan TTI for a given hour period, the metropolitan congestion factor from STEP 3 is divided by the number of road lengths analyzed. • **STEP 5:** A peak period TTI is determined by averaging the hour indices from STEP 4 during the peak hours as defined above." Source: INRIX

3.2.2 Variability of journey times

Journey time variability

This measures the variability in travel time from day-to-day for vehicles using parts of a road network; more specifically, the percentage of occasions when observed travel times do not exceed the mean values by more than a threshold value of T minutes or X%.

Figure 5 shows how this indicator has been applied in London, in response to the mayor setting TfL the objective of 'smoothing traffic flow'.

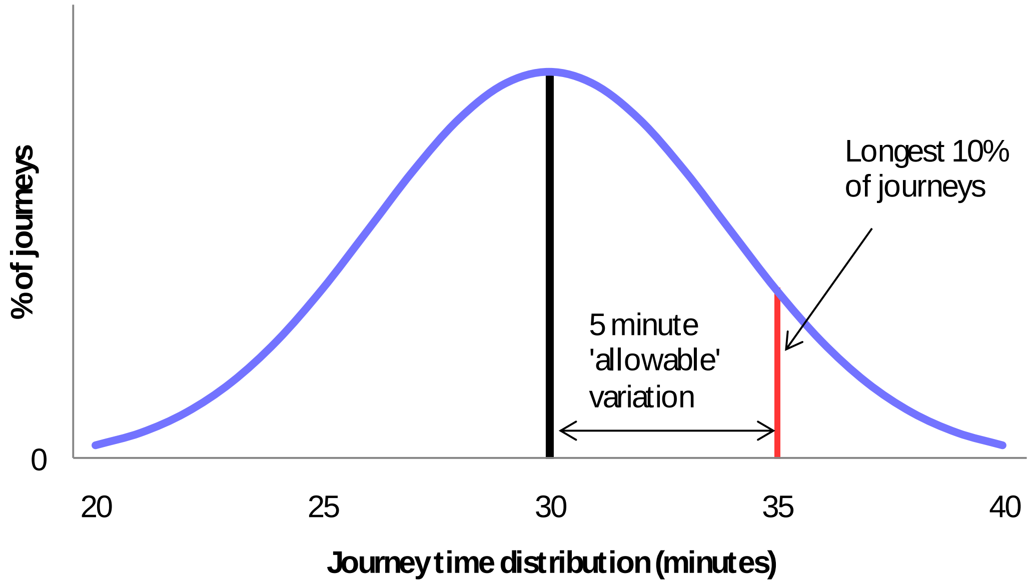


Figure 5: Conceptual representation of journey time variability around an assumed mean journey time, as measured in London. Source: TfL.

This measures the variability in travel time around a nominal 30-minute journey time, which is regarded as a typical duration for road journeys in London. The figure shows that actual journey times vary from day to day and are distributed about this mean value. It was decided that up to a 5-minute variation above the mean value would be considered to be ‘acceptable’. In other words, for a representative journey that would, on average, take 30 minutes, any duration up to 35 minutes is deemed to be ‘reliable’; note that no account is taken of the contribution to variability of journey times which are below the mean values. Therefore, the policy objective would be to increase the proportion of journeys within this 35-minute window, currently equating, in nominally adjusted terms, to 90 per cent of measured journeys in London, on a daily basis.

Falcocchio and Levinson (2015, pp. 114 and 115) report on two indicators of reliability which are commonly used in North America:

- The **Buffer Time Index**: “the amount of extra time to be added to the average trip time in the peak hour [recorded as a percentage increase, or a ratio – e.g. 1.4] if one aims to arrive on time 95% of the time”.

- The **Planning Time Index** (PTI): “represents the 95th percentile Travel Time Index (TTI)”. One empirical American study estimated this to be:

$$\text{PTI} = 1.7 \times (\text{Average TTI}) - 0.39$$

3.3 Measuring public transport performance

There are various ways in which public transport performance is measured, both at a network and at a journey level, taking the UK as an example.

3.3.1 Network performance

Such indicators describe how well the transport system is performing, in meeting system level targets. Rail tends to use different metrics than road-based bus services.

Figure 6 summarises the proportion of scheduled train services in London and the South East of England which operated and ran 'on time'. Here a train is considered to have arrived 'on time' if it reaches its destination within 5 minutes of the schedule arrival time. In this example, we can observe quite wide variations, from a high of 97% to a low of 82%.

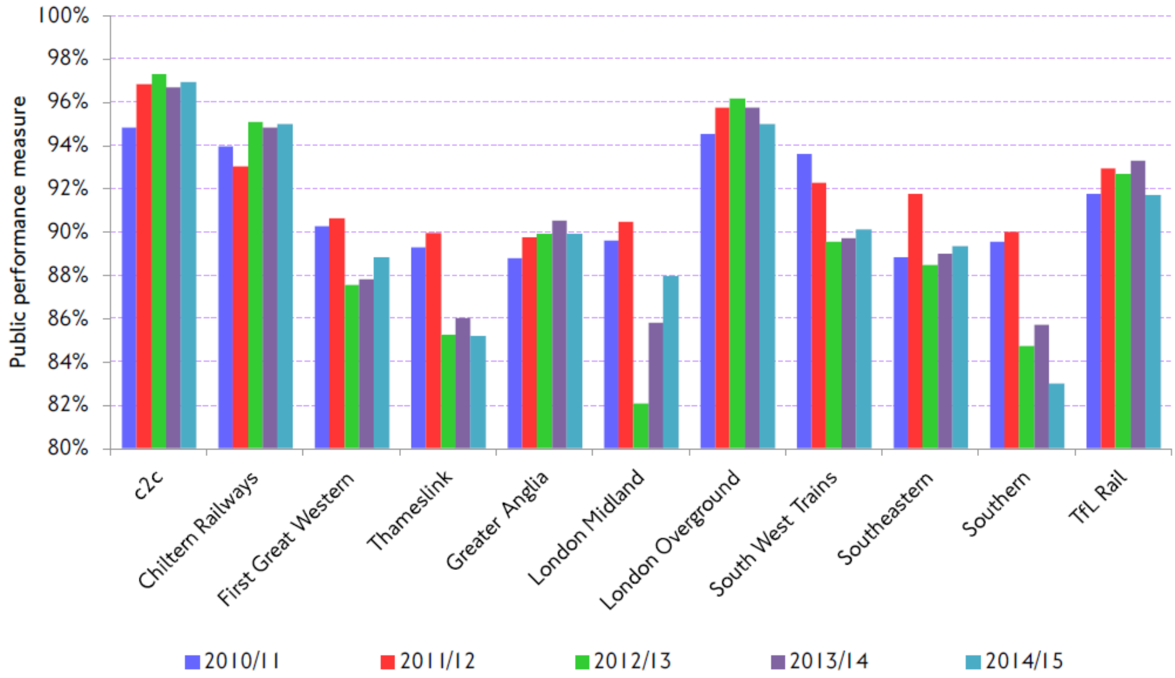


Figure 6: National Rail 'public performance measure' for London and the South East (moving annual average), combining punctuality and reliability.

Source: Transport for London (2015, Figure 4.3); data supplied by the Office of Rail and Road

In addition to delays and cancellations, another key measure of public transport performance concerns levels of crowding. Crowding on National Rail services in the UK is measured using the Department for Transport's 'Passengers in excess of capacity' (PiXC) indicator – which is a measure of overcrowding. This compares the observed passenger numbers on services arriving in or departing from central London, between 07:00 and 09:59 and 16:00 and 18:59, respectively, against the notional capacity of the services provided. Capacity is defined as the number of standard class seats on the train for journeys of more than 20 minutes; while for journeys of 20 minutes or less, an allowance for standing room is also made. This varies with the type of rolling stock but, for modern stock is typically approximately 35 per cent of the number of seats.

PiXC is defined as the ratio between the two, namely actual loading levels/maximum theoretical capacity, expressed as a percentage. Figure 7 shows PiXC results (for the morning peak period only) from 2008 to 2014, by train operator. In 2014 the PiXC value across all operators (combined) increased to 5.4 per cent, up from around 4 per cent in the previous four years. With the best cases at 1% or less and the worst at over 18% in 2010.

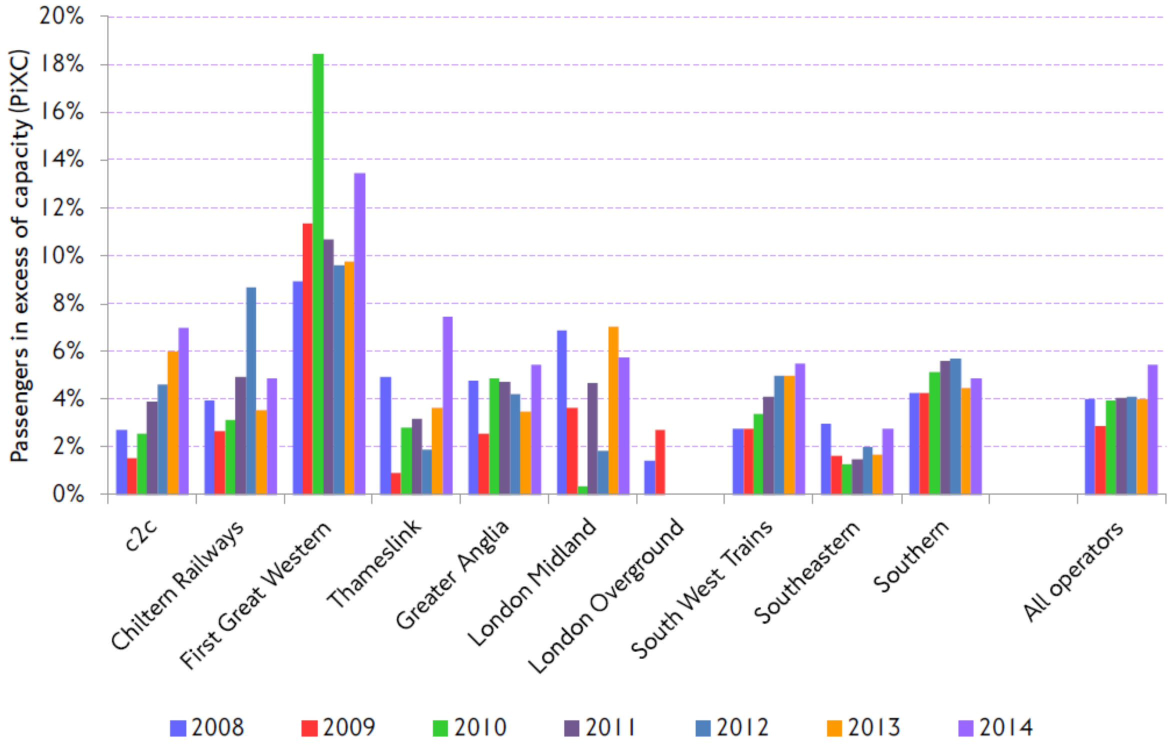


Figure 7: 'Passengers in excess of capacity' (PiXC) for national rail operators serving Central London in the morning peak period.
Source: Transport for London (2015, Figure 4.4); data supplied by the Office of Rail and Road

3.3.2 Journey experience

A second set of indicators provide an insight into how the public transport networks affect the journeys made by travellers. In the case of London, different indicators are used for bus and for underground journeys.

For **buses** on high service frequency corridors the indicator is '**excess waiting times'**, which computes the mean difference between waiting times, were buses to run at regular intervals according to the timetabled headway, and actual waiting times based on observed arrival times at bus stops – in both cases assuming random arrivals of passengers at stops. In London average values have roughly halved over time, from 2.0 minutes in 2001 to about 1.0 minute excess waiting time per passenger journey in 2016 – which mainly reflects a substantial increase in bus priority as well as contractual regimes which incentivise operational reliability.

For **underground** services, the indicator is '**excess (station to station) weighted journey times'**, both as an absolute number of additional minutes and as a percentage of the average generalised journey time. The 'generalised' journey travel time weights the different journey components (in-vehicle, walking waiting) according to their relative disutility using values obtained from passenger surveys.

Some 'subjective' measures of journey experience are discussed in section 5.2.3.

3.4 Indicators used by CREATE cities

A summary of the current objective indicators of congestion, road network and public transport performance in the ten CREATE cities is shown in Table 3. As can be seen, they are currently much more extensive in Stage 3 than in Stage 1 cities.

Table 3: Indicators of congestion and network performance currently used in the CREATE cities.

	Excess travel time (speed)	**Excess travel rate**	**Journey time reliability**	**Excess PT wait time**[1]	**Excess PT travel time**	**Other** Please specify
Berlin	(X)	(X)	(X)		(X)	
Copenhagen	X	X		X	X	
London		X	X	X	X	
Paris/Isle de France	X	X	X	X	X	Flow/capacity at peak hour
Vienna	(X)	(X)			X	
Adana		X		X	X	
Amman	X					
Bucharest	-	-	-	-	-	No regular analysis
Skopje			X (ad hoc)			
Tallinn	-	-	-	-	-	No regular analysis
INRIX	X	X				

[1] *Bus, tram and metro only*

4. Some Limitations in Applying the Current Indicators

There are limitations, both in relation to the reliability and representativeness of the data collected, and to the appropriateness of the indicators which are being used.

4.1 Data collection limitations

Several issues arise here, under two broad headings.

1. The **technical reliability** of the measuring equipment, including:
   - loop detector failure
   - mismatches using ANPR (Automatic Number Plate Recognition) algorithms
   - communication failure from GPS and mobile phone sources
   - locational inaccuracies from GPS and mobile phone sources
2. The **extent of coverage** of the data collection systems, in particular:
   - limited coverage of the Moving Car Observer method (both in space and time)
   - limited locations of loops, cameras and other detectors
   - limited penetration of vehicle-based GPS across the fleet and partial mobile phone data coverage from any one operator

Particular problems can arise with GPS data, for example, where fleet sizes are increased over time resulting in a differing mix of vehicle types, driving styles and journey patterns, which can lead to significant discontinuities in trends in measured travel times. This effect can be seen in Figure 8, showing average traffic speeds over time, for London.

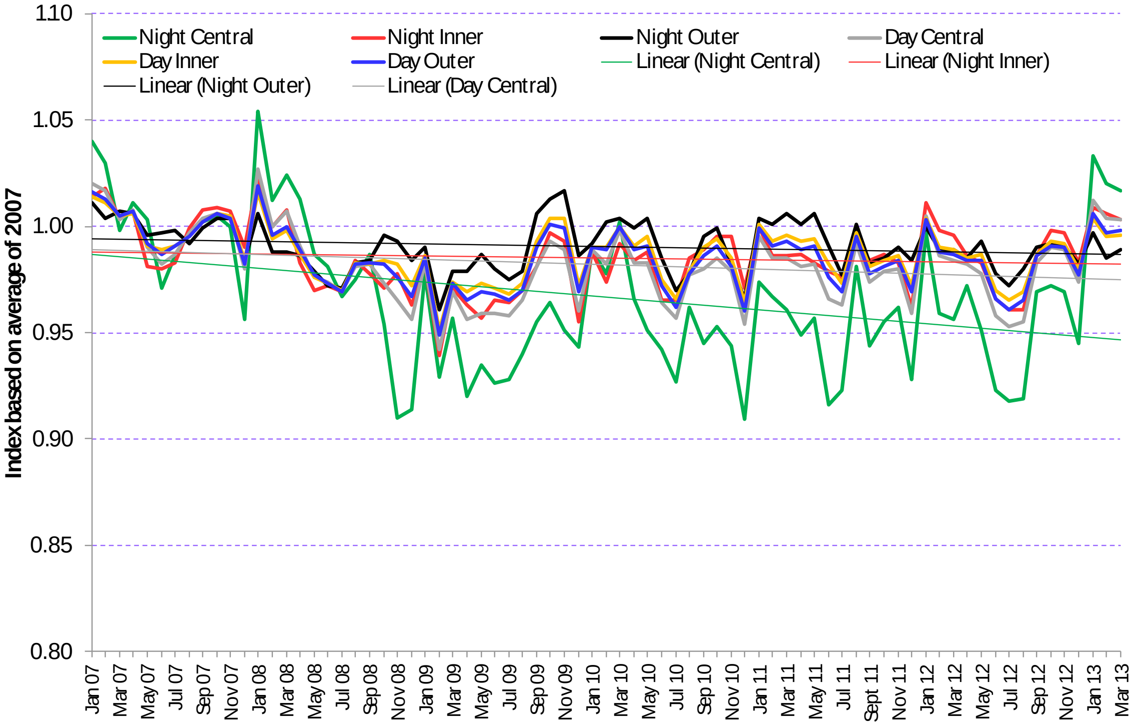


Figure 8: Trends for selected indicators of average traffic speed, 2006-2013.

As can be seen in this figure, particularly for night time average speeds in the Central Area, there appear to be two significant discontinuities in the series – around the end of 2007/start of 2008 (sharp drop) and again around the end of 2012/start of 2013 (sharp increase). These are suggestive of 'series breaks' in the data. This could be due to two related factors, associated with an increase in the number of probe vehicles:

- The balance of driver characteristics changes (e.g. higher proportion of cars vs. HGVs)
- The number of links in the network with sufficient data to give robust estimates increases, so the balance of link characteristics changes too.

However, independent statistical investigation by TfL has failed to definitively establish this to be the case for the data shown in Figure 8.

In addition, some data sources have limited spatial coverage, so that the conditions they capture may not be representative of the network as a whole. For example, the ANPR cameras in London (used to measure journey reliability) are only sited across the 580km of Transport for London Road Network (TLRN) owned by Transport for London – so it is possible that measures which improve reliability on the TLRN may actually cause an (unmeasured) deterioration in conditions on the remainder of London's road network, and that this may go undetected using this measure. Unfortunately this cannot be investigated given the current distribution of cameras and other recording devices.

4.2 Limitations in what the current indicators are showing

4.2.1 Excess vehicle travel time and excess travel rate

Here there are several caveats and limitations:

1. The measurement of an 'excess' journey time (or travel rate) depends on having reliable base line conditions from which to measure 'free flow' speeds. City authorities and private data suppliers vary in the time period over which they define these base line conditions – from as wide a window as 22.00 to 06.00 the next morning, to between 02.00 to 05.00. It is likely that the average measured speeds will be higher in the latter case than in the former, so that congestion measured in this way will appear to be greater than when a wider reference case time window is used – so consistency in measuring the baseline is important where comparisons are being made between cities.

2. As noted in section 4.1, not all links in the road network are included in the measurement of average speeds (except when this is based on door-to-door GPS or mobile phone data). Higher capacity links are more likely to be covered by CCTV, traffic loops, etc. and these are likely to support higher travel speeds. So, if cities increase their network coverage to include more lower-capacity roads, then average recorded overall network speeds are likely to decline.

3. Given the much greater use of the urban road network during the day (e.g. by delivery vehicles, by buses and by pedestrians and cyclists), then it would not be feasible – nor desirable - on a multi-modal transport network, to attempt to completely 'eliminate' congestion measured in this way, by replicating the night-time free-flow traffic speeds during the day. Hence such indicators of congestion are not very useful from a policy perspective, and do not encourage informed public debate about what would be regarded as a 'reasonable' level of network performance during the working day. Falcocchio and Levinson (2015, p.99) caution against using this excess travel time/rate indicator for comparing congestion levels between urban areas:

   "… in a large city it is not realistic to travel at free flow speed (or at the posted speed limit) in the peak hour. It is not logical, therefore to compare actual peak hour travel times to free-flow peak hour travel times when free-flow in the peak hour is a practical impossibility in a large city.
   "While the TTI may be an appropriate metric in tracking congestion over time for the same area, it should not be used to compare areas served by road networks with different free-flow speeds."

4. In many cities, traffic conditions may now be worse at weekends than on working days (due to more leisure travel by car and often a relaxation in parking restrictions), and this is not routinely captured in the application of these kinds of indicators.

5. The indicators do not usually take into account the legal speed limits, which means that average speeds above the speed limit during the free-flow parts of the day will increase the overall estimated excess vehicle travel time and increase the level of congestion. The values should probably be capped at the legal speed limit levels.

6. The indicators assume a linear negative relationship between speeds and congestion, e.g. halving the speed doubles the estimated congestion, which may not be reflect with driver's perceptions of congestion.

7. While such indicators may be viewed as 'objective', at the same time they are also partially arbitrary and subject to policy influence. For example, if legal urban speed limits are reduced on large parts of the road network (e.g. through the widespread introduction of 20mph or 30kph zones), in order to improve air quality or reduce noise levels or traffic collision severity, then measured congestion would suddenly 'appear' to have reduced substantially - since the baseline night time speeds would then become lower and so the observed differences in speeds between daytime and night time conditions automatically reduce. [Note that in the US 'Urban Mobility Report', the free flow speeds on freeways used to calculate congestion may be well in excess of legal speed limits! – see Litman, 2014.]

8. Indicators of congestion are often reported on a 'per vehicle' basis, rather than allowing for differences in vehicle occupancy. This takes no account of differential impacts on bus passengers, for example. Were private vehicle occupancy to increase over time (e.g. due to a growth in car sharing/pooling), then the number of people affected by congestion

would increase even if there was no increase in vehicle numbers; conversely, numbers would decrease if vehicle occupancy declined.

9. Furthermore, congestion indicators do not take into account the total numbers of people affected. Thus using existing indicators, a city might measure a growth in car congestion over time, even though fewer people overall are being affected (as is the case in London). If this has resulted from the reservation of more parts of the limited carriageway space for bus and tram lanes, which has resulted in those users now experiencing reduced delays, then looked at from an overall person movement perspective, average person door-to-door speeds may have been increasing alongside an increase in measured congestion.

   Litman (2014) illustrates this by comparing car commuting congestion levels in US cities as reported in the Urban Mobility Report, against the car user modal shares in each city:

   > *"….for example, it indicates that Washington DC has the worst congestion of all US cities because automobile commuters experienced 67 average annual delay hours, but since that region has only 43% automobile commute modal share, this averages just 29 hours per commuter overall. In contrast, Houston's automobile commuters only experience 52 annual delay hours, but since it has an 88% auto mode share this averages 46 hours per commuter, much higher than Washington DC."*

   He also reports that Sundquist and Holloway (2013) found that between 2000 and 2010, across a range of US cities, average commute times as a whole declined slightly in cities while at the same time the Travel Time Index increased – again illustrating the dangers of inferring impacts on traveller experiences from using this type of measure..

Congestion indicators only take into account people using the general road network; as more travellers chose to use rail services, buses in segregated lanes, or protected cycling and walking networks, then the proportion of travellers affected by general road congestion declines. Indeed, where road-space has been reallocated from cars to sustainable modes, then a recorded increase in congestion may reflect a conscious policy decision to enhance conditions for other modes. Data for the five CREATE Western European cities is shown in Table 4. Although the differences are not as marked as in the North American example – as all have been pursuing 'Stage 3' policies – the table compares conventional congestion values with average delays when spread across all travelers, showing the much-reduced impact when taking account of all travellers.

Table 4: Indicators of congestion do not reflect the impacts on travelers as a whole

	INRIX indicators (2016)		**% of all trips made by car (driver or passenger)**	**Indicators adjusted for mode share of car users**	
	% of travel time the *average driver* spent in congestion	Average number of hours *car drivers* spent in congestion/year		% of travel time of the *average traveller* spent in congestion	Number of hours in congestion per year, averaged across *all travellers*
London	14%	73	34%	5%	25
Paris	12%	65	25%	3%	16
Berlin	8%	40	28%	2%	11
Vienna	7%	39	29%	2%	11
Copenhagen	4%	24	29%	1%	7

Note: The INRIX indicators in the first columns are those described in Section 5.1.3 of this deliverable.

This suggests there is a need to take a more comprehensive view and adopt broader indicators of urban transport network performance (see section 5). There are other limitations of relying on an 'excess travel time' indicator to measure performance:

- Particularly for the freight and logistics sector, it is reliability (i.e. reducing variation and unpredictability) which is more important commercially than increasing average speeds. Private motorists also prefer to 'keep moving' rather than experience frequent start/stop driving – even if door-to-door journey times are less in the latter case.
- Providing sufficient urban road network capacity to operate in peak periods under free flow conditions is not the optimal level of investment. An alternative might be to maximise traffic flow – but this is much more difficult to determine over an urban network than on a limited access corridor – or base on willingness to pay calculations (see section 5.4).

Such factors have implications both for selecting the 'best' performance indicators and for the appropriate policy measures to manage the network to best meet user needs.

4.2.2 Journey time variability

While a useful indicator, journey time variability does not provide a complete picture of traffic conditions. In particular, because variability is a measure of the spread of journey times around an average, the average itself could deteriorate and this would not be evident in the indicator. As a result, journeys could become longer at the same time as being measured as being more reliable - by becoming "reliably slow(er)".

Second, achieving the policy objective of an increased proportion of reliable journeys assumes that it is possible to improve those aspects of road network operation that give rise to unreliability – a phenomenon which is affected both by changes in demand and supply (see Figure 9).

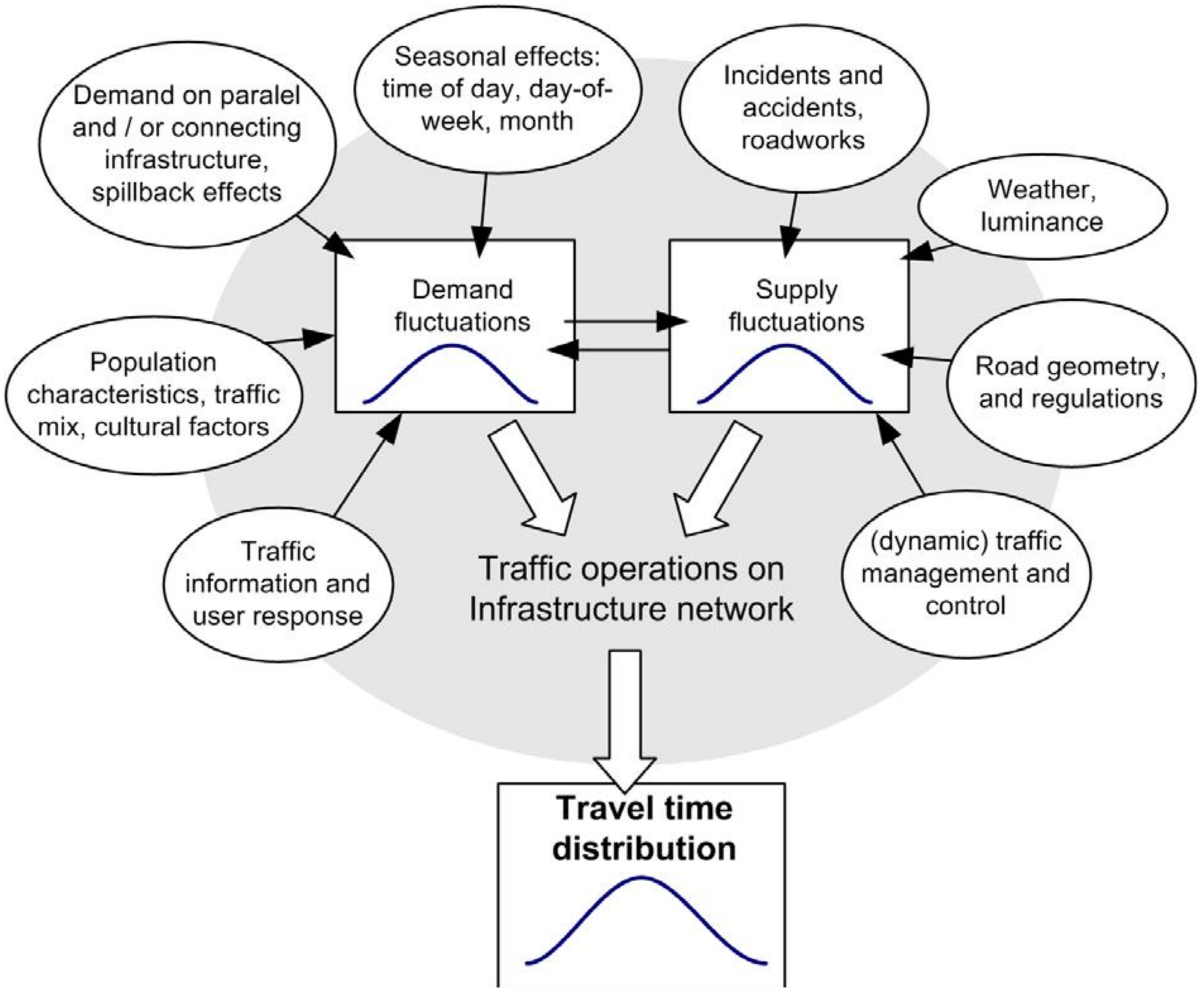


Figure 9: Schematic overview (not exhaustive) of factors influencing the distribution of travel times.
Source: van Lindt et al (2008, Figure 1).

Research by TfL, subsequent to the establishment of the journey time variability indicator for London (as shown in Figure 5), has suggested that just 20 per cent of the factors known to cause congestion and unreliability are susceptible to direct policy influence – the overwhelming contributor to congestion and unreliability is simply variation in the sheer volume of traffic (see Figure 10). It follows, therefore, that any improvements to these other contributors would have to be dramatic in order to affect the journey time reliability index - by even a percentage point or two. The track-record for this indicator bears this out: the trend in London has been very stable at around the 89 per cent 'reliability' level over the past five years and has not moved perceptibly up or down.

Van Lint *et al* (2008) raise a different concern. Using data from a heavily used freeway in the Netherlands, they show that the travel time distribution is not only very wide but also heavily skewed, and that this latter factor also needs to be taken into account in assessing network performance. Comparing eight measures of variance and of skew gives a different picture of the times of day at which the freeway is least reliable – and the measures are not highly correlated.

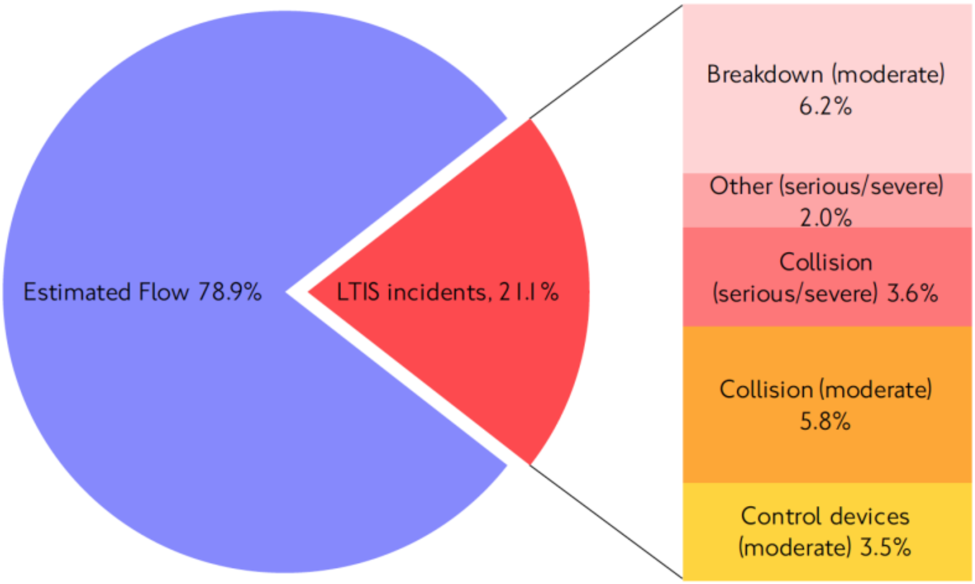


Figure 10: Proportional contribution of explanatory factors to the loss of journey time reliability in the weekday AM peak period.
Source: Transport for London

4.3 Limitations of existing public transport performance measures

The network performance measures provide a good overview of the extent to which the transport system as a whole is running as planned, but they do not give a complete picture:

- The 'public performance measure' in Figure 6 does not take into account the numbers of passengers on each affected train – it is likely that worst delays will be experienced on the peak trains; and
- The PiXC index of overcrowding (Figure 7) does not take account of any passengers who may not have been able to board the train, due to lack of space.

Although the journey-level indicators better capture passenger experiences and impacts on their journeys, there are still limitations. In particular, while excess waiting or travel time is a simple and easy-to-understand indicator, it is based on some key assumptions, which do not apply to all public transport trips. In particular:

- That the station or stop is accessible to all travellers, including those in wheelchairs.
- That there is sufficient capacity for passengers to be able to board the first bus or train to arrive at the station/stop. This may well not be the case at peak times, particularly for people with luggage or restricted mobility.
- That the first vehicle to arrive at the stop/station will serve passengers' intended destination.

5. Potential for New/Improved Indicators of Network Performance

5.1 Improved indicators of congestion and road network performance

There are several ways in which the indicators described in section 3.2 might be enhanced and refined. Several possibilities are discussed in this section.

5.1.1 Agreeing a common basis for defining 'free-flow' speeds, over time and between cities

This could either be based on:

- The same baseline time window across cities (e.g. 2am to 4am), or
- A definition based on performance characteristics (e.g. three-hour time period during which free-flow speeds are the highest)

While ensuring that the free-flow speed is not in excess of local speed limits – if that is the case, then speeds should be reduced, accordingly.

In order to better understand and analyse the basic differences in network configuration and network performance between cities (and between parts of the same city), it would be useful to derive indicators that are directly comparable, by taking into account differences in size, density, etc. Such indicators might include:

- Average free-flow network speeds as % of speed limits on the same segments
- Proportion of the total road network included in the speed measurements
- Density of junctions on higher-capacity roads (controlled and uncontrolled) per network km.

5.1.2 Adopting a more realistic metric for measuring road network performance

This could be based on various principles, in particular:

'Acceptable' congestion

Falcocchio and Levinson (2015) refer to the concept of 'acceptable congestion thresholds' based on what drivers, politicians and professionals regard as an acceptable average daytime speed. They suggest that this value will vary by size of urban area and type of road, but in general that (page 3):

> *"The beginning of congestion is generally perceived by drivers when their trip times increase by approximately 0.4-0.5 min/mile, and they become acutely aware of congestion when it increases by 0.8-1.0 min/mile."*

Litman (2014) notes that Transport Canada starts to calculate network congestion costs when conditions are below 50% to 70% of free-flow speeds, to represent a reasonable range of optimal urban-peak traffic speeds.

Falcocchio and Levinson (2015) provide other examples of acceptability thresholds, in relation to the relevant speed limits:

- Washington State uses a threshold of 'at or below 75% of posted speed'
- The Quebec Ministry of Transport uses a threshold of 'at or below 60% of posted speed'

'Acceptable' level of service

In general terms, a simple indication of the performance of a road network can be derived from measuring demand (observed flow) against capacity (design flow); as the former approaches the latter, speeds tend to drop and flow can become unstable. Falcocchio and Levinson (2015) report that in New York congestion is defined as arising in cases where the Demand/Capacity ratio exceeds 0.8, and severe congestion where it exceeds 1.0.

This idea has been taken further in the concept of 'level of service', which was originally developed to measure traffic flow conditions on links on limited access freeways in the USA, on a scale from A (free flow, unimpeded movement) to F (queuing traffic), using a composite measure taking into account speed, density and other more subjective factors. It has more recently been adapted to traditional urban road conditions (TRB, 2010), with scales provided for LoS values for motorised traffic both on urban links (varying by category of road) and at junctions. Thus, cites could consider whether network performance is adequate in terms of it meeting a specified level of service.

'Optimal' congestion

The economically optimal level of congestion is not zero with a road network always operating at free flow traffic speeds, so it would be more rational to define congestion as the 'inefficient' delay in excess of this optimal level. This concept is represented diagrammatically in Figure 11 below. The congestion equilibrium point is dependent not just on the capacity of the road network, but also on the quality and quantity of the public transport network.

5.1.3 More sophisticated measures of congestion

The availability of vehicle-based GPS systems and mobile phone data to track vehicle movement second-by second provide the opportunity to develop new kinds of vehicle-based congestion indicators. Two possibilities include:

- Time spent in stationary traffic – either in absolute or percentage terms
- Time spent traveling below a threshold speed (e.g. 10 kph) – either in absolute or percentage terms; an example is provided from the London Congestion charging scheme in Figure 12.

This would provide a means of capturing drivers' reported frustration at driving at very low speeds or in stop-start traffic.

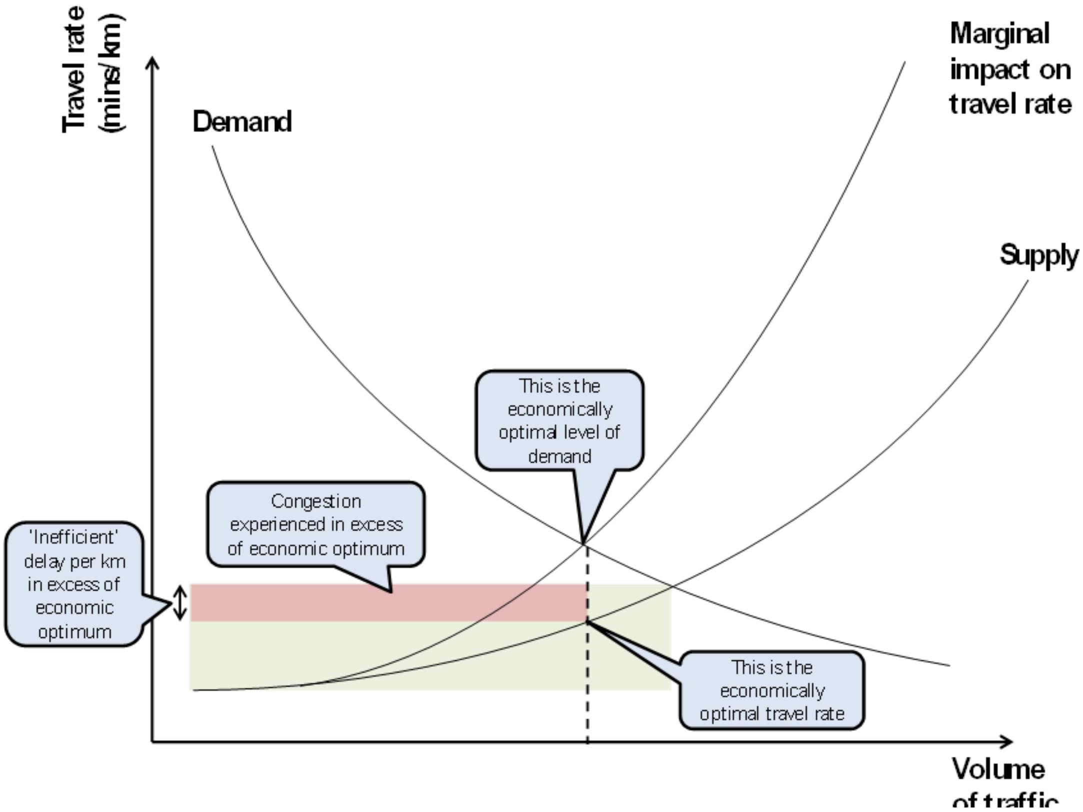


Figure 11: Distinguishing between total delay and inefficient delay.
Source: James, Clowes, TfL

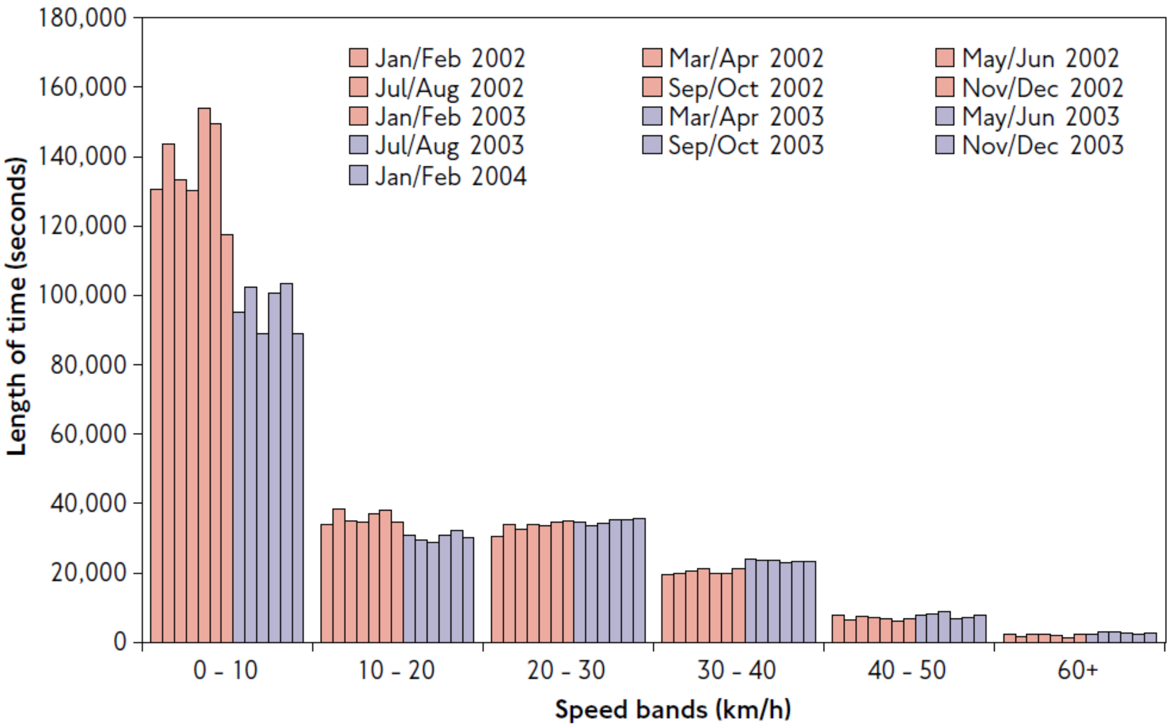


Figure 12: Time spent travelling at different speeds in the charging zone during charging hours.
Source: Transport for London (2004, Figure 2.5)

Recently, INRIX has introduced a new methodology based on GPS data, which allows for the classification of each moment as "congested" or "uncongested" in each segment of the road network, with congestion defined as a speed below 65% of the free-flow speed. This data can be used to calculate: the proportion of time spent in congestion in different parts of the city and at different times of the day, the proportion of time the average driver spent in congestion (adjusting for city size), and the total number of peak hours spent in congestion. These are then compared across cities (http://inrix.com/scorecard).

5.1.4 Taking into account vehicle numbers, occupancy and other factors

A simple measure of congestion as a comparison between free-flow and daytime speeds gives no indication of the numbers of vehicles or people affected. Here several enhancements could be made, by taking into account:

The number of vehicles using the road network

As noted earlier, it is quite possible for congestion per vehicle to increase while the total number of vehicles affected decreases, to the extent that overall time lost in 'congested conditions' by vehicles drops. This aggregate measure is thus a more informative indicator when taking a strategic view of overall movement in a city.

Average occupancy, by type of vehicle

Focusing on the effects of network conditions on vehicles is very much 'Stage 1' thinking. In 'Stage 2' the emphasis switches to person movement and person flows. Here there is greater interest in knowing what level of delay is experienced by the people inside the motorised vehicles.

Economic costs of delay

Having established levels of excess travel time for different categories of traveller, it then becomes practical to estimate the 'value of time losses' experienced by each group, and provided an overall estimate of the costs of delay. To this could be added the costs of fuel consumed while idling, the excess CO_2 emissions, etc.

Using this approach, Ceber (2014), in a report commissioned by INRIX, estimate current and anticipated 2030 levels of congestion (and other) costs in four countries and a sample city in each one (which includes London and Paris).

However, note that the traditional 'Stage 1' priority being given to travel time savings is being challenged from two directions:

- Arguments by Metz (2014) and others that, in the long run, travel time savings from road improvements are not taken up but instead 'lost' through increases in trip length, as daily travel time budgets remain unchanged; and

- Travel time is now being used more productively through the use of mobile communications, so that the case for investing in travel time savings is weakening.

So, even though 'lost time' may be stable, if some of that time can now be used more productively (e.g. through hands-free mobile telephone communication), then the economic costs of that congestion could be declining. There is some support for this hypothesis in the latest UK Department for Transport (2015) advice on recommended values of travel time savings. Here proposed business values of time savings, for example, have been reduced from £27.06 per hour for car drivers and £31.96 per hour for rail users down to a common value of £16.30 for trips between 50 to 100 kms.

5.2 Comprehensive metrics of transport system performance: 'Movement'

So far, all the measures which have been discussed are concerned with motorised vehicle travel, with a particular emphasis on journeys made in a car, and in the main are based on data accumulated from observations at the link level for higher level urban roads.

A 'Stage 3' perspective encourages consideration of movement by all modes of transport, and on a 'whole journey' basis. Indicators that capture aspects of this thinking include:

- Extending the vehicle-based measures to all transport modes
- Allowing for multi-modal (not just single mode) journeys, and measuring door-to-door performance conditions
- Measuring customer satisfaction with their journey experience

Such data cannot be readily captured using conventional recording devices, and generally relies on the availability of mobile phone or household travel diary survey data (unless people agree to carry bespoke GPS recording devices). Both data sources have their limitations:

- Algorithms for estimating the mode used for each trip are improving, but do not yet provide a completely reliable attribution of mode

- Household travel diary surveys use reported travel times (and sometimes reported distances), so are subject to rounding error - and also afford only a very limited sample size.

5.2.1 Extending vehicle-based measures to other modes and broader considerations

Measuring 'movement' performance

In principle, the more sophisticated vehicle-based indicators described in section 5.1 could be extended to cycling and walking trips – and rail-based urban trips too - through the use of GPS, mobile phone data, or household travel diary surveys. For example, the Horizon 2020 'TRACE' project (http://h2020-trace.eu/) has developed new movement tracking software services to improve the recording of cycling and walking trips.

In recent years new measures of network 'Level of Service' have been developed to cover non-car modes of transport (TRB, 2010), including public transport passengers. For walking and cycling, this uses a combination of speed, density and delay, and for public transport also considers service frequency, reliability and crowding. Further details of the USA research which underlies these new measures are provided in Dowling *et al* (2008). For an example of recommended LoS measurement for pedestrians in London, see Transport for London (2010a).

Again, performance could be assessed either against a pre-determined acceptable level of service, or by comparing daytime and night time conditions – although disparities are likely to be much less for the non-vehicle mode users and, in the case of rail services, higher frequencies and peak express services could well mean that conditions are better, not worse, at peak times during the day.

This raises the question as to whether conventional congestion-based measures are very useful when comparing network performance between road and rail-based transport modes, or motorised and non-motorised modes.

Measuring features of modal provision

Recent Australian research (Green and Epsada, 2015) goes further and includes not only measures of ease of movement in Level of Service standards, but also provision for movement, in terms of roadside information, condition of pavements, security, etc. For public transport users, Dowling *at al* (2008) also take into account seating and shelter.

This moves the debate into the area of street auditing, where there is a wide range of tools available. The UK Transport Research Laboratory has developed three modal versions (see https://trlsoftware.co.uk/products/street_auditing):

- CERS – Cycling Environment Review System
- FERS – Freight Environment Review System
- PERS - Pedestrian Environmental Review System

Each has a number of components. For example, PERS assessments are sub-divided into:

- Pedestrian Route review
- Pedestrian Link review
- Pedestrian Crossing review

And are then further sub-divided into review elements. For example, the Link review assess: Effective width, Dropped kerbs, Gradient, Obstructions, Permeability, Legibility, Lighting, Tactile information, Colour contrast, Personal security, Surface quality, User conflict, Quality of environment and Maintenance. Assessors score each element on a five-point scale, and some are weighted more highly than others.

In the USA, Cain et al (2012) describe a detailed audit tool comprising four components:

> *"The **route section** included items related to land use and destinations, transit stops, street amenities, traffic calming, hardscape and softscape aesthetics, and the social environment. The **segments section** assessed sidewalks, street buffers, sidewalk slope, bicycle facilities, shortcuts, visibility from buildings ("eyes on the street"),*

building aesthetics, trees, setbacks, and building height. The ***crossings section*** *assessed crosswalks, slopes, width of crossings, crossing signals, and pedestrian protection (e.g., curb extension, protected refuge islands). The* ***cul-de-sacs section*** *assessed the potential recreational environment within a cul-de-sac and included items about the size and condition of the surface area, slope, surveillance from surrounding homes, and amenities (e.g., basketball hoops)."*

5.2.2 Taking into account multi-modal journeys

In order to have a comprehensive picture of how transport provision affects the daily lives of urban travellers, it is necessary to take account of multi-modal journeys. Most urban journeys that are not made exclusively on foot or by cycle involve multiple modes – if only a walk to/from a car park or bus stop and the ultimate trip origin and destination. Many public transport journeys may be more complex than this and involve multiple vehicle modes (e.g. bus and metro or tram).

This requires travel diary or mobile phone data records. Indicators include:

- Door-to-door travel times
- Door-to-door network distances
- Average door-to-door speeds

An example of car driver trends between 1975 and 2010 in Great Britain is shown in Figure 13, using data from the National Travel Survey.

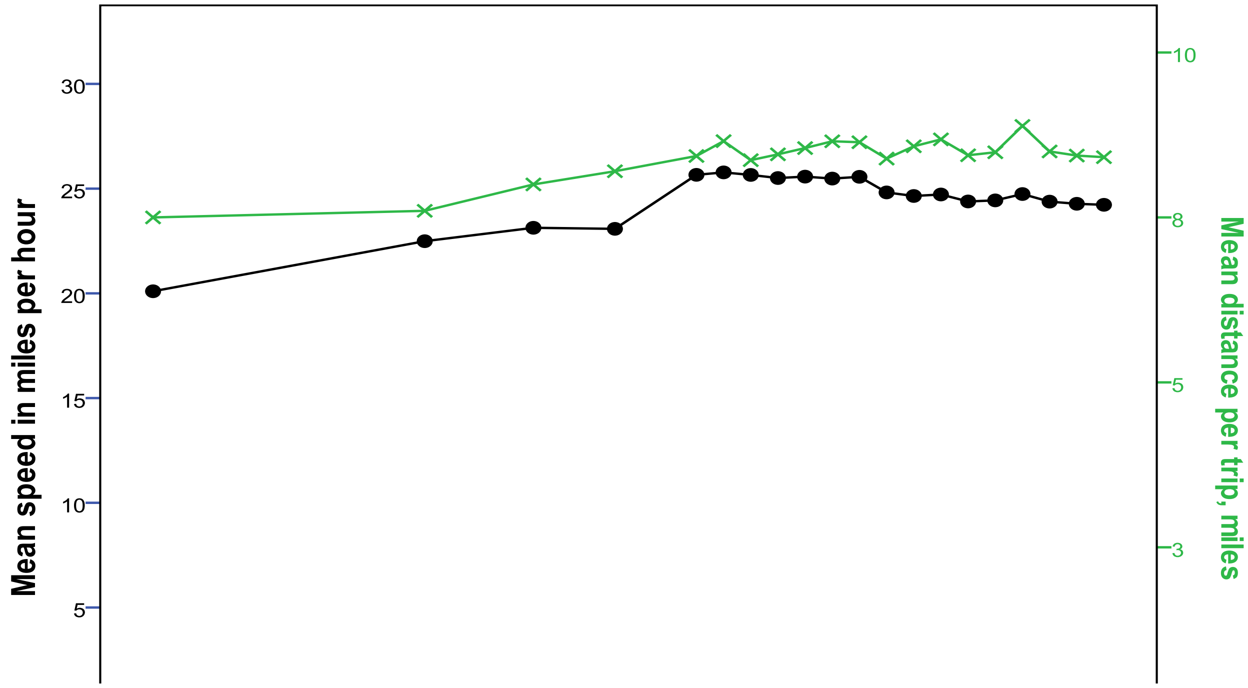


Figure 13: Trends in average door-to-door car driver trip lengths and average speeds in Great Britain, between 1975 and 2010.

Here it can be seen that, across the country as a whole after a sustained period of increase, trip lengths have stabilised and travel speeds have declined slightly since the mid-1990s, possibly due to a combination of lower speed limits and increasing traffic congestion – but the aggregate effect is small.

Incorporating such information might give a rather different picture of transport system performance than the more traditional vehicle-based measures. For example:

- Slight increases in road traffic congestion (and lower door-to-door speeds for car drivers) due to increased provision of bus lanes, or surface pedestrian crossing facilities might be more than offset by reductions in door-to-door travel times for bus users with walk stages in their trips.

- Trip lengths might vary over time: if land use densities increase then road speeds may go down, but if trip lengths drop with increasing density, then door-to-door travel times would fall.

Table 5 shows changes in reported average door-to-door speeds for trips made by London residents wholly within the GLA area, by main mode (i.e. that used for the longest distance in a multi-modal journey) between 2005/06 and 2016/17. Over this time period there has been no substantial change in average travel time or trip distances.

Table 5: Average door to door speeds by main mode, London residents
Source: Transport for London

	National Rail Overground	LU/DLR	Bus/tram	Taxi	Car driver	Car passenger	Cycle	Walk
2005/06	13.1	11.5	6.4	12.2	12.1	11.8	8.2	4.2
2006/07	13.5	10.8	6.2	12.7	12.7	12.4	9.4	3.8
2007/08	13.1	10.9	6.2	13.0	12.9	12.2	8.9	3.7
2008/09	12.8	11.0	5.9	11.5	12.8	12.2	9.5	3.2
2009/10	12.5	10.7	5.8	12.4	12.9	12.7	8.8	3.2
2010/11	13.1	11.0	6.0	12.6	13.0	12.5	8.6	3.3
2011/12	12.6	11.2	6.0	12.2	13.2	12.7	8.3	3.1
2012/13	12.5	11.0	6.0	12.7	13.2	12.8	9.1	3.2
2013/14	12.8	11.2	5.9	13.1	13.1	12.9	9.1	3.1
2014/15	12.5	11.6	6.0	13.1	13.0	12.7	8.9	3.2
2015/16	12.6	11.2	6.0	12.4	12.7	12.5	9.2	3.3
2016/17	12.1	11.3	6.1	13.7	12.4	11.9	9.0	3.7

These are very similar

As can be seen:
- There is no evidence of slower door-to-door car speeds associated with the increases in measured congestion over the past decade – suggesting that the latter is a misleading measure of the impact of network conditions on everyday traveller experiences.
- Average road and rail speeds are pretty similar – which supports the hypothesis that road and rail speeds in Stage 3 cities are approximately in equilibrium.
- Bus door-to-door speeds are roughly half those of rail-based modes, although speeds have not been declining, despite increases in measured congestion.

Similar information can be presented on a geographical basis, by showing average door-to-door speeds across the city. Figure 14 presents such information for average public transport journey times in Berlin on a weekday between 09.00 and 11.00 to major destinations in the central areas of the city, by 20 minute time bands, for people within 500 metres of a bus stop or station.

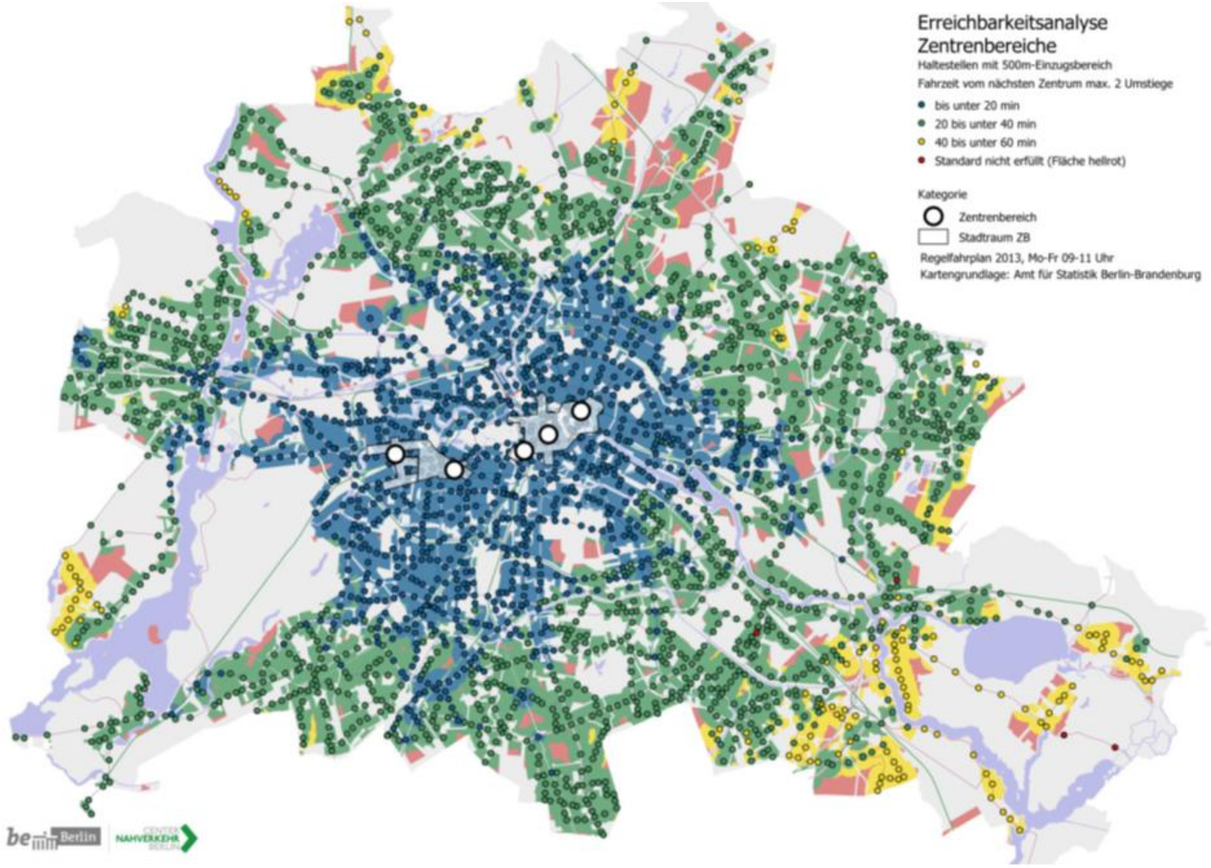


Figure 14: Average public transport journey times from different parts of Berlin to central area attractions, Monday to Friday, 09.00 to 11.00.
Source: Figure 35, NVP-Monitoringbericht 2009 – 2011/2012

5.2.3 Measuring customer satisfaction with their journey experience

Increasingly, city authorities, national governments and transport service providers are directly measuring customer satisfaction and customer experience. In London, for example, since 2010 Transport for London has been measuring satisfaction with various aspects of the network among road users who have used the TLRN (Transport for London Road Network); this is owned by TfL and covers 580 km of the busiest roads in the capital. The survey covers both movement (speed, predictability, congestion, etc.) and asset provision and condition (street lighting, even surfaces, information provision, etc.). Modes covered include car, pedestrian, bus, motorcycle/ scoter/moped, taxi/commercial delivery/emergency vehicle and cycle. But there is currently no equivalent information about user perceptions on the rest of the London road network.

Coverage of public transport users is more complete. Here TfL measures overall customer satisfaction for each main public transport mode (see Figure 15). Again, this can be broken down into specific attributes, such as journey time, length of time waiting for a service, reliability, crowding, etc. [NOTE: 'DLR' = Docklands Light Railway; 'Overground' = suburban railway services run by TfL; 'Tramlink' = tram system (partly on-street) centred on Croydon in South London].

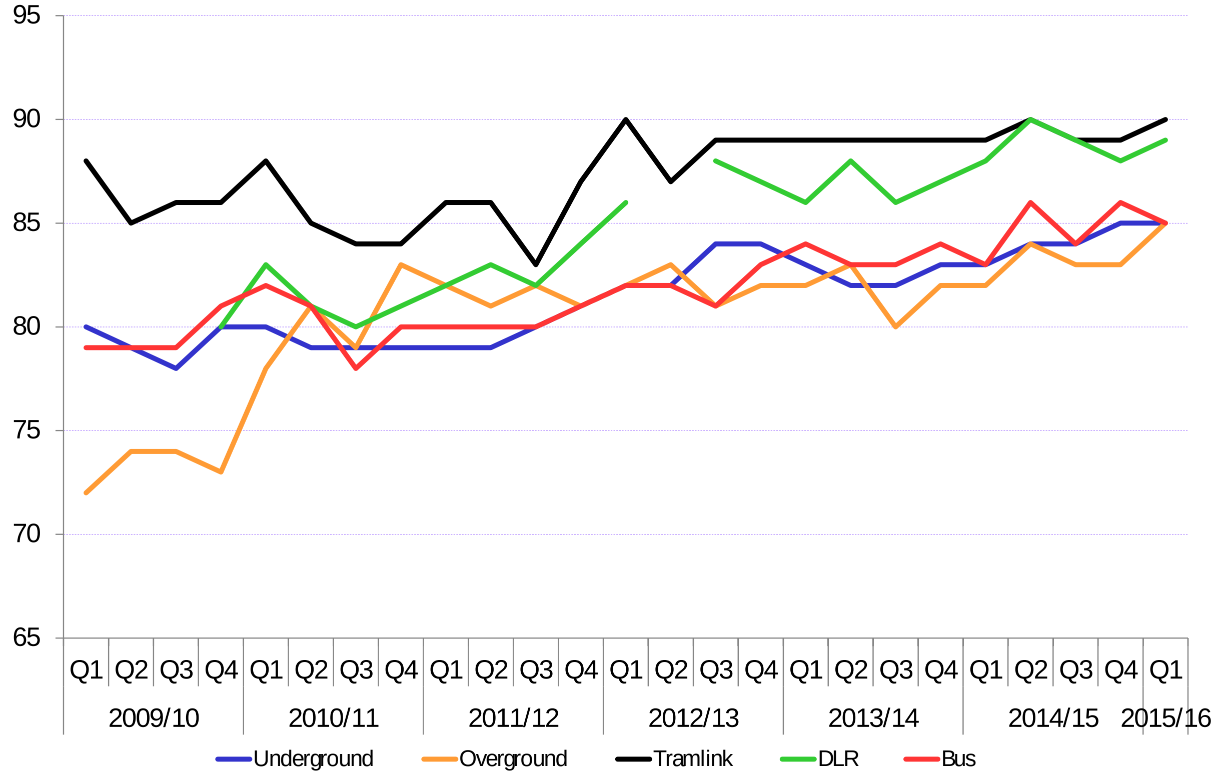


Figure 15: Overall customer satisfaction scores for each public transport mode.
Source: TfL Customer and Employee Insight.

5.3 Comprehensive metrics of transport system performance: 'Place'

One of the defining characteristics of 'Stage 3' city policies is to consider most of the urban road network as providing for 'place' activities as well as the traditional focus on 'movement' activities – performing the role of urban 'streets' rather than 'roads'. Place considerations take into account several factors, including:

- Providing access to and servicing of the frontages (residences, shops, restaurants, etc.) adjacent to the highway, often by motorised vehicles.
- Encouraging economic, social and cultural activities on the footway, for example by providing suitable 'street furniture', such as benches and lighting.
- Enhancing the physical condition of, and the experience provided by, the street environment

5.3.1 Access to, and servicing of street frontages

Ease of parking and loading is essential if local businesses are to thrive and residents to have their daily servicing needs provided for, yet often very little attention is given to this aspect of street performance.

There are three ways in which this might be measured:

- Observation of levels of parking and loading activity
- Satisfaction ratings among car, truck and van drivers
- The number of notices that are served for illegal parking and loading (called 'PCNs' – Penalty Charge Notices, in the UK), which gives an indication of where provision is inadequate (assuming consistent levels of enforcement - which may not be the case in many European cities).

As part of developing 'New metrics for 21st century streets', New York City (undated) has developed four key metrics to assess 'efficiency in parking and loading':

- Vehicle travel speeds and volumes
- Double parking
- Parking duration
- Number of unique visitors

5.3.2 Levels of economic, social and cultural activities

Increasing recognition has been given to the importance of a vibrant business and resident community in creating liveable cities, and the role which transport policies can play in either encouraging or suppressing such activities. Here the economic 'health' of the street has been measured in several ways, including:

- Footfall (number of pedestrians passing a given point)
- Number/percentage of empty properties
- Business turnover
- Property or rental values

Jan Gehl has spent decades working on designs to bring back public life to urban streets and public spaces, and in Gehl and Birgitte (2013) describe various ways of measuring patterns of public life. Key measures of success include:

- The numbers of people staying in an area (not just walking through)
- The amount of time each person spends there; Standing, sitting, etc.
- The kinds of activities they are undertaking – in particular, the mix of 'optional' vs. 'essential' activities
- The composition of people taking part in on-street activities: more females, and young and old people shows greater inclusion

5.3.3 The physical condition of, and the experience provided by, the street environment

The street provides a physical backdrop to place activity and affects the ways in which it is experienced. Several organisations have developed ways of measuring the street environment, from simple methods based on personal and professional judgement to more formalised procedures.

In the UK, for example, Urban Design Skills (a consultancy company) has developed ‘Placecheck’ https://placecheck.info/en), a simple set of 21 questions which are intended to stimulate awareness of a street or local area, and what might be done to improve conditions. The questions group under four broad themes:

- A special place (what makes it special and what potential does it have?)
- A well-connected, accessible and welcoming place
- A safe and pleasant place
- A planet-friendly place

A more comprehensive approach has recently been trialled by TfL, who has developed ten indicators of a ‘healthy’ street (Transport for London, 2017, p.13) – see Figure 16 and a more detailed description in Deliverable 5.2 (Sections 3.7 and B2.3).

Pedestrians from all walks of life

London’s streets should be welcoming places for everyone to walk, spend time in and engage in community life.

People choose to walk, cycle and use public transport

Walking and cycling are the healthiest and most sustainable ways to travel, either for whole trips or as part of longer journeys on public transport. A successful transport system encourages and enables more people to walk and cycle more often. This will only happen if we reduce the volume and dominance of motor traffic and improve the experience of being on our streets.

Clean air

Improving air quality delivers benefits for everyone and reduces unfair health inequalities.

People feel safe

The whole community should feel comfortable and safe on our streets at all times. People should not feel worried about road danger or experience threats to their personal safety.

Not too noisy

Reducing the noise impacts of motor traffic will directly benefit health, improve the ambience of street environments and encourage active travel and human interaction.

Easy to cross

Making streets easier to cross is important to encourage more walking and to connect communities. People prefer direct routes and being able to cross streets at their convenience. Physical barriers and fast moving or heavy traffic can make streets difficult to cross.

Places to stop and rest

A lack of resting places can limit mobility for certain groups of people. Ensuring there are places to stop and rest benefits everyone, including local businesses, as people will be more willing to visit, spend time in, or meet other people on our streets.

Shade and shelter

Providing shade and shelter from high winds, heavy rain and direct sun enables everybody to use our streets, whatever the weather.

People feel relaxed

A wider range of people will choose to walk or cycle if our streets are not dominated by motorised traffic, and if pavements and cycle paths are not overcrowded, dirty, cluttered or in disrepair.

Things to see and do

People are more likely to use our streets when their journey is interesting and stimulating, with attractive views, buildings, planting and street art and where other people are using the street. They will be less dependent on cars if the shops and services they need are within short distances so they do not need to drive to get to them.

Figure 16: Ten indicators of a healthy street.
Source: Transport for London (2017).

This is based on a mix of objective and subjective data. For the latter, TfL has developed an on-street survey sampling from its nine Movement/Place street types across London. Eleven questions were included, about how attractive people perceive that street to be in terms of:

- How clean the air is
- How noisy the street is
- How enjoyable the street is to be on
- The ease of crossing the road
- How easy it would be to find somewhere to sit or rest
- How easy it would be to find shelter (for example, if it was raining)
- How intimidated from road traffic people feel
- How stressful the street is to be on
- How safe from crime and anti-social behaviour people feel
- How safe from being involved in a traffic collision people feel

5.4 Broader indicators

5.4.1 Access to opportunities

Policies in ‘Stage 3’ cities tend to be increasingly concerned with using transport to improve access to employment, healthcare, social networks, etc. – rather than with simply improving mobility as an end in itself.

There is a wide range of existing accessibility indicators, from simple ones (such as ‘% of employment with **t** minutes of the residential population by mode **m**, or cumulative distributions) to more complex accessibility indicators (e.g. Hansen, 1959) which apply some discount to destinations at increasing distance from each person’s residential location.

Such indicators describe the potential for movement rather than observed travel behaviour or network performance, and are influenced equally by the characteristics of the transport system (which is likely to be under a degree of policy influence) and of the land use system (mix, distribution and density) – which may well not be under direct government control or influence. In the latter case, in a country with weak planning controls, a deteriorating accessibility score may arise from market forces largely outside government control and so may not provide a good indicator of the success of a transport strategy.

For example, TfL measures access provision across London in a variety of ways. Figure 17 illustrates the number of jobs accessible by public transport within 45 minutes door-to-door journey time of each location in Greater London.

Several factors need to be borne in mind when developing accessibility indicators:

- There are varying population needs (and preferences): children vs. adults, blue vs. white collar employees

- Increasing access indefinitely is not necessarily beneficial: people only need access to one good hospital or one good school. Metz (2104) suggests that access to three food supermarkets is sufficient – after that there are strong diminishing returns. The ‘TEA’ COST Action is investigating the concept of ‘sufficiency’: http://www.teacost.eu/.

- Some people may be willing to trade off access for improved amenity, for example, or positively prefer to live in remoter areas.

If access is chosen as an indicator of success, then it should be possible to come up with a simple formulation that weights the varying needs of different groups.

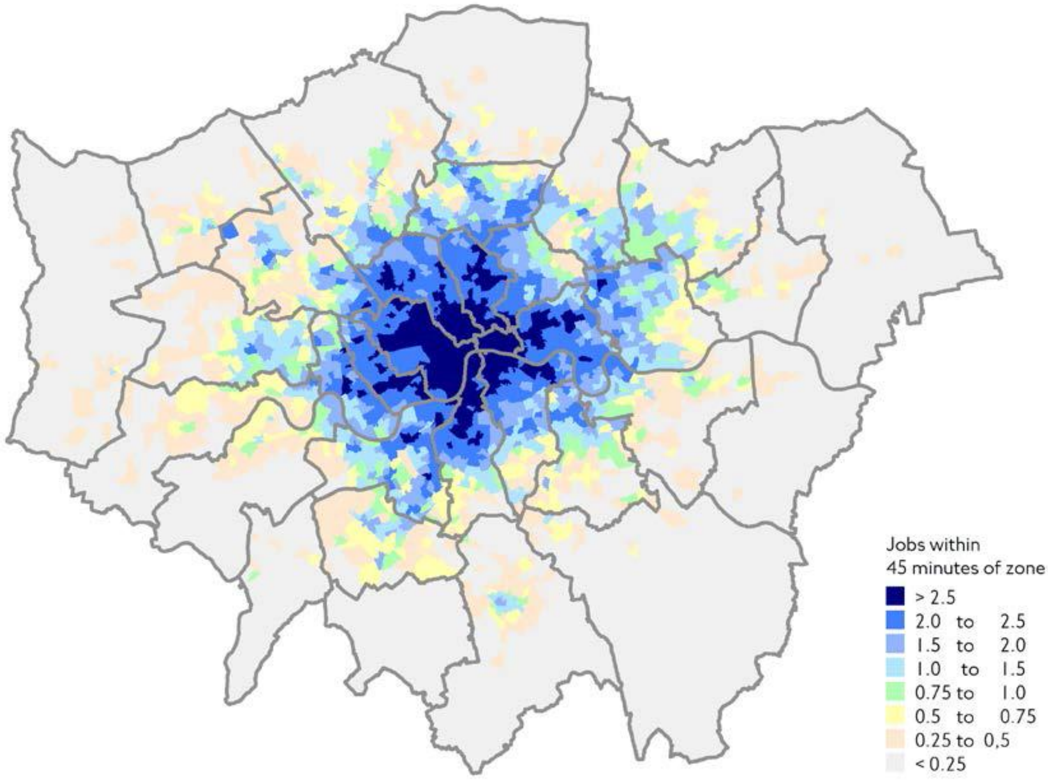


Figure 17: Number of jobs (millions) available by mass public transport within 45 minutes travel time of each location, 2015.
Source: Transport for London (2015)

5.4.2 Wider benefits

Our 'Stage 3' cities are also increasingly recognising the potential cross sector benefits of investing in transport infrastructure – especially that which encourages the greater use of sustainable (non-car) modes of transport, In particular:

- Transport investment can stimulate economic development, through enlarging labour market catchment areas and unlocking agglomeration benefits. The former could result from increasing car accessibility, but densification relies on high capacity public transport, particularly rail-based systems.

- Improvements in health/reductions in obesity resulting from reductions in car use and increases in walking and cycling – either as the main mode on shorter trips or the access/egress mode on longer trips made by public transport.

- Reductions in street crime, as a result of providing higher quality, better lit street environments which attract larger numbers of people.

- General increases in liveability and improvements in the public realm, resulting from the reduction in the dominance of motor vehicles and the redesign of urban streets (with more emphasis on 'Place' and less on 'Movement') that attract large numbers of residents and visitors.

In a 'Stage 3' city, where many streets are seen as an important part of urban public space, then it might be considered acceptable to have lower speeds in order to increase the attractiveness of the streets for pedestrians and cyclists, and to improve the quality and experience of the urban realm. In the City of London, for example, some streets have been converted to public space and network capacity reduced as a result - with consequential reductions in average speeds - in order to create a higher quality environment. And TfL has recently introduced sections of 20mph road on the TLRN, in recognition of this argument.

Finally, Figure 18 shows objective measures of transport performance can be augmented by customer satisfaction scores on some of the key dimensions.

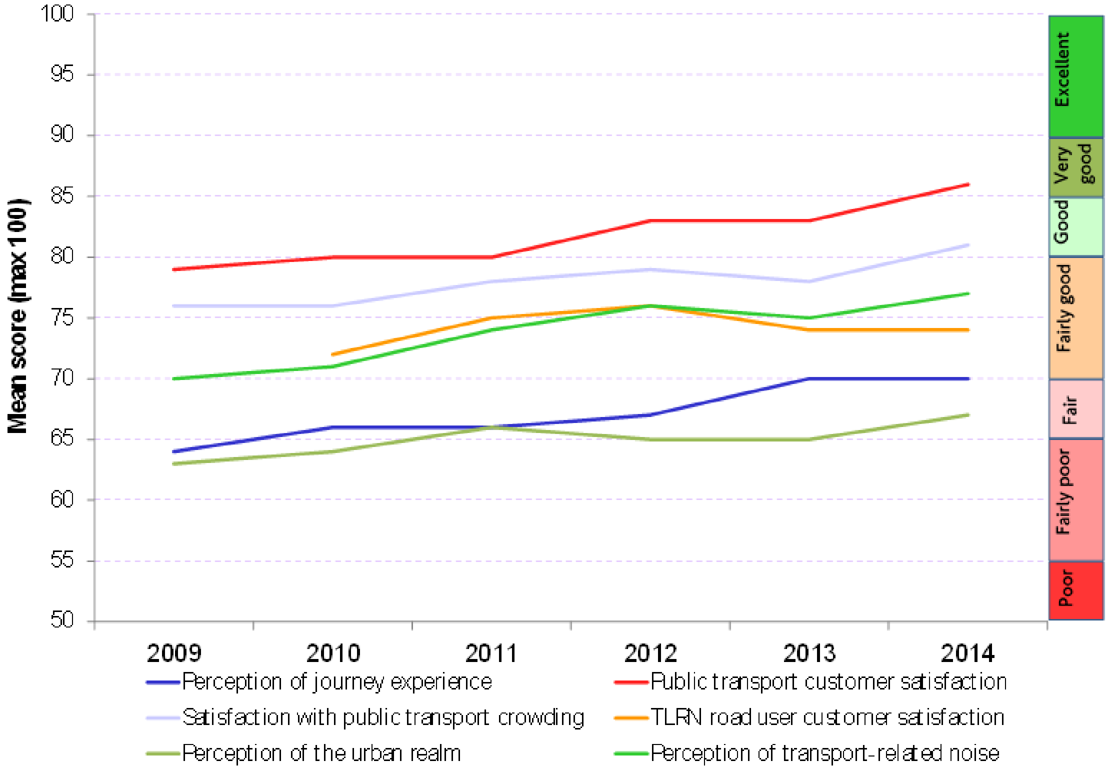


Figure 18: Summary of trends in perception-based MTS strategic outcome indicators for transport and quality of life. Mean scores out of 100.
Source: TfL Customer and Employee Insight surveys

6. Conclusions

This deliverable has reviewed a wide range of metrics for assessing the performance of transport networks and the achievement of wider transport-related policy goals. It has identified potential problems of interpretation with some of the most commonly used measures of traffic congestion, suggested some ways in which these might be reduced, and introduced ideas for a adopting a much wider range of indicators.

There are two broad issues that need to be considered when determining which indicators to use to establish how 'successfully' a transport network has been performing.

First, political priorities and the context in which an outcome is judged. As noted in section 2, what is considered to be the primary goals of an urban transport system tend to change over time, often following a progression from improving network performance for motor vehicles ('Stage 1'), to a concern with facilitating movement by all modes of transport ('Stage 2'), then leading on to a broader concern about urban liveability, public health and quality of life ('Stage 3').

As the context broadens, delays to motor vehicles may be seen as less critical, and politicians and the public may be willing to trade this off to obtain other benefits (e.g. lower urban speed limits in order to achieve safety, air quality and noise benefits). At the same time, advances in communication technology may enable some of this 'lost' time to be used more productively.

Second, there are wider and more fundamental questions of how the impacts of transport policies are to be monitored and identified, as distinguishing between 'differences' and 'changes' and attributing causation can be quite challenging (e.g. see Jones, 2015). Such issues are addressed in Work Package 3.

7. Acknowledgements

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9. APPENDIX: Inventory of Congestion Indicators [OECD/ECMT, 2007, Table 2.2]

Indicator	Description	Notes
1. Speed-based indicators		
Average Traffic Speed	Average speed of vehicle trips for network	Does not adequately capture congestion effects
Peak Hour traffic speed	Average speeds of vehicle trips during peak hours.	Can serve as a benchmark for reliability measures based on actual average or median speeds
2. Temporal/Delay-based indicators		
Annual Hours Of Delay	Hours of extra travel time due to congestion.	All delay-based indicators depend on a baseline value for calculating the start of "delayed" travel – when this baseline is free-flow speed, the term "delay" becomes misleading since it is not at all clear that travellers on the network would ever be able to achieve delay-free speeds at peak hours.
Annual Delay Per Capita	Hours of extra travel time divided by area population.	
Annual Delay Per Road User	Hours of extra travel time divided by the number of peak period road users.	
Average Commute Travel Time	Average commute trip time.	
Estimated Travel Time	Estimated travel time on a roadway link (used in conjunction with variable message signs)	
Congested Time	Estimate of how long congested "rush hour" conditions exist	
Delay per road kilometre	Difference between reference travel time and congested travel time per network kilometre	
Travel Time In Congestion Index	Percentage of peak-period vehicle or person travel that occurs under congested conditions.	The use of the travel time index and the travel time rate also depend on the identification of a baseline value for signalling the start of congested conditions – when this value is based on free flow speeds, the same reservation as noted for other "delay"-type indicators holds
Travel Time Index	The ratio of peak period to free-flow travel times, considering both reoccurring and incident delays (e.g., traffic crashes).	
Travel Time Rate	The ratio of peak period to free-flow travel times, considering only reoccurring delays (normal congestion delays).	
3. Spatial indicators		
Congested Lane Miles/kms	The number of peak-period lane miles/kms that have congested travel.	Spatial indicators also depend on threshold values. These may be based on the median/average speeds typically achieved or on free-flow speeds (see note above).
Congested Road Miles/kms	Portion of roadway miles/kms that are congested during peak periods.	
Network Connectivity Index	An index that accounts for the number of nodes and interchanges within a roadway network	This is an indicator of the potential for congestion to arise, whether or not this potential is realised depends on a number of other factors

Indicator	Description	Notes
4. Service level/capacity indicator		
Roadway Level Of Service (LOS)	Intensity of congestion delays on a particular roadway or at an intersection, rated from A (uncongested) to F (extremely congested).	These indicators have had the favour of roadway managers. They typically reference the design capacity of a roadway and are typically implicitly used to maximise throughput up to the design capacity of the roadway link in question.
Roadway Saturation Index	Ration of observed flow to design capacity of roadway	
5. Reliability Indicators		
Buffer index	See planning time index below	These indicators try to capture how road users typically make trip decisions on congested networks – they explicitly take into account the importance to many users of making trips "on time" rather than simply making trips at a high rate of speed.
Congestion Variability Index	An index relating the variability of travel speeds on the network.	
Planning time index	An index that accounts for a time buffer that allows an on-time arrival for 95% of trips on a network	
Mean vs. variance travel times	Measure of the standard deviation of travel times on a link or on the network for a given period	
Distribution of travel times: Percentile - mean	Measure of the difference between the 80th or 90th percentile of the travel time distribution and the median or 50th percentile	
6. Economic cost/efficiency indicators		
Annual Congestion Costs	Hours of extra travel time (generated by travel below reference speed) multiplied by a travel time value, plus the value of additional fuel consumption. This is a monetised congestion cost.	As noted above, the selection of free-flow speeds when trying to account for "congestion costs" is highly problematic.
Current marginal external congestion costs	The additional external costs (not borne by users) of every additional vehicle/use entering the network.	
Total deadweight loss	The sum total of the overall losses (costs-benefits) incurred for a given level of use/traffic	
Average deadweight loss per vehicle/km	The dead weight loss divided by the number of vehicles/km giving rise to that loss.	
7. Other indicators		
Congestion Burden	The exposure of a population to congested road conditions (accounts for availability and use of alternatives)	
Excess Fuel Consumption	Total additional fuel consumption due to congestion.	Again, determining the point of reference for "additional" fuel consumption can be problematic if based on free-flow speeds.
Excess Fuel Consumption Per Capita	Additional fuel consumption divided by area population	