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COSTS OF CONGESTION: LITERATURE BASED REVIEW OF METHODOLOGIES AND ANALYTICAL APPROACHES
FINAL REPORT

COSTS OF CONGESTION: LITERATURE BASED REVIEW OF METHODOLOGIES AND ANALYTICAL APPROACHES
FINAL REPORT

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EXECUTIVE SUMMARY

1. The primary objective has been to conduct an international literature review on the costs of traffic congestion. This included the following sub tasks; to describe congestion within Scotland, to review definitions of congestion and how it has been measured, to describe the methods used to measure congestion costs and finally to provide an outline of the literature concerning the link between economic growth and congestion ('decoupling').

2. Limited literature exists on the locations of congestion in Scotland and this does not define congestion. The approach here was to use existing data on the impacts of congestion (delay, speed reductions and reliability problems) to describe the locations where the impacts of congestion are greatest. A broad picture emerges:

- Whilst at the national level only 11.5% of trips are affected by congestion, this figure disguises large geographic, temporal and journey purpose variations.
- Congestion impacts are largest in the cities of Glasgow, Aberdeen and Edinburgh, where up to 42% of AM peak travellers experience congestion related delay.
- The trunk road network that experiences the most congestion is that in the vicinity of these cities, plus the approaches to the Forth estuarial crossings.
- Peak hours are more congested than the off-peak. Commuting and business related trips are more affected than trips for 'other' trip purposes. No data is available on congestion impacts for freight movements.
- Congestion related delays are reported throughout Scotland, beyond Aberdeen, Glasgow and Edinburgh and their vicinity. The frequency and incidence is, however, higher in the large cities.

3. Despite frequent use of the term, congestion is often understood but not formally defined. Perceived congestion may be as important as more objective evidence in driving the need for policy measures. The definition given by the Highways Agency (DMRB, 1997) captures the wide understanding of congestion as:

> *'the situation when the hourly traffic demand exceeds the maximum sustainable hourly throughput of the link.'*

4. According to Goodwin 2004:

> *'Congestion is defined as the impedance vehicles impose on each other, due to the speed-flow relationship, in conditions where the use of a transport system approaches its capacity'.*

5. These two definitions reflect the two fundamental approaches to interpreting congestion: firstly a 'traffic engineering' perspective (which underlies many measures of congestion) and secondly an economic view (related to principles behind marginal costs of congestion). At the practical level of measuring congestion, approaches are classed as travel time (or speed) based measures, volume based measures, area based measures and summary indices (or more complex model outputs). In practice, the simpler measures are more commonly applied than relatively complex measures.

- A commonly applied measure divides the ‘total delay’ by the ‘volume of traffic’ to give the ‘average amount of delay’ encountered by a vehicle travelling one kilometre. Delay based measures, however, disregard vehicle occupancy, values of time and other factors (e.g. environmental impacts resulting from congestion).
- Simple measures based on speed are used particularly for a motorway context (for example, ‘a congested state exists when the traffic speed is below 50km/hr’).
- A more complex measure is the ‘congestion reference flow’ (Highways agency, 1997), based on capacity, number of lanes and other traffic related variables (junctions are considered separately to links).
- The ‘level of service’ indicator is a basic congestion scale running from A to F and describes operational conditions on a route or section (using variables such as speed, travel time, disruption to flows and safety). It is widely used in the USA.

6. To measure the costs of congestion, research shows three economic terms that can be used; the Marginal External Cost of Congestion, the Total Cost of Congestion and the Excess Burden of Congestion. These are summarized below.

- *Marginal cost* refers to the change in total transport network costs for a single additional trip (or vehicle-km). Related concepts are s*hort run marginal costs* (assuming capacity is kept fixed) and *long run marginal costs* (allowing capacity to be expanded). *Marginal external costs* are items of marginal cost that are not borne by the trip maker, (e.g. for road trips they include road wear and tear, increased accident risk and environmental costs). A specific marginal external cost item is ‘delay to other users’, often referred to as the *Marginal External Cost of Congestion*.
- The *Total Cost of Congestion* gives the cost of congestion compared to a state of zero congestion. A frequently quoted figure is that congestion costs the UK economy £20 billion/ year (but there is no supporting evidence for this).
- The *Excess Burden of Congestion* compares the cost of congestion in the current traffic state to a traffic state that would be expected with optimal prices in place (optimal to maximising economic output). The Excess Burden of Congestion differs from the Total Cost of Congestion as it is highly likely (with optimal prices and an optimum level of baseline capacity) that congestion will be present on the transport network. It relates to a situation where capacity is fixed. Estimates of the Excess Burden of Congestion for the UK or at a city level have been produced and two major points emerge. Firstly, costs estimated by the Excess Burden of Congestion are substantial, but significantly less than those based on the Total Cost of Congestion approach. The second is that, in similar vein to the Total Cost of Congestion approach, there is substantial variation in the figures produced.

7. The appropriate choice of measure will vary according to the end use of the data. Where the aim has been to consider road pricing measures, the Marginal Cost of Congestion is normally calculated. To review the benefits of significant investment decisions, the Total or Excess Burden of Congestion may be calculated.

8. The Total Cost of Congestion is the easiest of the measures to calculate, but may have least policy relevance due to the cost of alleviating congestion. Calculations are based on either mathematical models (to estimate costs in the current state and the uncongested state) or actual measurements of vehicle speed to infer changes in journey time. The Excess

Burden of Congestion gives a cost estimate that it is possible to address using transport policy. Unfortunately it is more complicated to calculate, requiring transport models that can estimate the impacts of road pricing. Estimating Marginal Cost and Marginal External Costs is not trivial as it is necessary to model how costs (travel time, reliability, etc.) change with an additional vehicle-km or trip. Four principal methods are based on link speed flow relationships, area speed flow curves, network assignment models and microsimulation models.

9. In terms of data requirements, all three approaches require some form of transport model (which may be static or dynamic) and estimates of the other impacts that congestion causes (e.g. pollution, accidents, etc.). Other factors are:

- Marginal costs for each of these impacts (i.e. for each additional trip) are also required (travel time, reliability, climate change, air pollution, noise, accidents).
- Empirical evidence suggests that the results are sensitive to the transport models used and the values used for the costs of the impacts.
- Transport models that provide estimates of junction delay in urban areas will give more robust results than those which do not, particularly as congestion costs are most significant in urban areas.
- Uncertainty in the values used for the cost of environmental impacts can significantly affect the final estimates of the costs of congestion.

10. With respect to breaking the link between transport and economic growth (‘decoupling’), there is strong empirical evidence that growth in travel is related to income, the cost of travel and the ‘need to travel’. The key issues are as follows:

- Where transport policy increases income and reduces cost (e.g. by reducing congestion), other measures are needed to either prevent increased travel demand (for example road pricing to ‘lock in’ the benefits) or to reduce the need to travel. Some measures may be quite difficult to implement politically, such as road pricing.
- There is empirical evidence at EU level and internationally that decoupling has taken place over time, to a different extent for the passenger and freight sectors.
- Research has identified particular policies and instruments which could be used to promote decoupling whilst maintaining economic activity and achieving sustainability goals. These policies are likely to have a more successful impact if implemented together in packages.

11. The underlying relationships are, however, complex and further understanding of the demand for travel is needed before drawing firmer conclusions on the links between transport and the economy.

CHAPTER ONE INTRODUCTION

1.1 This review lies within research associated with the Scottish Executives' high level transport objective which has a focus on promoting economic growth by enhancing the effectiveness of the transport network and reducing congestion. Congestion is seen as having significant impacts on a number of sectors including the environment and economy as a whole and therefore has an increasing prominence on the political agenda. Whilst an increasing amount of research and literature is emerging with respect to tackling congestion (including the potential for economic instruments such as road pricing and the benefits of 'packages of measures'), less evidence is available on the full costs of congestion.

1.2 The primary objective of the work has been to conduct an international literature review on the costs of traffic congestion, providing a comprehensive list of sources and reflecting evidence on how costs are distributed. This has included the follow sub tasks:

- To describe congestion within the traffic situation in Scotland
- To review definitions of congestion and how it has been measured in past research and practice
- To describe and assess the different methods used to measure the costs of congestion
- To outline the literature concerning the link between economic growth and congestion ('decoupling')

1.3 In terms of the scope of the work, the main emphasis has been on the second and third tasks, with the first and last providing context to the findings.

1.4 The review covers both the interurban and urban road contexts. The Executive is responsible for the management of the inter-urban trunk road network and Local Authorities for the remainder of the network. As 'city regions', centred on Scotland's congested urban areas, are increasingly being viewed as a mechanism for promoting economic growth, the cost of congestion in urban areas is important to the objectives of this research. As a result, the evidence on measurement and costs of urban congestion has been included within the scope of the review. The research has concentrated on literature that has been produced in the past 5 years with some key pieces of evidence extending back around 10 years. It has not been the intention to review the methods adopted to reduce levels of congestion, the literature on packaging of measures or evidence on barriers to the implementation of economic and other transport measures. These are all very relevant issues if the full costs of congestion are to be taken at some future date into marginal social cost pricing schemes, either alone or in policy packages. Their inclusion would, however, require a much more extensive piece of work than is envisaged within this project. Whilst a key aspect to the review has been the methodology used in deriving the costs, the scope has been confined to describing the methodologies and any reported advantages and disadvantages, but not to generate recommendations or guidance on which should be used.

1.5 In terms of the structure of the report, following the executive summary an overview of the evidence of congestion in areas of Scotland is given in chapter 2. This is followed in chapter 3 by a summary of the different ways in which congestion is defined in the literature and perceived by users. In chapter 3, quantified measures of congestion are given using evidence from the international literature. Following a short background to the question of measuring the costs of congestion in chapter 4, a more detailed elaboration of the three main approaches (marginal cost, total cost and ‘cost of excess burden’ is given in chapters 5 and 6 of the report. Finally an outline of research into the issue of decoupling is described in chapter 7 with overall conclusions in chapter 8. Appendices have been included to allow a greater degree of detail on some sections of the findings. In addition to this report, a database of literature sources has been separately produced for the Scottish Executive.

CHAPTER TWO CONGESTION IN SCOTLAND

2.1 Both Scotland's trunk road network and its urban network are subject to congestion (Scottish Executive, 2006 p7). Such congestion is localised in both time and space. As congestion affects the performance and quality of the transport system through increased travel times; deterioration in the 'driving experience' with stop-start conditions; and reliability problems (leading to travel time variability and large unexpected delays), data sources are required that capture these impacts in order to describe the locations and time periods where congestion occurs. A review of the available literature indicates only one paper (Scottish Executive, 2005) which has attempted to assess the level of congestion in different parts of Scotland using the same objective criteria - and this has only a limited focus: the most congested parts of the trunk road network. Local studies associated with the development of Local Transport Strategies (LTSs) and Road Traffic Reduction Act (RTRAs) targets can also report on congestion, as can STAG Part 1 and 2 reporting procedures for proposed schemes whose objectives are to reduce congestion. Such reports have been excluded from this review because different criteria for measuring congestion can be applied in different studies, and therefore there is no objective manner to compare different locations and secondly the scale of the survey that would be required warrants a study in its own right.

2.2 As a result of a lack of studies using the same criteria to measure congestion throughout Scotland, the contribution that other available data sources make towards describing where congestion occurs in Scotland have been considered. Aside from the traffic count data upon which the Executive's trunk road congestion indicator report is based (Scottish Executive, 2005), three further sources have been identified: the Scottish Household Survey (SHS) (MORI Scotland et al., 2003-4), the Transport Model for Scotland (TMfS) (Lumsden, 2005) and journey time data (at a national level) held by and surveyed by ITC Holdings (see http://www.itisholdings.com). The first source gives a measure of delay, whilst the second and third sources can potentially give a measure of journey speed/time and variability in journey speed/time. A data source that considered the manner that congestion impacts on the 'driving experience' has not been identified, nor has it been possible to locate a data source that provides freight specific information. Within the constraints of the current project, additional analysis of the SHS and TMfS data has been undertaken to give background information on traffic delay in Scotland. Previous research experience with the journey speed data held by ITIS Holdings (for example, Grant-Muller, 2005) has been good and as a result this may warrant consideration as a future data source for measuring the journey time and reliability impacts of congestion, particularly if used to give more detailed information on the performance of particular sections of the network.

Perceived delay

2.3 Since 2003, as part of its travel diary the Scottish Household Survey has asked car drivers whether or not they were delayed by traffic congestion on their journey and if so to quantify that delay. The responses to this question reflect perceived delay, as there is no objective measure to the delay perceived beyond that reported. Table 2.1 indicates the proportion of peak hour trips that respondents indicated were delayed by congestion by local authority, whilst Annex 1 presents a more detailed analysis of the 2003 and 2004 SHS datasets. The salient points that can be drawn from Table 2.1 and Annex 1 are set out below.

- 11.5% of trips by road in Scotland experience some form of congestion related delay, whilst 88.5% of trips experience no congestion related delay. The average delay across all trips is 1.3 minutes, however, the average delay for those who actually experience some delay is 11 minutes.
- The delay varies over the different road user groups. Higher proportions of commuters (18%) and business/work related trips (17%) experience delay compared to trips with ‘other’ trip purposes (8%).
- The delay varies by time period – with trips occurring during weekday and morning peaks experiencing the highest chance of being delayed. On average 25% of trips in the weekday AM and PM peak are delayed compared to only 8% at other times of the day.
- The delay varies in a geographic context. Travellers with a destination in the Glasgow RTP, the Aberdeen RTP and the Edinburgh RTP experience the largest number of delays. Within each of these RTPs the largest number of delays are experienced in the cities themselves – with Aberdeen having the highest proportion of its trips delayed. The geographic variation in the proportion of trips experiencing delay during peak hours is very marked with over 40% of trips with a destination in Aberdeen being delayed in the morning peak, whilst less than 10% of trips in Dumfries and Galloway, Argyll and Bute, the Shetland Islands and the Orkney Islands being delayed.
- Average delay per trip follows the patterns set out above – i.e. average delay per trip is highest in the RTPs related to Aberdeen, Glasgow and Edinburgh. The range of delay is from 2 minutes per trip for trips with a destination in Glasgow and Aberdeen to 0.1 minute per trip for trips in the Shetland Islands.
- Interestingly however for those people who are delayed the average delay is broadly the same across the whole of Scotland with a range of 7.5 to 12.1 minutes. This suggests that certain ‘capacity pinch-points’ give rise to localised delay in all parts of Scotland. Clearly however the number of people affected and the number of capacity pinch points varies geographically – giving rise to the geographic spread in the proportion of travellers experiencing delay.

Table 2.1 - Proportion of trips delayed by congestion by Local Authority (peak hour trips only)

PEAK HOUR TRIPS ONLY		
Council area of destination	Whether part of car/van trip delayed due to traffic congestion	
	Yes	No
Aberdeen City	42.2%	57.8%
Edinburgh, City of	38.3%	61.7%
East Renfrewshire	33.3%	66.7%
Glasgow City	33.2%	66.8%
Midlothian	32.7%	67.3%
Falkirk	31.1%	68.9%
Renfrewshire	30.9%	69.1%
North Lanarkshire	29.1%	70.9%
East Lothian	28.4%	71.6%
South Lanarkshire	28.0%	72.0%
South Ayrshire	27.3%	72.7%
Dundee City	27.1%	72.9%
Inverclyde	25.0%	75.0%
East Dunbartonshire	24.8%	75.2%
Clackmannanshire	24.4%	75.6%
West Lothian	23.1%	76.9%
East Ayrshire	20.0%	80.0%
West Dunbartonshire	19.4%	80.6%
Fife	17.8%	82.2%
Angus	17.2%	82.8%
Aberdeenshire	16.9%	83.1%
Moray	16.7%	83.3%
Perth & Kinross	16.7%	83.3%
Stirling	16.4%	83.6%
Highland	15.4%	84.6%
North Ayrshire	15.3%	84.7%
Scottish Borders	12.5%	87.5%
Eilean Siar	10.7%	89.3%
Dumfries & Galloway	9.4%	90.6%
Argyll & Bute	8.3%	91.7%
Shetland Islands	2.9%	97.1%
Orkney Islands	0.0%	100.0%
Total	25.4%	74.6%

Notes to table
Source: Scottish Household Survey 2003-4 (Authors' analysis)

Modelled/synthesised delay

2.4 The congestion mapping utility in the Transport Model for Scotland (Lumsden, 2005) compares freeflow travel times (as defined in the core network coding of the model) with capacity restrained travel times (when the model is in equilibrium) for each link and turning movement in the network. The resultant delay per veh-km for each section of the network (500m grids) is calculated and plotted through a GIS system. As can be seen from Table 3.2 the urban local authorities of Glasgow, Edinburgh and Aberdeen have the largest proportion of their road network subject to more than 0.3 mins[1] of delay per veh-km. Road links with more than 0.3 mins delay per veh-km form the top 10% of links with the most delay per veh-km. As can be seen from Figure 3.1 to Figure 3.5 these delays are not spread uniformly across the road networks of these authorities. In Glasgow the areas experiencing the most delay per veh-km are in the city centre near and along the M8, along the arterial routes through the West End and in pockets on the south side. In contrast, almost all the largest delays per veh-km in Aberdeen City occur in the city centre, whilst in the City of Edinburgh the largest delays are scattered throughout the city including the city centre, the western arterials (A8 and A90), in the suburbs on both the south side (Gorgie Rd, Slateford Rd and Morningside) and the north side (e.g. Ferry Rd, Granton and Newhaven) as well as on the Forth Road Bridge.

2.5 A review of the 'congestion mapping' figures (Kocak, 2005) identifies that delay 'hotspots' occur principally in urban areas and that the trunk road network contains very few hotspots – as identified using this delay indicator. Sections of the trunk road network which this analysis indicates have 'low' levels of congestion, but where congestion is typically viewed as a problem include: the A8 and A80 in North Lanarkshire (see Figure 3.5), the A720 (Edinburgh City Bypass) (see Figure 3.2) and the M90 (just north of the Forth Road Bridge). This peculiarity is attributed to the nature of the delay indicator, as substantial reductions in speed on the motorway network (from 70 mph down to 45 mph) are required to generate a delay in excess of 0.3 minute per veh-km, whereas much smaller reductions in speed are required to generate the same delay on the urban road network (from 30 mph down to 24 mph). Clearly this raises an issue regarding the most appropriate indicator(s) with which to measure congestion – this is discussed more fully in the following chapter.

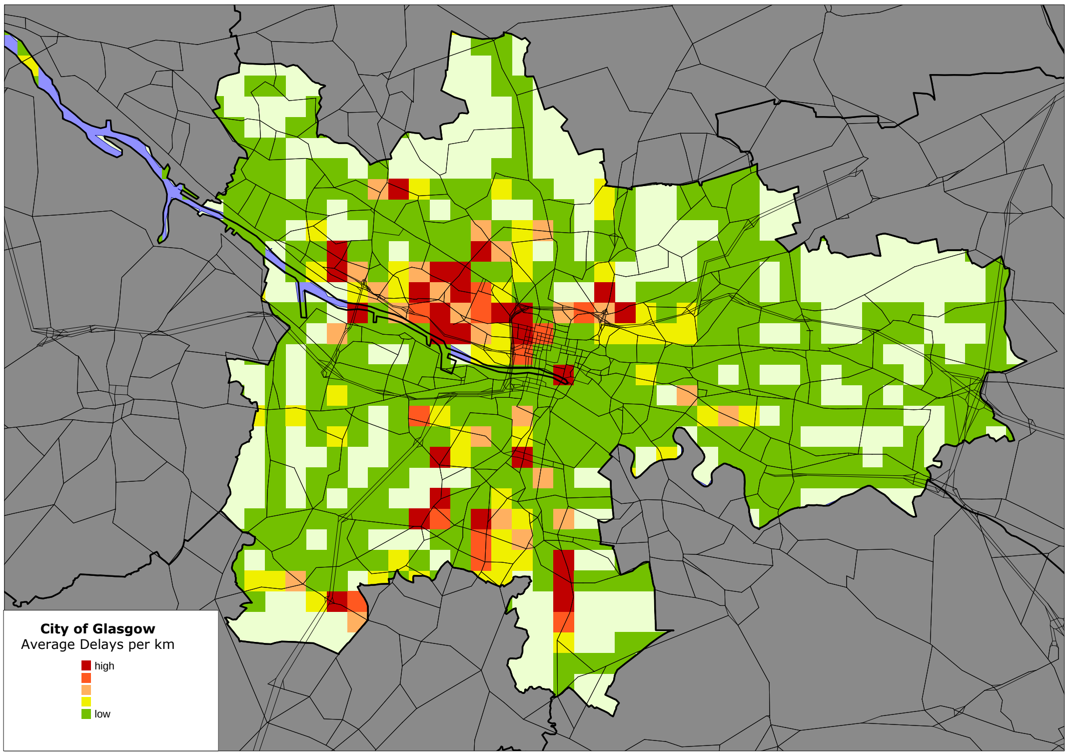
[1] 0.3 minute is 18 seconds

Table 2.2 - Proportion of road network subject to congestion by Local Authority (AM peak trips only)

Local Authority [(2)(3)]	Proportion of road network [(1)] in the 2002 AM Peak by local authority subject to an average travel time greater than free-flow speed by:					
	> 0.4 mins/veh-km	> 0.3 and <= 0.4 mins/veh-km	> 0.2 and <= 0.3 mins/veh-km	> 0.1 and <= 0.2 mins/veh-km	> 0 and <= 0.1 mins/veh-km	0 mins/veh-km
City of Glasgow	49%	6%	6%	10%	25%	4%
City of Edinburgh	40%	5%	6%	11%	23%	14%
City of Aberdeen	33%	4%	3%	15%	43%	2%
City of Dundee	5%	10%	6%	23%	33%	23%
North Lanarkshire	7%	5%	4%	17%	55%	13%
East Dunbartonshire	7%	2%	5%	14%	53%	19%
Falkirk	5%	1%	3%	17%	63%	11%
East Renfrewshire	6%	0%	5%	6%	70%	12%
Midlothian	4%	2%	1%	8%	71%	14%
South Lanarkshire	5%	1%	4%	9%	72%	9%
Renfrewshire	4%	1%	4%	9%	70%	10%
Fife	3%	1%	2%	8%	77%	8%
Stirling	2%	1%	3%	8%	80%	6%
North Ayrshire	2%	1%	1%	3%	82%	12%
Inverclyde	1%	1%	0%	2%	81%	15%
Clackmannanshire	1%	1%	2%	15%	69%	12%
East Lothian	2%	0%	2%	2%	70%	25%
West Lothian	1%	0%	2%	5%	83%	8%
East Ayrshire	1%	0%	1%	3%	91%	4%
Perthshire & Kinross	1%	0%	0%	1%	85%	13%
South Ayrshire	1%	0%	2%	3%	87%	8%
Dumfries & Galloway	0%	1%	0%	1%	77%	21%
Aberdeenshire	0%	0%	1%	4%	75%	21%
The Borders	0%	0%	0%	0%	90%	10%
Angus	0%	0%	0%	3%	84%	13%
West Dunbartonshire	0%	0%	4%	6%	66%	24%
Total	8%	2%	2%	7%	69%	12%
Notes:						
1. Proportion of road network represented in the Transport Model for Scotland (principally roads that have more than just a local function).						
2. Excludes the 6 local authorities not full represented in the TMfS: Argyll and Bute, Highland, Moray, Shetland Islands, Eilean Siar and Orkney.						
3. Rank based on the proportion of links with a travel time greater than 0.3 mins/veh-km over free-flow travel times						

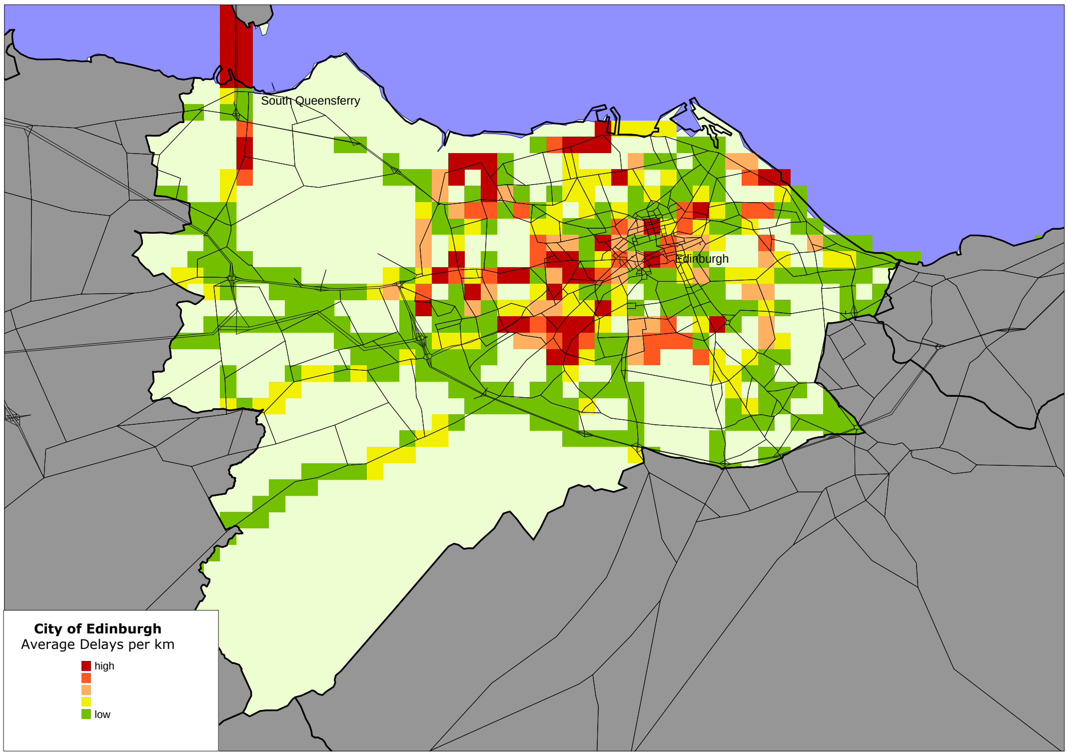
Notes to table
Data source: Robinson (2006). Data analysis: authors

Figure 2.1 - Glasgow City Congestion map (2002 AM Peak)



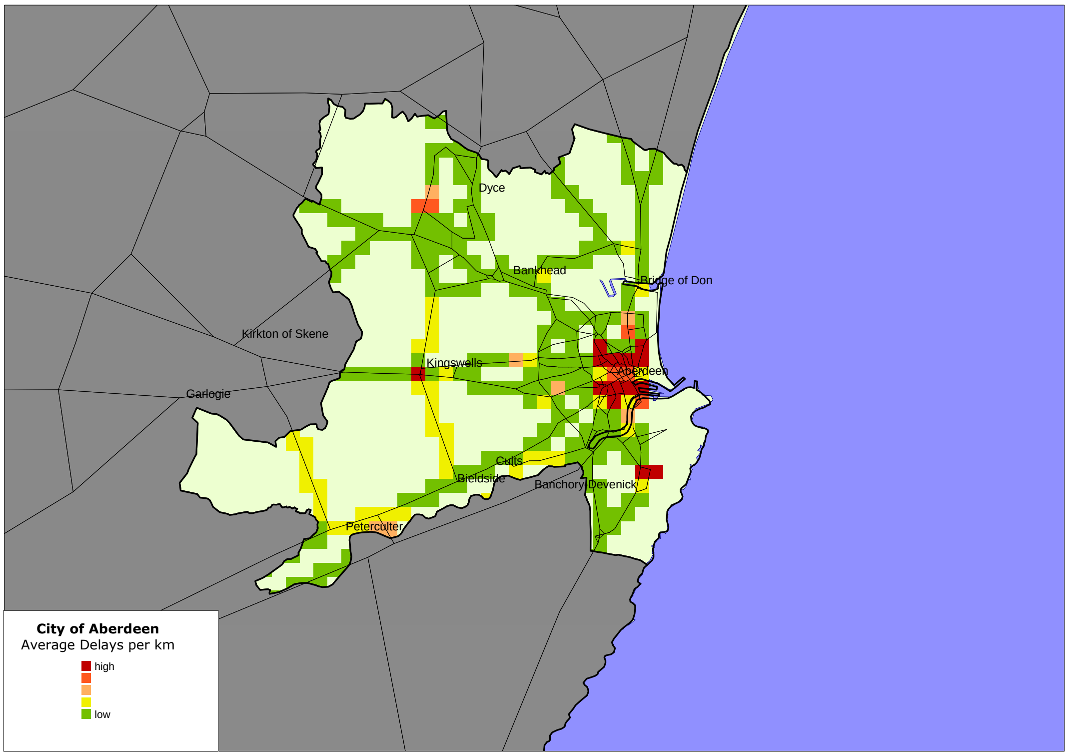
Source: Kocak (2005)

Figure 2.2 - City of Edinburgh Congestion map (2002 AM Peak)



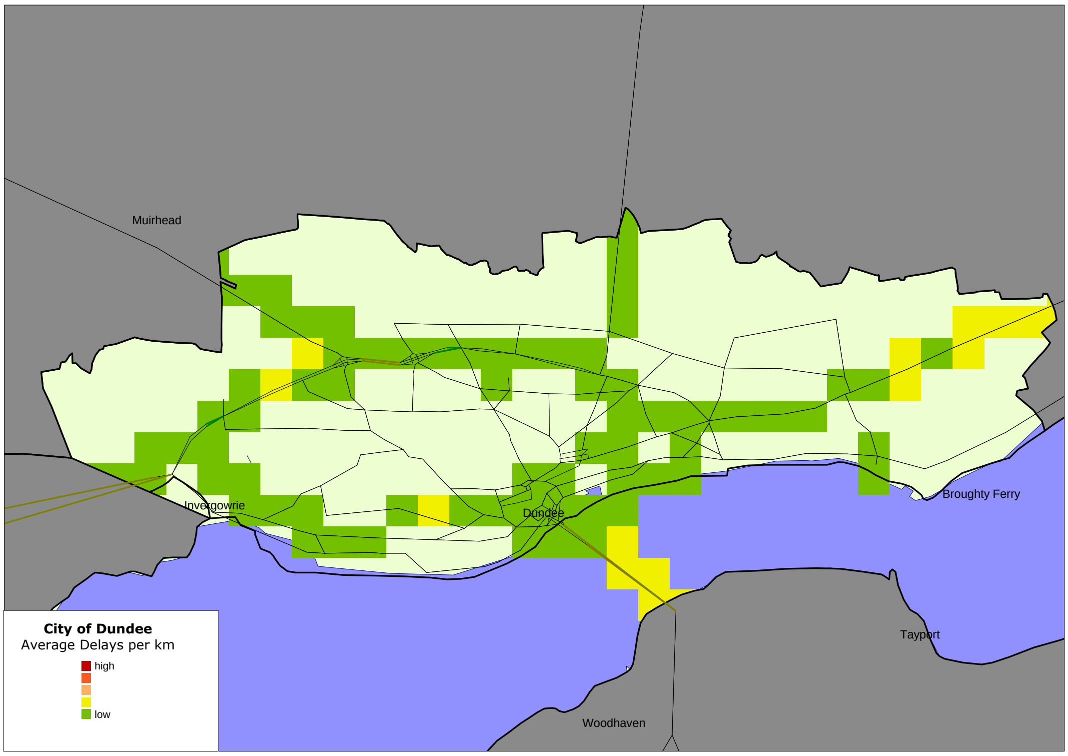
Source: Kocak (2005)

Figure 2.3 - Aberdeen City Congestion map (2002 AM Peak)



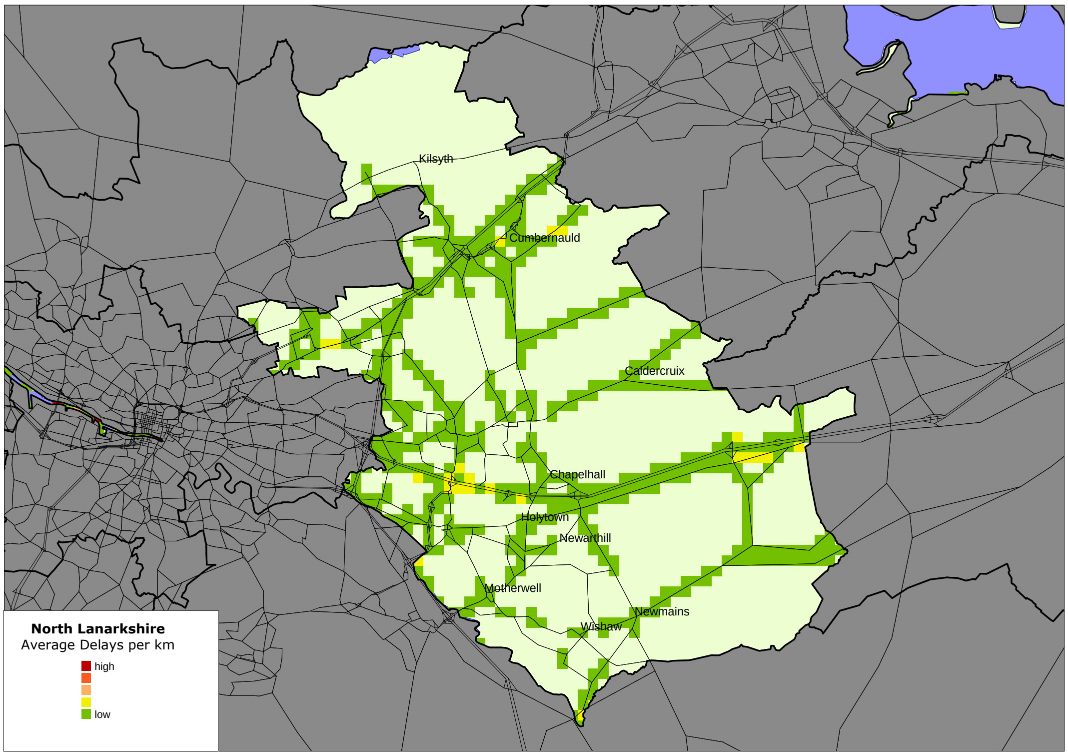
Source: Kocak (2005)

Figure 2.4 - Dundee City Congestion map AM Peak



Source: Kocak (2005)

Figure 2.5 - North Lanarkshire Congestion map AM Peak



Source: Kocak (2005)

Congestion on Scottish Trunk Roads 2003

2.6 The report *Congestion on Scottish Trunk Roads 2003* (Scottish Executive, 2005) uses traffic count data to develop congestion indicators for 22 routes on the trunk road network throughout Scotland. These locations have been chosen to include "those sections of the network which currently experience congestion or which are thought likely to [experience congestion] over the coming years". The locations are set out in Table 2.3 and Table 2.4. The first thing to note is that with the exception of four routes these locations are all in urban or peri-urban areas. Of the four exceptions three are estuarial crossings and the other is the M8 between Glasgow and Edinburgh. From this it can be seen that the sections of the trunk road network that policymakers perceive to have, or will have, a congestion problem are those where traffic flows are heavily influenced by the urban environment or where capacity bottlenecks potentially exist (estuarial crossings).

2.7 The previous analysis identified that trips with destinations in Glasgow, Aberdeen and Edinburgh are those that are subject to the most delay. Table 2.3 and Table 2.4 provide further confirmation of this position for Glasgow and Edinburgh, in that it is sections of the trunk road network that are closest to these cities that have the largest proportion of traffic experiencing speed reductions and journey time reliability problems. The localised nature of these speed and reliability impacts can again be observed as it is only certain routes in an area and certain directions of travel that experience the worst of these impacts. For example the A90 through Dundee in an eastbound direction has 10% of the vehicles experiencing a speed reduction of more than 25% of the freeflow speed, whilst 0% of vehicles experience such a reduction in the westbound direction. A similar effect can be seen on the approaches to the Kincardine Bridge.

Table 2.3 - Speed reduction on trunk roads by route

Area	Trunk road route	Speed: %age of vehs with speed reduced by more than 25% of freeflow speed		
		Direction-1	Direction-2	Average for both directions
Glasgow	M8 St James Int to Baillieston Int	11%	13%	12%
Glasgow	M80 Steppes Bypass / A80 to M80 J4	7%	7%	7%
Kincardine Bridge Approaches	A977 (Gartarry Rbt)/A985 (Longannet)/A876/M876 to M9 Jcn 7	12%	2%	7%
Edinburgh	A720 City Bypass from A1 to M8	7%	7%	7%
Forth Bridge Approaches	A92 Cowdenbeath Jcn amd M90 Jcn 4 to Forth Road Br	7%	4%	5%
Dundee	A90 Inchture to A90 Forfar Rd	10%	0%	5%
Glasgow	A725	5%	5%	5%
Glasgow-Edinburgh	A8/M8 Baillieston to Hermiston Gait	6%	3%	5%
Edinburgh	M9 from M8 Claylands to M9 Spur	3%	4%	3%
Aberdeen	A96 Muggiemoss Rbt to Blackburn	3%	3%	3%
Glasgow	M77 Greenlaw Jcn to M8 Jcn	5%	1%	3%
Aberdeen	A90(N) Balmeddie to Muggiemoss Rbt	1%	5%	3%
Ayrshire	A77 Dalrymple to Dutch House Rbt	1%	4%	3%
Glasgow	M73 to M74 J7	2%	2%	2%
Ayrshire	A78 Stevenson to Dutch House Rbt	2%	2%	2%
Aberdeen	A90(S) Muggiemoss Rbt to Stonehaven	1%	2%	1%
Edinburgh	A1 Macmerry to A720 Jcn	2%	0%	1%
Dundee	A90 Forfer Rd (Tealing) via Tay Br to Forgan Rbt	1%	0%	1%
Erskine Bridge	A898/A898	1%	1%	1%
Perth	M90 Bridge of Earn to Broxden and Friarton	0%	1%	0%
Perth	A9 from junction B934 to Luncarty	1%	0%	0%
Ayrshire	A77 nr Fenwick to Dutch House Rbt	0%	0%	0%

Notes to table
Source: Scottish Executive (2005); Authors' analysis.

Table 2.4 - Reliability (journey time variability) on trunk roads by route

Area	Trunk road route	Reliability: %age of vehs with journey time 15% longer than average for that period.		
		Direction-1	Direction-2	Average for both directions
Glasgow	M8 St James Int to Baillieston Int	9%	11%	10%
Kincardine Bridge Approaches	A977 (Gartarry Rbt)/A985 (Longannet)/A876/M876 to M9 Jcn 7	9%	3%	6%
Glasgow	M80 Steppes Bypass / A80 to M80 J4	6%	5%	6%
Edinburgh	A720 City Bypass from A1 to M8	5%	5%	5%
Glasgow	A725	6%	4%	5%
Aberdeen	A90(N) Balmeddie to Muggiemoss Rbt	2%	6%	4%
Glasgow-Edinburgh	A8/M8 Baillieston to Hermiston Gait	4%	3%	3%
Edinburgh	M9 from M8 Claylands to M9 Spur	4%	3%	3%
Forth Bridge Approaches	A92 Cowdenbeath Jcn amd M90 Jcn 4 to Forth Road Br	4%	3%	3%
Glasgow	M77 Greenlaw Jcn to M8 Jcn	4%	2%	3%
Aberdeen	A96 Muggiemoss Rbt to Blackburn	3%	2%	2%
Glasgow	M73 to M74 J7	3%	2%	2%
Aberdeen	A90(S) Muggiemoss Rbt to Stonehaven	1%	4%	2%
Erskine Bridge	A898/A898	1%	2%	2%
Ayrshire	A77 Dalrymple to Dutch House Rbt	1%	3%	2%
Dundee	A90 Inchture to A90 Forfar Rd	2%	1%	1%
Ayrshire	A78 Stevenson to Dutch House Rbt	1%	1%	1%
Dundee	A90 Forfer Rd (Tealing) via Tay Br to Forgan Rbt	1%	1%	1%
Perth	M90 Bridge of Earn to Broxden and Friarton	0%	1%	1%
Perth	A9 from junction B934 to Luncarty	1%	1%	1%
Edinburgh	A1 Macmerry to A720 Jcn	1%	1%	1%
Ayrshire	A77 nr Fenwick to Dutch House Rbt	1%	0%	1%

Notes to table
Source: Scottish Executive (2005); Authors' analysis.

2.8 To summarise, there is only a limited availability of literature on the locations of congestion in Scotland. Notwithstanding that, a number of data sources exist that contain information on the impacts of congestion (delay, speed reductions and reliability problems). The information that does exist does not define congestion per se, nor does it define the point at which congestion is perceived to be a problem. In describing the locations where congestion exists in Scotland the approach has therefore been to describe the locations where the impacts of congestion are greatest. No commentary is given as to whether this level of impact is perceived to be a problem, as the data analysed does not contain such information.

2.9 From the analysis of the available data a broad picture emerges. Whilst at the national level only a minority of trips (11.5%) are affected by congestion, this figure disguises large geographic, temporal and journey purpose variations. Congestion impacts are largest in the cities of Glasgow, Aberdeen and Edinburgh (where up to 42% of AM peak travellers experience congestion related delay and up to 49% of the AM peak network generates delays). The trunk road network that experiences the most congestion is that in the vicinity of these cities as well as on the approaches to the Forth estuarial crossings. The peak hours are more congested than the off-peak and commuting and business related trips are more affected by congestion than trips for ‘other’ trip purposes (there is no data on the impact of congestion on freight movements). Congestion is not however just confined to Aberdeen, Glasgow and Edinburgh and their vicinity as congestion related delays are reported throughout Scotland, it is just that their frequency and incidence is higher in the large cities – ultimately it only takes one over-capacity junction to impose a congestion related delay on travellers.

CHAPTER THREE DEFINITIONS OF CONGESTION

3.1 A review of literature has revealed a persistent view that there is no single definition of congestion, although the concept is commonly understood and the term is used widely by academics, policy makers and laypersons. There are a number of examples of substantial research projects considering aspects of congestion at national and European level which do not include a definition of congestion as part of the work. In fact, the definition of congestion will vary according to the context (urban, interurban) and can be both an objective state of the transport network and a subjective condition for the transport network user. As a result a number of definitions exist and these are outlined below. Following a summary of the three states of congestion, research on congestion from a transport users perspective is given, followed by rather more formalised definitions which lend themselves towards quantified measures.

Types of congestion

3.2 The three types of congestion are outlined by Brownfield et al (2003) as Recurrent congestion, Non-recurrent congestion and the Pre-congestion state, as shown in Table 3.1. These types are based upon the frequency and predictability of the congestion – factors which will impact on driver behaviour. The costs associated with each type of congestion are likely to be different. Non-recurrent congestion costs may be more difficult to quantify due to the inherent sparseness of adequate amounts of data needed – it may be argued that the costs could be higher as drivers have not been able to take the possibility of congestion into account in planning their journey or alternatively the costs may be less dramatic as drivers pre-developed strategies for coping with congestion will not have come into play. Some routes are increasingly subject to non-recurrent congestion however, for example with accident black spots. In these cases drivers may ‘learn’ an expected cost in terms of likely delay and successful contingency routes. The Pre-congestion state will carry some costs similar to those of congestion, including loss of control over drivers’ environment, deterioration in the environment and other impacts.

Table 3.1 - Summary of types of congestion

Congestion Type	Definition
Recurrent congestion	Occurs at regular times at a site. It can be anticipated by road users that normally use the route during those times. Examples of recurrent congestion are morning or evening peak hour congestion, or congestion due to a regular events such as a street market on a particular day each week
Non-recurrent congestion	Occurs at non-regular times at a site. It is unexpected and unpredictable by the driver and is normally due to incidents such as accidents, vehicle breakdowns or other unforeseen loss of carriageway capacity
Pre-congestion (Borderline congestion)	Occurs where free-flow conditions breakdown but full congestion has not yet occurred. This may occur either side of the time period when congestion occurs or upstream or downstream of congestion that is already occurring.

Notes to table
Source: adapted from Brownfield, 2003

Perceived congestion

3.3 Perceived congestion is as important a concept as the formalised definitions. The need to introduce policy measures to improve congestion may be driven at least in part by the political considerations arising from a large number of transport systems users that believe congestion is a problem in the parts of the network they use. This may in turn relate to the historical state of the network, which is likely to influence users expectations of their journey and finally their perception of whether the current levels of efficiency reflect a congestion problem or not. Transport system users in a geographical area which has a history of slow, unreliable and delayed journeys may have a different perception of (and greater degree of tolerance towards) levels of congestion than those in areas with a recent history of relatively free flow conditions. A number of studies have therefore looked at perceived perception i.e. the state of the traffic system from the users' subjective interpretation. These studies have highlighted a number of ways of viewing what congestion is, which have relevance for measures aimed at putting users at the centre of transport policy.

3.4 A qualitative study carried out for the Department for Transport (DfT, 2001) reported alternative definitions of congestions based on the perceptions of drivers. Group discussions took place with 83 drivers of cars and light commercial vehicles from six areas of England (covering a variety of locations and possible congestion difficulties). In addition to eliciting views on definitions of what congestion is, a range of other traffic problems were discussed and a small number of different indicators of congestion reviewed for public value and acceptability. In general, the concept of congestion was widely understood but there was considerable variation on how it may be specifically described. Three main themes arose:

- *'stationary or near jam conditions'*
- *'loss of speed due to weight of traffic'*
- *'slow progress'*

3.5 The latter is related to vehicle density, even though traffic may not be at a standstill. For example having to drive at 40 or even 50 mph on a crowded motorway is perceived by some drivers as congestion, even though traffic is still progressing at reasonable speed. The most favoured definition related to delays rather than density though, with the description of stationary or very slow moving (<5mph) traffic prevailing. Two formal definitions were presented as follows:

- *'Traffic is congested if there are so many vehicles that each one travels slower than it would do if the other vehicles weren't there'*

- *'Traffic is congested if there are so many vehicles that they are brought to a standstill or can only crawl along'*

3.6 Interestingly, these two definitions reflect the two fundamental approaches to interpreting congestion. The first is strongly related to the principles behind marginal costs of congestion (discussed further in chapter 6) and the second reflects a 'traffic engineering' perspective which underlies many of the indicators and measures of congestion (summarised in chapter 4).

3.7 Comparing definitions in the urban and interurban contexts, the ability of traffic to proceed through junctions is seen by some as the defining characteristic of congestion. Leonard (1993) defines congestion in urban areas as being:

> *'the condition when the free movement of traffic through junctions starts to break down'*,

proposing a five-point scale of congestion graded from free-flowing to gridlock conditions. In the motorway environment however, speed is more likely to be the factor defining congestion. Recent work on perceived congestion on motorways includes that of DfT (2005), where respondents were able to indicate their own definition of congestion. Just over half of all respondents said they thought congestion on a motorway was defined by a traffic jam with complete stops of 5 minutes, this being the dominant response. Less than half of respondents (45%) considered a motorway to be congested if they had to travel at less than 20 mph and 39% if they experienced stop/start traffic for more than 15 minutes. Less than 20% considered the motorway to be congested if they had to travel at around 50mph.

Formalised definitions of congestion

3.8 Formalised definitions of congestion begin to express congestion more rigorously and in terms which may be strongly related to indicators or form the basis for quantified measurement. The definition given by the Highways Agency (DMRB, 1997) captures the wide understanding of congestion and relates it to characteristics of the network. This states that congestion is

> *'the situation when the hourly traffic demand exceeds the maximum sustainable hourly throughput of the link.'*

3.9 At this point, traffic is likely to experience one or more of the following: flow breakdown with speeds varying considerably, average speeds drop significantly, the sustainable throughput is reduced and queues are likely to form. The definition forms the basis for the Congestion Reference Flow, which is a quantified measure of congestion and described in chapter 4 below. According to Goodwin 2004:

> *'Congestion is defined as the impedance vehicles impose on each other, due to the speed-flow relationship, in conditions where the use of a transport system approaches its capacity'.*

3.10 This expresses congestion as a phenomenon which involves the interrelation of vehicles and the idea of impedance arising to others from an additional vehicle on the network. This particular definition dovetails with the economic approach to measuring marginal congestion costs described in chapter 6.

3.11 Research into the relationship between congestion and accident risk for the DfT (Brownfield et al, 2003) sought to define congestion in a way which was quantitative and easily measurable, considering the urban and interurban contexts separately. Twenty sites from across England were used as a basis to gather evidence, including four motorway sites, nine peri-urban sites and seven urban sites. For an interurban (or peri-urban) link, the following definition was derived:

'An interurban or peri-urban link is defined as being congested when the point average speed taken over 3 minutes is below 50% of the speed limit'

3.12 This was based on broad agreement with empirical evidence found from other studies, which indicated that highly congested roads with speed limits of between 30 and 40 mph have an average speed of approximately 20mph and observations of motorway speed flow curves that showed flow breakdown occurring between 30mph and 40 mph. For the urban links, the following definitions were applied:

'An urban link (with a signalised exit) is defined as congested when traffic cannot exit the link within one cycle. An urban link with an unsignalised exit is defined as congested when traffic cannot exit the link within a time equivalent to one signal cycle (the cycle time equivalent was calculated by estimating what the cycle time would be if the link exit was signalised.'

3.13 The two definitions are in line with the previous findings by DfT, 2001 and Leonard, 1993, with speed forming the criteria for interurban congestion and stops forming the criteria in the urban case. The supporting basis for these urban definitions included the fact that if traffic is consistently delayed by more than one cycle, the junction is likely to be close to saturation (and therefore congested), which implies a high volume/capacity ratio.

3.14 In summary, despite the past research into congestion and frequent use of the term, the state of congestion is often understood but not formally defined. Perceived congestion is an important factor alongside more objective definitions in driving the need for policy measures. Definitions vary according to two major dimensions – the traffic engineering perspective and the economic cost driven dimension which in fact relate to two major efficiency objectives i.e. system efficiency and economic efficiency. Users' perceptions were generally consistent with one or other of these dimensions. Congestion in urban areas can be distinguished from that in the interurban context as it can be recognised by the inability to exit a link within a traffic cycle. Congestion in an interurban context may be defined through speed of travel (or ultimately stopping). Both perceived and formalised concepts of congestion lend themselves to more objective measurement and indicators, which are described in chapter 4.

CHAPTER FOUR INDICATORS AND MEASUREMENT OF CONGESTION

4.1 At the practical level of measuring congestion, more concrete indicators are needed. A wide number have been developed – some in the UK context but many in the USA, although literature suggests that only a small number form the basis for regular monitoring of the network. A summary of the approaches used is given here.

4.2 As part of a report on the role of a national road traffic reduction target, DfT (2000) produced summaries of traffic congestion alongside a number of traffic related impacts for England (such as pollutants, safety and social impacts). It conceded that whilst 'a number of transport commentators have attempted to estimate congestion, using a variety of definitions, an ideal measure has yet to be identified'. As input to that report, The Commission for Integrated Transport (CfIT) advised a measure based on:

The total amount of delay encountered, calculated across all traffic from the difference between the actual speed encountered and free flow speed

4.3 This forms the basis for the National Transport Model forecasts (DfT, 2003), which are then key inputs to the FORGE Road Capacity and Costs model (DfT, 2005). In fact an alternative measure was used in the report by DfT (2000) which divides this estimate of total delay by the volume of traffic to give the average amount of delay encountered by a vehicle travelling one kilometre.

Average delay by a vehicle travelling one kilometre = total delay to travel one kilometre/volume of traffic Where total delay = actual speed - free flow speed (for all vehicles)

4.4 This average delay calculation is incorporated in the Transport Model for Scotland congestion mapping process; output from which forms the basis for the analysis presented in chapter 3. The second measure was believed to be advantageous in providing a better picture of how changing traffic levels and different policy packages can affect time lost to congestion. A detailed illustration of the use of this measure, with assumptions and reference input data is given in DfT (2000b), where figures on road traffic congestion are produced by road class, time of day and geographical location for England in 2000. Neither measure, however, gives an indication of the variability in time taken for a specific journey, or the relative importance of delays to different types of journey. It should also be noted that delays are measured purely in terms of vehicle journey time and no allowances are made for differences in occupancy rates, values of time, or for additional factors such as additional operating or environmental impacts that congestion can generate.

4.5 Simple measures relating to speed are also used to indicate congestion, particularly for a motorway environment. A current example would be the M42 Active Traffic Management (ATM) scheme (Grant-Muller, 2005) where eight separate indicators have been identified to demonstrate the impacts of ATM in changing levels of congestion, as shown in

Table 4.1. Other work also advocates simple speed related measures, for example Dijker et al, 1998, who proposed that traffic is considered in congested state when the traffic speed is below 50km/hr. The different indicators in Table 5.1 are relatively straight forward measures individually, but intended to give a more comprehensive picture of different aspects of congestion when taken together. Although simple to calculate, the data requirements to produce all 8 indicators are substantial and involve continuous loop monitoring of the area. As loops do not provide actual journey times (rather inferred journey times from speed), additional journey time data would be preferably produced, either through ITIS, ANPR matching or surveys. It is beyond the scope of this work to elaborate on reliability of data sources, but it should be noted that ITIS, ANPR and surveys also have inaccuracies in reflecting the state of the system. Experience has shown the use of loops for mean journey time may be adequate, but using these to produce estimates of variability of journey times may be less satisfactory, with less correspondence between loop based data and other data sources on this indicator. Whilst loop based data generally supports speed based indicators, the accuracy of loop based data at low speeds (less than 25 mph) diminishes, bringing into question the ability to use this data source to generate data for the 25 mph threshold. In addition, where congestion is a result of incidents or unexpected phenomena, the algorithm to convert loop data into journey times performs less well.

Table 4.1 - Congestion indicators for the M42 ATM project

Indicator	Definition
1. Mean Journey Times	Mean journey time on a link-by-link basis, for specified time periods These to be combined into meaningful journeys, e.g. full ATM section, by direction.
2. Variability of Journey Times	Standard deviation (variance) in journey times on a link-by-link basis, and on a route basis: • within-day variability • between-day variability
3. Throughput	Total number of vehicles per time interval that pass a point on the carriageway
4. Total Time Speed Less Than 25mph and 50 mph	Total time during which the average speed of vehicles drops below 25/50mph, per pre-defined time interval and per section (between junctions)
5. Number of Occurrences Speed is Less Than 25mph and 50 mph	Number of vehicles with average speed below 25/50mph, per pre-defined time interval and per section (between junctions)
6. Queue Lengths	Four types of queue to be measured, • queues due to flow breakdown • queues at exit slip roads • queues on on-slips • queues to join the ATM section Queuing traffic is defined as a platoon of vehicles whose speed does not rise above 25mph.
7. Speed differential between lanes	Difference in mean speeds between each of the lanes per section, plus difference in extremes in distribution
8. Delay per hour/day	Measure of delay per hour/day on the ATM stretch, where delay is reflected through difference between free flow and actual journey time.

Notes to table
Source: adapted from Grant-Muller (2005)

4.6 The congestion reference flow (Highways agency, 1997) gives a quantified measure of congestion for a link as follows (junctions must be considered separately).

CRF = CAPACITY * NL * Wf * 100/PkF * 100/PkD * AADT/AAWT

where CAPACITY is the maximum hourly lane throughput
NL is the Number of Lanes per direction;
Wf is a Width Factor
PkF is the proportion (percentage) of the total daily flow (2-way) that occurs in the peak hour;
PkD is the directional split (percentage) of the peak hour flow;
AADT is the Annual Average Daily Traffic flow on the link;
AAWT is the Annual Average Weekday Traffic flow on the link.

4.7 Suggested values that may be used in the calculation are given within Highways Agency, 1997. Links of the same standard will have different CRF values according to factors such as the proportion of heavy vehicles, the peak to daily ratio, the peak hour directional split and the weekday/weekly flow ratio.

4.8 The level of Service indicator (LOS) is one of the basic congestion measures applied widely in the USA and which has also been proposed by the Scottish Office (1998). It uses a scale running from A to F to describe operational conditions on a route or section of route taking into account speed, travel time, manoeuvrability, disruption to flows, comfort, convenience and safety. An 'A' rating represents the highest quality of service with free-flow conditions and users travelling at their desired speed. On single carriageways, passing demand is significantly below passing capacity and no platoons of three or more vehicles occur. On dual carriageways and motorways, minor disruptions to flow are easily absorbed without changes in speed. At the other end of the scale, an 'F' rating represents the worst quality of service with heavily congested flows and traffic demand exceeding capacity. Passing is virtually impossible on single carriageways and, on dual carriageways and motorways, long queues form which are subject to stop/start conditions.

4.9 Summary indices can be used to give congestion measures for a wider area rather than particular links and the desirability of these will depend upon the end use of the measure. One example is that given by Leonard (1993), who outlines a travel time based Congestion Index for comparative use in urban areas:

$$CI = \sum \frac{t_i + d_i}{t_i}$$

Where CI = Congestion Index
t_i = free flow travel time
d_i = excess travel time

4.10 This can be applied for all vehicle journeys or for single links of corridors. Where links are summed separately, it is necessary to apply a flow weighting:

$$CI = \frac{\sum f_a \frac{t_a + d_a}{t_a}}{\sum f_a}$$

Where CI = Congestion Index
t_a = free flow travel time on link a
d_a = excess travel time on link a
f_a = flow along link a

4.11 The choice of a summary index or more specific link/junction based measures depends upon the end use of the data. Where the objective is to identify or monitor particular points in the network - for example for the purposes of monitoring congestion problem sites - an index will lose the desirable granularity in the information. This may be the case where the intention is to provide information to the traveller to advise journey planning for example. Where the objective is to assess costs and benefits of a particular scheme or policy, a wider indicator of congestion (or series or indicators, as is the case with the M42 ATM) would provide better information.

4.12 A number of indicators have been developed and are commonly applied in the USA and these are summarized in Table 3.1 below. In addition to those reported here, a wide tranche of literature on incident detection algorithms exist, many of which involve heavy instrumentation of the highway and frequently a Neural Network based analysis. These are not discussed further here as they lie outside the scope of the work, but see for example Wang et al, 2005.

4.13 It can be seen from Table 2.1 and the indicators given above, that a number of common approaches exist. These are typified as travel time (or speed) based measures, volume based measures, area based measures and summary indices (or more complex model outputs). A comprehensive comparison of each of these using a single data source has not been found (and would be a topic for future research), so the relative advantages and disadvantages relate to their particular ability to reflect the objectives of measuring congestion as discussed above and data requirements. In terms of use in practice however, results given by Statewide Planning Scenario Synthesis, 2005 suggest that the simpler measures (LOS, volume/capacity ratio, delay) are more commonly applied than relatively complex measures.

Table 4.2 - Congestion Indicators adopted in practice within the USA

Indicator	Description
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).
Travel Time Rate	The ratio of peak period to free-flow travel times, considering only reoccurring delays (normal congestion delays).
Travel Time Index	The ratio of peak period to free-flow travel times, considering both reoccurring and incident delays (e.g., traffic incidents).
Percent Travel Time In Congestion	Portion of peak-period vehicle or person travel time that occurs under congested conditions.
Congested Road Miles	Portion of roadway miles that are congested during peak periods.
Two times Free Flow	Evaluation of amount of peak travel time with is two times free flow travel time or more (generally used to indicate extreme congestion)
Travel Rate index	Used to indicate overall rate of progression by calculating the added time needed to make a trip under congested conditions summed across a network of roads
Benefit/Cost (HERS)	Highway Economic Requirements System State – engineering/economic forecasting software used to identify possible highway problems and prioritise future investment. Uses traffic engineering data (speed, road length, volumes etc) as inputs to a model.
Buffer Time index	Weighted average for all sections of (95^{th} percentile travel rate mins/mile – average travel rate mins/mile)/(average travel rate mins/mile)%
Lost productivity Estimate (or Lost Efficiency)	Calculated by subtracting the peak period volume from the official capacity over a given time interval.
Congested Time	Estimate of how long congested "rush hour" conditions exist
Congested Lane Miles	The number of peak-period lane miles that have congested travel.
Annual Hours Of Delay	Hours of extra travel time due to congestion.
Oregon travel cost index	Contains a trade-off between the costs of land use and costs of delay, calibrated to favour compact land use. E.g. a 20 mins ride on a 2 mile road is favoured over a 20 mins ride on a 10 mile road.
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 Traffic Speed	Average speed of vehicle trips for an area and time (e.g., peak periods).
Average Commute Travel Time	Average commute trip time.
Average Per Capita Travel Time	Average total time devoted to travel.

Notes to table
Source: author, from various sources

4.14 If the end use for an indicator is to provide information for transport users, then the public acceptability of a particular measure is an issue to be considered. Six different measures of congestion were presented to a group of 83 drivers of private and light commercial vehicles cars in DfT (2001) in order to asses their user value and acceptability as follows:

Table 4.3 - Alternative congestion measures to assess user acceptability

Basis for Measurement	Measurement specification
Measures based on time lost per unit travelled for a typical journey and average vehicle	1) Secs/mile lost due to congestion 2) Mins/100 mile journey lost due to congestion 3) Hours/year lost due to congestion
Time spent in Jams (at standstill or speeds <mph)	4) % of time sent in jams 5) Mins spent in jams/hour of driving
Risk of serious delays	6) chances of serious delay

4.15 It may be worth noting that none of the above measures were well received by the sample of drivers questioned, but the time spent in jams was possibly most favoured. Measurement in terms of percentages or risk were perceived as most complex and least useful by the group. The notion that, in general, less complex indicators are favoured by both practitioners and travellers may be useful for future choice of indicators in the case for Scotland.

4.16 At a European level, a review of research has revealed a considerable programme of research concerned with congestion and road management from a system efficiency perspective, including SPECTRUM (1994), COSMOS (1996) and RECONNECT (2002). Much of this was undertaken within the early DRIVE programme of EU funded work, but related research has continued. Research has been concerned with the early prediction, detection and management of incidents in addition to optimizing the performance of the system as a whole. Formal definitions of congestion are difficult to identify, although the term is used widely within the research. One project with a formal definition is PRIME, which aimed to increase the effectiveness of incident detection and management on motorways and adjacent urban networks through the development of dynamic traffic management procedures. PRIME used the following as an indicator of congestion:

> % change in Average Loop Occupancy Time per Vehicle (ALOTPV) between periods with and without incidents

Wider impacts of congestion

4.17 In addition to the quantified indicators of congestion based around travel time or speed, research has shown that there are wider actual and perceived impacts of congestion, some of which are more difficult to quantify.

4.18 In a study aimed at improving the understanding of the extent to which accident risk increases in congestion for DfT (2003), despite an initial presumption that accident risk may increase in congested conditions, it was found that for urban and peri-urban sites, accident rates during periods of recurrent congestion are lower than those in uncongested conditions (less than half the accident rate[2]). This was ascribed to the familiarity of regular road users with site conditions during periods of congestion and substantially lower speed of vehicles. Different results were found for motorway sites where the accident rate in congested conditions was nearly twice the rate in uncongested conditions; however the proportion of

[2] Defined as the number of accidents per lane-km.hr and not taking flow into account

accidents that were fatal or serious was lower in congested conditions. For motorway sites the accident rate for Two Wheeled Motor Vehicles (TWMV's) in congested conditions was found to be more than seven times the rate in uncongested conditions. For TWMV's, cyclists and pedestrians the proportion of fatal or serious accidents remained the same in urban and peri-urban congestion, probably reflecting the overall vulnerability to injury of these road user groups.

4.19 The perceived impacts of congestion were also discussed by DfT, 2001 as part of the qualitative findings from group discussions. These were reported on the basis of personal experience by car and light commercial vehicles from six areas in England involving travel of at least 2,500 miles per year and can be summarised as follows:

- Competitive or aggressive driving
- Driving found to be harder or more tiring
- Limited freedom of action or ability to travel where and when drivers wish
- Increased risk of accidents or mishaps
- Intensified pollution
- Increased fuel consumption
- Major source of driver stress – making many respondents feeling frustrated, angry, anxious, confused and/or exhausted.

4.20 These are consistent with other research findings, for example EU (2003). In moving forward towards a method of measuring the costs of congestion, both the quantified indicators and wider impacts of congestion have a role to play. Some aspects of the wider impacts are difficult to incorporate in costs and this is widely acknowledged – a typical example would be driver stress. The outline of methods to measure costs of congestion begins with a broad background in chapter 5, followed by more detailed descriptions the measurement of marginal costs in chapter 6 and total and excess costs in chapter 7.

CHAPTER FIVE BACKGROUND TO MEASURING COSTS OF CONGESTION

5.1 In measuring the costs of congestion, there are a number of issues to highlight which affect the approach that may be taken and the interpretation or use of the output as follows:

- A difference exists between the total costs of congestion, the marginal costs of congestion (the effect on congestion of one extra vehicle) and the costs of the 'excess burden of congestion'. In chapters 6 and 7 below these three types of congestion costs are defined in greater detail and the relevant literature reviewed.
- The methods used to measure costs of congestion can be typified as primarily static versus dynamic methods, with some approaches forming a hybrid between these. The broad principles are described below, with further detail on relevant studies which have used different methods given in chapters 6 and 7.
- The appropriate approach to measuring costs of congestion will vary according to the end use of the data. For example, in cases where the aim is to consider road pricing measures, the marginal cost of congestion has been calculated. To review the benefits of significant investment decisions, the total or excess burden of congestion may be calculated. The purpose of the research here is to provide objective evidence on each based on the existing literature. The work will inform subsequent stages of research to be conducted by the Scottish Executive and at this point it is not possible to propose recommended methodologies until the nature of that programme is defined.

5.2 Dynamic methods of calculating the costs of congestion essentially relate to an iterative process between supply, demand and the cost of travel. Some care is needed with the terminology in order to avoid confusion between a dynamic approach to calculating costs and a dynamic network model. The latter is termed dynamic in a traffic engineering sense – i.e. dynamic assignment techniques vs. static (steady state) techniques. In fact a dynamic method of modelling the cost of congestion can use either a static or dynamic traffic model. The advantage of using a dynamic model is that it attempts to represent detailed changes at the spatial level e.g. in route choice and also the temporal level e.g. departure time choice.

5.3 The estimation of marginal cost and marginal external costs (defined and described in chapter 6) is a far from trivial task. Primarily this arises as it is necessary to model how user costs (travel time, reliability, etc.) change in response to an additional vehicle-kilometre or trip. Additionally it is a fundamental requirement that that marginal cost functions for each of the cost components (detailed in Table 5.1) are available. Shires (2006) identifies four principal methods for the calculation of congestion impacts on the **users of the transport system**. These methods are set out below.

5.4 **Link speed-flow relationships.** This method is relatively simple and assumes a single link speed-flow relationship for all links of a certain type (quality, time period, location) in the transport system. Diversion from one link type to another is not possible; however, trip suppression and generation can be modelled using simple elasticities.

5.5 **Area speed-flow curves.** This method uses a single speed/flow relationship to represent average travel times in a particular area of the network. That is a single relationship is taken to represent average travel times on all links within a particular area and at all junctions in that area. Different areas of the network have different relationships attributed to them. Diversion between areas is possible as is trip generation and suppression. An example of such a model in Scotland would be the TRAM/DELTA model developed by MVA for the City of Edinburgh Council for the appraisal of congestion charging.

5.6 **Network assignment models.** This method utilises detailed transport network models which model link and junction delay. Diversion between different roads (links) is possible and depending on the complexity of the model diversion between modes is also possible. The Scottish Executive's Transport Model for Scotland is an example of a network assignment model.

5.7 **Microsimulation models:** Microsimulation models have a more recent history than the above three model types. They offer a detailed representation of the behaviour of individual vehicles in a system and can respond in real-time. Whereas the above three model types utilise relationships describing average behaviour, microsimulation models simulate the behaviour of vehicles in response to dynamic changes in the transport network (e.g. incidents, vehicle actuated traffic signals, etc.). Microsimulation models are typically developed for smaller areas of the network than network assignment models. A significant number of these model types have been developed for parts of the Scottish road network over the last 10 years including: Edinburgh city centre, Edinburgh city bypass and Forth Bridge approaches, the corridor studies (M74, M8 and M80), M8 (through Glasgow), Perth, Stirling, Ayr and parts of Dundee, Inverness and Aberdeen.

5.8 Static methods are generally based upon the idea of an 'area' speed/flow relationship that can be simply inverted to give an estimate of travel times for different flows on a network. This can also be linked to an equilibrium traffic assignment model and assumes a stationary state of congestion and continuous demand – in practice this may be criticised as unrepresentative of the real life instances of congestion.

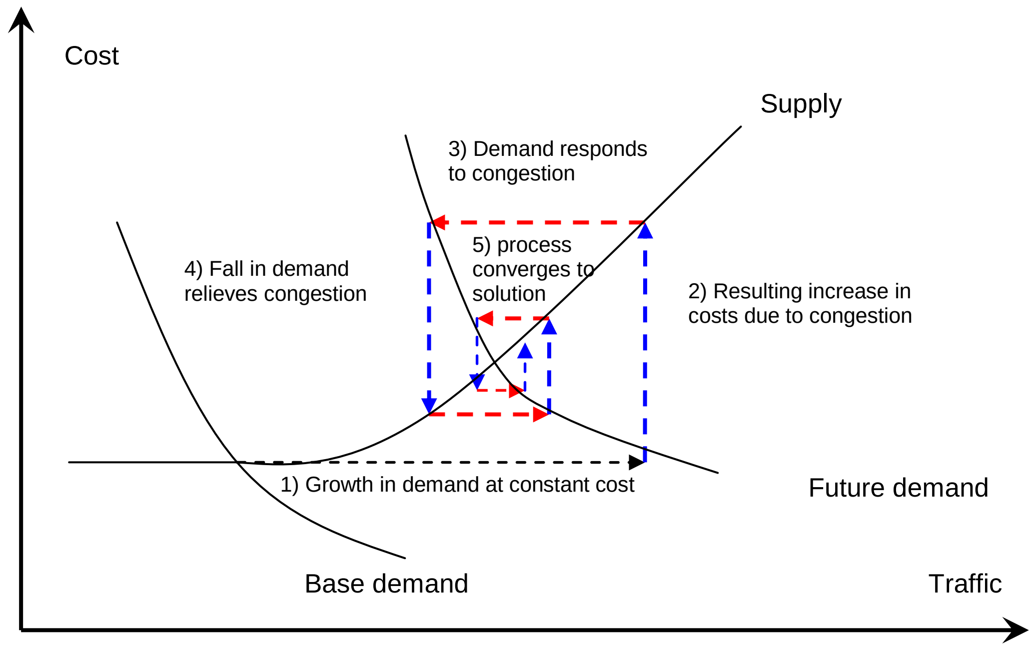
5.9 Within each approach, the economic total cost of congestion is generally given by Delay *multiplied by* (Volume of traffic) *multiplied by* (Value of Time). The variation between the different approaches relates generally to:

- how vehicle delay is measured or estimated (i.e. the definition of the baseline level of delay)
- how the volume of traffic is measured or estimated
- how the value of time is incorporated
- whether values for the environment, reliability, accidents are included

5.10 These factors will, in turn, relate to the scale at which costs are required – driven by the overall objectives of the study. The total cost of congestion is, however, only one measure of costs and in chapters 6 and 7 further elaboration of alternative measures is given (specifically marginal costs and the costs of the excess burden of congestion.

5.11 An example of the modelling of the supply curve in higher scale national models is that adopted in the UK FORGE model (DfT, 2005). The fundamental basis is a representation of the relationship between supply, demand and cost of travel. This is illustrated in a 'cobweb pattern' cycle of iterations as shown in figure 6.1 below. The costs are essentially fuel and vehicle operating costs plus a monetary valuation of time costs. It is outside the scope of this report to consider optimal means of modelling congested networks, but there are criticisms of the traffic flow based approach (see Hills and Gray, 1999) and there is a train of argument which suggests it should be trip based and have a temporal dimension to accommodate departure time changes (see DfT 2001a).

Figure 5.1 - Supply and Demand Cobweb (source: DfT 2005)



5.12 The FORGE model produces output according to a number of 'congestion bands', but these are not readily available in the documentation, however, the fundamental basis for the congestion outputs is that of the difference between free flow travel time and actual travel time.

5.13 For a focused geographical area, such as a particular city in Scotland, it is feasible to establish a dynamic network model and even a microsimulation model which can give detailed outputs on particular links and junctions and represent the time dimension of congestion through changes in driver behaviour. For a larger scale estimate of costs, a national model would be appropriate – in the case of Scotland potentially based upon extensions to the Transport Model for Scotland. As discussed above, this may lose some of the degree of sophistication in picking up the dynamic time dependent elements of congestion. In terms of data requirements, the methods utilise the standard sources of data that form inputs to micro or macro level models i.e. loop counters plus household survey data or interview data to give information on trip purpose. Proposed Values of time are available from a number of studies (see chapter 4 below) and can be used at disaggregate level to reflect a number of trip purposes according to geographical location. A summary of data and modelling considerations in measuring cost is given in Appendix D, based on work by Nash and Sansom, 1999.

5.14 It lies outside the scope of the work to analyse National Transport Models, but a number already exist at European level and these are reported in DfT (2001) – notably models for the Netherlands, Norway, Sweden, Denmark, Switzerland, Austria, Germany and Italy. In general these have similar objectives of measuring the impacts of policy and infrastructure measures. The model for the Netherlands is particularly concerned with policy measures intended to reduce traffic congestion.

5.15 A considerable tranche of research has been carried out at EU level over a period of 10 years or more into the marginal social costs of travel and transport pricing more widely (including implementation, pricing principles and consequences for transport market imbalances). Whilst this research extends well beyond the scope of this project into a much wider set of issues, an overview of the relevant work is given below.

5.16 An initial set of research (e.g. PETS, QUITS, TRENEN) concentrated primarily on developing pricing principles, on measuring the various elements of marginal social cost and on case studies to model implementation impacts. Research then turned towards implementation issues, with projects such as AFFORD and MC-ICAM (which identified the need for policy packages and phased approaches, as set out in the 1998 White paper). The REVENUE project specifically examined the use of revenue from transport pricing whilst PROGRESS, CUPID and DESIRE were concerned with the practical issues of implementing road pricing in urban and inter-urban areas respectively. The RECORDIT project specifically focusing on intermodal freight transport costs and on the identification of policies and measures to reduce the current market imbalances between intermodal and all-road transport services. More recently, SPECTRUM has been concerned with the potential to move towards a greater use of economic policy instruments either alone or as part of a package (with regulatory or physical measures) in managing the transport network. The project was concerned with a comprehensive socio-economic assessment of benefits, rather than efficiency alone. UNITE has had three main objectives aimed at supporting the introduction of a fair and efficient pricing policy for transport across Europe. Firstly, to develop pilot transport accounts for all modes, for the EU15 and additional countries, secondly to provide a comprehensive set of marginal cost estimates relevant to transport contexts around Europe; and finally to deliver a framework for integration of accounts and marginal costs, consistent with public finance economics and the role of transport charging in the European economy. On-going research includes the GRACE project, which is concerned with researching improvements in the accuracy and reliability of social cost calculations, with particular emphasis on the water and air modes and on generalization issues. Part of the work of GRACE is to consider the complexities of urban road congestion and the consequences for modelling and estimating the costs as a result. Case studies are being carried out as part of the research, including a network model of Edinburgh. The approach will be iterative, applying a single model (SATURN) to a range of pricing structures of various levels of sophistication, estimating the optimal pattern of tolls, interviewing road-users then amending and re-running the model. The definition of congestion within this work is that proposed by the DfT formed from the difference between the free flow and actual travel times. At the time of writing, the project is yet to report case study outcomes. Other on-going relevant research includes the HEATCO project, which is seeking to promote the harmonisation of social cost calculations, particularly in the framework of EU transport infrastructure investment decisions. The DIFFERENT project, only recently underway, is investigating the scope, feasibility and effects of differentiated pricing schemes. This tranche of work is likely to continue with further projects funded by the EU, for example with the recent invitation to tender on ‘the impact assessment of the internalization of the external costs of transport’ (TREN/E1/395/2006). All these projects have included case studies and some have included Edinburgh as an illustration – if the future direction of subsequent research by the Scottish Executive is towards fair and efficient pricing schemes, these would be relevant sources for more detailed information on questions such as internalization approaches, pricing levels and wider impacts of introducing economic measures within the transport sector.

CHAPTER SIX MEASURING THE MARGINAL COST OF CONGESTION

6.1 As identified in chapter 5, there are several economic terms that can be rightfully called the cost of congestion, the first of which is the marginal cost of congestion. Chapter 7 discusses the two other terms that appear in the literature, that of the Total Cost of Congestion and the Excess Burden of Congestion.

Marginal costs

6.2 *Marginal cost* is an economic and financial concept and refers to the change in *total cost* that occurs when the quantity produced changes by one unit. It is a very useful and important concept as it illustrates the manner that, in the case of a transport system, total transport network costs change as vehicle-kilometres or numbers of trips change.

6.3 The marginal cost often differs from *average cost* (total transport network cost divided by number of trips). This is because the cost of producing an additional unit of output (e.g. a trip or vehicle-kilometre) may increase (e.g. as capacity is approached) or may decrease due to economies of scale, scope or density in the supply of the transport service. Marginal cost of road travel typically increases with each additional unit of demand, as roads become more congested, whilst that for rail travel may decrease with demand due to economies of density (e.g. longer trains) and scope (e.g. more services).

6.4 There is also a distinction between short and long run marginal cost. *Short run marginal costs* are those associated with keeping capacity fixed, whilst *long run marginal costs* allow capacity to be expanded (the cost of the capacity expansion itself forms a component of the long run marginal cost).

6.5 *Marginal external costs* are items of marginal cost that are not borne by say the trip maker. With respect to trips made by road they include road wear and tear, delays to other users, increased accident risk and environmental costs. When these are added to those costs borne directly by the user (e.g. fuel, their own time) the result is called *marginal social cost*. One of the marginal external cost items is delays to other users and this in fact is often referred to as the *marginal external cost of congestion* (MECC). The MECC specifically refers to user costs and does not include other cost items that may also change with levels of congestion (e.g. accident risk and environmental costs). A number of well known authors use MECC (Walters, 1961; Glaister, 1981; Newbery, 1988; Button, 1993) in this sense. It does however appear that some authors use the term *marginal cost of congestion* and *marginal external cost of congestion* inter-changeably (e.g. Dodgson *et al.*, 2002; Shires, 2006). It is important to note that the MECC is defined as the external costs that are borne by the users of the transport system (e.g. delay and reliability costs).

Components of marginal external cost

6.6 Table 6.1 sets out a categorisation of the marginal costs of a change in road traffic vehicle kilometres. The congestion category within this tabulation would strictly speaking include all non-monetary related user impacts including reliability impacts and the impacts on the quality of the driving experience (e.g. stop/start conditions).

Table 6.1 - Definition of marginal external cost for road traffic vehicle kilometres

Cost Category	Marginal Cost Basis
Infrastructure costs	Mainly wear and tear costs that can be related to increased vehicle kilometres.
Vehicle operating costs	Cost of an additional vehicle-kilometre
Congestion	Costs imposed by one user on all other users of the system
Scarcity	Opportunity cost of providing a service that precludes other services being run
Mohring effect	Benefits of increased service frequencies due to additional vehicle km
Accidents	External costs of an additional vehicle km, including the increase/decrease in accident risk
Environmental costs	Costs of an additional vehicle kilometre on air pollution, noise and climate change
Fuel duties	Revenue associated with an additional vehicle km
Vehicle excise duty	Revenue relating to an additional vehicle km – only for those vehicles where an increase in vkm would result in an expansion of the vehicle fleet (e.g. HGVs, PSVs, but not cars, LDVs)
Value added tax	On fuel duties
Fares, freight tariffs	Associated with an additional vehicle km

Notes to table
In the presence of imperfect economic markets positive consumption externalities (e.g. agglomeration effects and imperfect competition in transport using sectors of the economy) would be a further cost category
Source: Samson et al. (2001)

6.7 There is a substantial literature on the calculation of the marginal costs of each of the cost categories in Table. A review of all these categories is beyond the scope of this report. The reader is therefore referred to Bickel *et al*. (2005, 2006) for reviews on environmental and safety costs and Link et al. (1999) for infrastructure costs. With respect to the marginal external costs of congestion, these costs arise as a result of delay to other users of the system and reliability impacts on other users. This and the linkage between changes in congestion and the economy are reviewed below.

Marginal Value of Time

6.8 There are countless examples in everyday life of people's willingness-to-pay to save travel time – think of the premium fare a high speed train service attracts. Clearly therefore time savings have value. So why do people and businesses value time savings? This apparently simple question has to be answered using many areas of economic thought including that of labour supply, home production and transport. From the perspective of businesses time lost for production costs money. Staff are paid for the time they work, including the time spent travelling which if lost for production is a cost to the business. Money is also bound up in stock inventories including that in distribution warehouses. Therefore transport improvements that help increase staff productivity or reduce stock inventories help improve business efficiency. Businesses recognise this and are willing-to-pay for the time saving (e.g. by paying a premium for a high speed rail fare or paying for air travel rather than train travel). Individuals value savings in their personal travel time for a variety of reasons. A primary reason, similar to that of businesses, is that the time individuals spend travelling is lost to production– but in this case production is leisure activities and household business activities (washing, cooking and shopping). The improvements in in-car entertainment systems, mobile phones, lap-tops, portable DVD players all, however, make time spent travelling more enjoyable (or productive in an economic sense) for the individual. Such improvements in the 'usefulness' of personal travel time are cited as one of the reasons why empirically the value of non-working time has been observed to increase at less than the rate of income growth. The other reason why individuals value travel time savings is that individuals operate within a time budget. There are only 24 hours in a day, some of which has to be spent asleep, at work and engaged in household production tasks. This leaves limited time for travelling to access locations for work, leisure and household related activities. Thus the choice set of possible workplaces, schools, swimming pools, cinemas, retail parks, etc. is limited by travel time, particularly when some of these activities have to be undertaken at or between set times. Reductions in travel time can therefore increase individuals' choice regarding the activities they undertake and this increased choice is of value.

6.9 There is a substantial volume of evidence on the marginal value of travel time. Wardman (2001) identified 143 value of travel time datasets in the UK, of which 2 relate to the 1986 and 1994 UK national value of time studies. The latter of which is the basis of the current appraisal values for the UK. The values set out in appraisal guidance (DfT, 2005) range from £10.18 to £44.69 per hour for people travelling during the course of work, whilst the average values for commuting trips is £5.04 per hour and other non-working trips is £4.46 per hour. These 'average' values for commuting and other non-work trips belie a very large range. Such values vary systematically by income, distance, age, gender and household type (see for example Whelan and Bates, 2001). The main determinants of the variation are however income and distance (Mackie et al, 2003 p30).

6.10 Whilst it is fairly apparent that the value businesses place on travel time savings lead to business efficiency savings, it is less clear how such savings translate into increased profitability as companies re-structure, re-organise, expand output and change the size of their workforce (including reducing the size of the workforce as travel time savings can increase labour efficiency). The impact of savings in non-working travel time on the general economy (e.g. through a reduction in congestion) are even more opaque. The retail and service sectors rely on customers accessing their premises to sell their products and all businesses rely on their workforce accessing their premises. Clearly therefore changes in non-work travel time affect the wider economy but the extent of this affect is not clearly understood. What, however, is understood is the social welfare[3] value that businesses and individuals place on changes in travel time. Travel time savings therefore form one of the inputs into a social cost-benefit analysis.

Marginal Value of Time spent in congested conditions

6.11 Time spent in congested conditions can be more onerous on the traveller than time spent travelling in freeflow conditions. This arises because of the increased burden placed on the driver of the vehicle and from the irritating effect of stop-start conditions. Reliability problems also increase in congested conditions. A number of studies have therefore set out to

[3] Social welfare in economics is a measure of the well-being of society. If this measure is converted into monetary units a value can be attributed to this well-being. It is the aggregate change in the value of social welfare that is examined in social cost benefit analysis. It should, however, be noted that the change in social welfare, arising as a consequence of a transport project, may differ quite significantly from the aggregate financial impacts brought about by that project.

differentiate the value of travel time by whether the travelling is undertaken in congestion or not.

6.12 Wardman's meta analysis identified that travelling in congested conditions is valued 48% more highly on average than time spent driving in free flow traffic; Eliasson's Swedish study found similar values (about 1.5) for driving in queues (Eliasson, 2004), whilst Steer Davies Gleave (2004) found values ranging from 1.2 times in-vehicle-time (for busy conditions/light congestion) to almost twice in-vehicle-time for 'gridlock' conditions. The UK value of time study found that travel time in congested conditions was about 40% higher than in free-flow conditions for commuters though only just significant at the 95% level, whilst no significant effect was found for the 'other' non-work trip purpose (Mackie et al, 2003, p31). This led to a recommendation for further research in this area, rather than a recommendation that values of time in congested conditions should be increased. Outside of Europe the recent New Zealand value of time study and guidelines suggest that high levels of congestion may lead to values of time savings between 1 and 1.5 times in-vehicle-time depending on the degree of congestion and whether the congestion occurs on urban or rural roads.

6.13 It should be stressed that these aggregate values for time spent in congested conditions implicitly include the values for reliability that are discussed below. Including both the value for time spent in congested conditions and the value of reliability would double count the economic impact of reliability.

Marginal Value of Reliability

6.14 One of the impacts of congestion is reliability problems. Reliability, or lack of, is considered to impose a significant cost on business travellers and commercial goods traffic (see for example SACTRA, 1999; McQuaid *et al.*, 2004). Travel time variability and large unexpected delays are two of the consequences of reliability problems. The distinction between them is that travel time variability is considered 'predictable' as it occurs from day to day, whilst it is not possible to attach a probability to the likelihood of an 'unexpected delay'. The distinction is therefore slightly blurred, as essentially they are both forms of uncertainty in travel time. In contrast to the value of travel time, the value journey time reliability is not well understood.

6.15 The main body of the literature on the value of reliability (VoR) relates it to the value of travel time (VoT) through a reliability ratio (RR). The value of reliability (VoR) can be calculated by multiplying the value of travel time by the reliability ratio (i.e. VoR = VoT x RR). The reliability ratio concept gives a relationship between one minute's standard deviation of travel time and one minute's travel time. A reliability ratio of 1 implies that a reduction of the standard deviation of travel time of 1 minute has equal value to a 1 minute travel time saving. A reliability ratio of one is recommended by the Department for Transport – though it is noted that the evidence on this matter is of variable quality (DfT, 2003). Other studies have found a quite a range in the reliability ratio, from 0.35 to 2.4 (see literature reviews of Noland and Polak, 2000; Eliasson, 2004; De Jong *et al.*, 2004a). In a workshop of international experts convened by AVV, the transport research centre of the Dutch Ministry of Transport, some consensus regarding reasonable reliability ratios for passenger transport was reached (Hamer *et al.*, 2005) (see Table 7.2). No consensus on a reliability ratio for commercial goods traffic was reached. Kouwenhoven *et al*. (2005) have since derived a reliability ratio for commercial goods traffic. This has been derived from the Dutch guidelines on the value of change in the percentage of goods that arrive on time (see Table 6.3).

Table 6.2 - Reliability ratios

Journey purpose	Mode	Reliability ratio
Commuting (passenger)	Car	0.8
Business (passenger)	Car	0.8
Other (passenger)	Car	0.8
All (passenger)	Train	1.4
All (passenger)	Bus/tram/metro	1.4
Commercial Goods Traffic	Road	1.2

Notes to table
Source: Hamer *et al*. (2005), Kouwenhoven *et al*. (2005)

6.16 Research has found that the value of unexpected large delays is typically quite high, however, with the exception of one study, Eliasson (2004), this research relates to unexpected delays experienced on public transport and not by road. Eliasson in a large Swedish study found values around 3.5 times the value of in-vehicle-time (per minute of delay) for car drivers.

6.17 For commercial goods VTTS, reliability is treated explicitly by some of the most up-to-date studies, e.g. de Jong et al (2004b), Vandaele et al (2004), Bruzelius (2001). For example, the results of de Jong et al (2004), for the Netherlands indicate that a 10% change in reliability, measured as the percentage of deliveries not on time, can be valued as shown in Table 6.3.

Table 6.3 - Values of a 10% change in reliability (de Jong et al, 2004)

Mode	Type of goods	Values in 2002 € at PPP factor prices per vehicle/train/vessel/aircraft
Road	High value raw materials	1.31
	Low value raw materials	1.01
	Final products perishable	2.67
	Final products non-perishable	2.51
	Container	2.95
	Average	1.77
Rail	All	898.00
Inland waterway	All	63.00
Sea (short or deep)	All	931.00
Air		15,400.00

Notes to table
Converted to 2002 € at PPP factor prices by Bickel *et al.* (2005, p143)
Source: de Jong *et al.* (2004)

6.18 Another common approach is to recommend a multiplier on the value of expected travel time savings, to represent reductions in delay time. Typically factors of 2.0–2.5 appear in the literature. Bruzelius (2001) put forward a specific factor, 2.0, but also suggested that further research is required in order to validate it for use. Fowkes (2001,p7), cites evidence gathered on behalf of the Highways Agency in the UK, that the ratio of the value of delay time to expected goods travel time is in the region of 2 for chemicals, paints, food, drink and groceries, and 3 for other commodities. It seems that the commercial goods VTTS is sensitive to the nature and value of the goods being transported.

6.19 At this point in time there is still uncertainty as to what the value of reliability is for both personal and freight related travel. However, there can be no doubt, given the qualitative and increasing quantitative evidence, that these values can be significant and large. Unfortunately a still more significant challenge exists once values for reliability have been identified, that of forecasting how reliability will change as a consequence of a transport policy (e.g. motorway widening). As evidenced by the UK work in this field (Ove Arup and Partners *et al.*, 2004) this is a far from trivial task. Furthermore methods have yet to be developed for peri-urban and urban areas and for complex freight distribution chains.

Marginal Economic Impact

6.20 In the last decade there has been an increasing policy interest in the productivity impacts of transport. Through transport efficiency improvements the productivity of the economy can increase. In text book economics there is an equality between the economic benefits that occur in the transport market (time savings, reliability improvements, etc.) and the economic impacts that are felt in the general economy (including productivity gains from efficiency improvements). That is the marginal economic impact of reducing congestion would be the sum of the marginal values of the different congestion related impacts (i.e. the sum of time savings, reliability benefits, etc.). Such an equality, however, relies on a number of technical economic conditions relating to perfect economic markets. The consequences of departing from these conditions are now the subject of some debate. If these conditions do not hold then for example agglomeration benefits may occur as may additional benefits in the labour and product markets. There is no direct evidence on the impact of congestion *per se* on agglomeration and other wider economic impacts. However, the fact that reduced levels of congestion imply quicker journey speeds it is possible to utilise the evidence base on the impact of journey speeds to understand the impact that congestion has on the wider economy. There is a small but growing evidence base that changes in regional density, through , increased journey speeds, can have a significant effect on regional productivity (Rosenthal and Strange, 2004; Rice and Venables, 2004; Graham, 2005). Rice and Venables estimate for the UK that the agglomeration economies from a 10% reduction in commuting time will lead to an increase of 1.12% in labour productivity. Graham estimates an average elasticity of productivity to effective employment density of 0.04, though this disguises significant variation by region and industrial sector. An elasticity of 0.04 implies that if employment density (number of people living within a certain journey time) increases by 10% productivity would increase by 0.4%.

6.21 In a review of the available evidence on the additional economic impact that imperfect markets might have on total economic impact, Laird *et al.* (2005) find a range of -15% to +147%. That is total economic impact is -15% to 147% higher than that measured using a conventional economic appraisal (i.e. travel time savings and reliability improvements). It should be noted that the upper end of the range is only associated with projects that have a very significant impact on accessibility (e.g. a new high speed rail network/line).

6.22 Table 6.4 identifies twelve studies that have considered the marginal external costs of congestion. In the main the driver for these studies has been the road pricing agenda and most of these studies report the marginal external cost of congestion in the presence of a road user charge. Because a road user charge will alter demand levels and therefore congestion the marginal external costs of congestion with a road user charge in place are not the same as without a road user charge in place. Only Samson et al. (2001) who estimates marginal external costs for roads in Great Britain (for 1998) and the DfT (2004) who updated Samson et al.'s figures to a 2000 price base and different forecast years, publish estimates of marginal external costs that relate to a situation without road user charges in place. These are re-produced in Table 6.5 and Table 6.6 respectively. Annex 2 reproduces the optimal congestion charges (i.e. MECC at optimal demand levels) calculated by a set of studies, including those in Table 6.4, reviewed by Shires (2006). As can be seen from Table 6.6 congestion forms the largest proportion of quantifiable external costs – estimated to be around 77 per cent in 2000 increasing to around 88 per cent of external costs in 2010. Accident and emissions costs account for the remainder and, unlike congestion costs, are forecast to fall over time. Figures in Table 6.6 are averages, i.e. 7.3p represents the extra cost of the 'typical' additional vehicle anywhere on the road network. Marginal external costs will vary widely across the country, with time and place, in line with congestion and other externalities. The potential environmental costs such as biodiversity and landscape were excluded in the calculations due to lack of data.

6.23 As far as it is possible to tell from the study reports that are available it appears almost all of the studies have included monetary values for environmental impacts (noise, air pollution, climate change), accidents, vehicle operating costs and travel time delays due to congestion. None of the studies appear to have included reliability impacts in their estimates nor have they included benefits or dis-benefits associated with agglomeration and imperfect markets.

6.24 As Shires (2006) identifies the different transport modelling methods used to model congestion costs can give rise to differing results in the estimates of the marginal cost of congestion. One would expect the more aggregate modelling techniques (link speed/flow and area speed/flow) to be approximations to the techniques that explicitly account for junction delays (e.g. network assignment and microsimulation). Where junction delays are important elements of congestion costs one might expect the largest divergence between these aggregate and disaggregate modelling methods. Similarly assumptions regarding behavioural responses to increased delay have a fundamental impact on the marginal cost of congestion. This is because the calculation of the marginal cost has to be calculated with the aid of a model from simulations of network user costs and different levels of demand. Shires (2006) also identifies that the marginal external costs of congestion can differ dramatically between similar sized cities and between countries, even when the same modelling methodology is applied (see for example Milne, 2002). In part this is due to the different levels of congestion in the cities, stemming from a mixture of topology, historical development of the network and economic development. These differences make it very difficult to transfer results from one city to another (e.g. Edinburgh to Glasgow) or even to disaggregate results from a higher level down to a more disaggregate spatial level (e.g. from Great Britain to Scotland).

Table 6.4 - Comparison of studies

<table>
<tr><th rowspan="2">Study</th><th colspan="4">Methodology</th><th rowspan="2">Network Size</th><th rowspan="2">Study area(s)</th></tr>
<tr><th>Link</th><th>Area speed/flow</th><th>Network assignment</th><th>Micro-simulation</th></tr>
<tr><td>Sansom et al. (2001)</td><td>X</td><td></td><td></td><td></td><td>National</td><td>Great Britain</td></tr>
<tr><td>Proost (2002)</td><td>X</td><td></td><td></td><td></td><td>National, Large cities</td><td>Belgium, Ireland, Amsterdam, Brussels, Dublin, London.</td></tr>
<tr><td>Glaister and Graham (2003)</td><td>X</td><td></td><td></td><td></td><td>National</td><td>Great Britain</td></tr>
<tr><td>Dodgson et al. (2002)</td><td>X</td><td></td><td></td><td></td><td>National</td><td>Great Britain</td></tr>
<tr><td>ECMT (2003)</td><td>X</td><td></td><td></td><td></td><td>National</td><td>Britain, France, Germany, Netherlands, Finland.</td></tr>
<tr><td>Link and Stewart-Ladewig (2006)</td><td>X</td><td></td><td></td><td></td><td>Range of inter-urban schemes</td><td>Finland inter-urban road network,
German HGV toll network, Swiss trans-alpine routes, French toll motorways, Zurich airport, Rotterdam port.</td></tr>
<tr><td>DfT (2004)</td><td colspan="2">X</td><td></td><td></td><td>National</td><td>Great Britain</td></tr>
<tr><td>Tricker et al. (2006)</td><td colspan="2">X</td><td></td><td></td><td>Large cities</td><td>Oslo, Warsaw, Edinburgh.</td></tr>
<tr><td>Santos (2004), Santos (2000), Newbery and Santos (2003)</td><td></td><td>X</td><td>X</td><td></td><td>Medium sized cities</td><td>Northampton, Hull, Cambridge, Lincoln, Norwich, York, Bedford, Hereford</td></tr>
<tr><td>May et al. (2002a, 2002b); Sumalee et al. (2005)</td><td></td><td></td><td>X</td><td></td><td>Medium and large sized cities</td><td>Edinburgh and stylised networks</td></tr>
<tr><td>Milne (2002)</td><td></td><td></td><td>X</td><td></td><td>Large cities</td><td>Edinburgh, Helsinki, Salzberg</td></tr>
<tr><td>De Palma and Marchal (2002)</td><td></td><td></td><td></td><td>X</td><td>Large city</td><td>Paris</td></tr>
</table>

Source: Shires (2006) and authors' research

Table 6.5 - Road sector marginal external costs Great Britain 1998

Cost Category	Marginal external cost (pence per vehicle km, 1998 prices and values)	
	Low	High
Infrastructure costs	0.42	0.54
Vehicle operating costs	0.87	0.87
Congestion	9.71	11.16
Mohring effect	-0.16	-0.16
Accidents	0.82	1.40
Noise	0.34	1.70
Air pollution	0.02	0.78
Climate change	0.15	0.62
VAT not paid	0.15	0.15
Total	12.32	17.05

Source: Samson et al (2001)

Table 6.6 - Estimated marginal external costs and tax paid by road users (£b)

Pence per km	Marginal external cost of congestion (a)	Environment and safety costs (b)	Fuel duty and VAT on duty (c)	Uncovered externality (a+b) – c (d)
Year 2000	7.3	2.2	5.2	4.3
2010	12.3	1.6	3.9	10.1

Source: DfT (Devereux et al, 2001)

CHAPTER SEVEN MEASURING THE TOTAL COST OF CONGESTION AND EXCESS BURDEN OF CONGESTION

7.1 Aside from the marginal external cost of congestion, there are two other methods associated with calculating the cost of congestion. The first, the Total Cost of Congestion, has developed over the course of the last half century, whilst the second, identified here as the 'Excess Burden of Congestion', is more recent and whose development has occurred as a result of the increased interest in optimal transport investment decisions and road pricing. The principal difference between the two methods is that the Total Cost of Congestion approach has as its baseline a state of zero congestion; whilst the Excess Burden of Congestion has its baseline a situation in which the optimal amount of road capacity is provided. As will be drawn out in the discussion below it is not necessarily the case that the optimal level of road capacity is associated with a state of zero congestion – primarily because there are costs associated with providing capacity.

Total cost of congestion

7.2 The underlying approach associated with the Total Cost of Congestion (TCC) method is that a visionary state of zero congestion is envisaged against which the current situation is compared. Table 7.1 summarises the estimates of the total cost of congestion and the methods employed as identified by our survey of the literature. As can be seen from this table a number of different methods have been used, though the age of some of these studies means that some of the specifics of the methods are slightly obscure.

7.3 The most frequently quoted estimate that congestion costs the economy £20 billion per year is an update of the £15 billion estimate calculated in a 1989 CBI study. The update reflects movements in prices over the intervening time period. It is however unclear as to exactly when and who undertook this update and no report has been identified. The 1989 CBI report uses data on the cost of congestion as a proportion of GDP (2.6% to 3.1%) taken from OECD analysis as its means of calculating the cost of congestion. We have not been able to trace the source of these OECD figures, though an OECD 1991 report (Bouladon, 1991 – cited in Quinet, 1994) identifies the cost of congestion as a proportion of GNP as 2.1% in France, 3.2% in the UK, 1.3% in the USA and 2% in Japan. Again the age of these studies means that it is unclear the exact methodology used to calculate the cost of congestion as a proportion of GDP or GNP.

7.4 The other studies set out in Table 7.1 use two broad methodologies. The first, adopted by Newbery (1995), Dodgson and Lane (1997) and Tweddle et al. (2003), is to use mathematical models to estimate costs in the current situation and in the uncongested situation. In all instances only link speed/flow based models are used, rather than the more sophisticated area speed/flow curve models, or network assignment models or microsimulation models (see chapter 5.3). The latter two model types can give a more accurate representation of junction delay. The final methodology adopted is one that uses actual measurements of vehicle speed to infer changes in journey time and was used by Trafficmaster (1996 and 1997) and the Scottish Executive (2005).

7.5 Whilst from the information that is available it is uncertain exactly how the OECD figures were calculated it does seem that in all the studies identified the marginal values of the different impacts of congestion (e.g. values of time) were used. For example an estimate of the time lost due to congestion was made and then this was multiplied by the marginal value of time.

7.6 As can also be seen from Table 7.1 the different studies consider different impacts of congestion. Whilst saying that in all instances the costs of increased travel time are included. However some studies also include increases in fuel costs and other forms of vehicle operating costs, whilst the Trafficmaster study (cited by Santos (1999)) also includes the cost of missed deliveries and higher maintenance costs[4]. As far as it is possible to tell no studies have included the reliability costs associated with congestion nor have they included the additional environmental or accident burdens that congestion can impose. There is significant variation between the estimates in the Total Cost of Congestion associated with the British road network. For example, the NERA study (Dodgson and Lane, 1997) estimate a figure of £7 billion whilst the Institute for Transport Studies study (Tweddle et al. 2003) estimate a figure of £15.2 billion. Both studies use similar modelling methodologies and both relate to 1996 traffic levels. Clearly small differences in modelling methods and assumptions can have a significant impact on the results. Interestingly the frequently quoted figure of £20 billion, with its suspect methodology (i.e. it is not based on estimates of traffic delay), is comparable to the costs of congestion estimated in a more rigorous manner by the Institute for Transport Studies for 1998.

7.7 The Total Cost of Congestion approach to measuring the cost of congestion is not unique to the UK. The total cost of road traffic congestion in the 15 countries of the European Union is estimated at more than 120 billion euros a year (EU, 2003) or by some estimates 0.5% of the EU GDP (SUMMA, 2004). Every year the Texas Transportation Institute in the US estimates the cost of congestion in 85 of the largest urban areas in the US (Schrank and Lomax, 2005). Their latest estimate is that in 2003 the total cost of congestion was US$61.3 billion. This estimate includes delay costs and extra fuel costs only. Actual speeds are derived from reported traffic speeds in conurbations and compared to ‘desired’ speeds. Quinet (1994) in a survey also identifies similar studies associated with Japan (Osaka conurbation and Tokyo conurbation), France (Paris conurbation), Switzerland (Berne and Zurich) and the Netherlands. All of these studies compare some estimate of actual speeds/travel times to desirable or reasonable speeds/travel times.

[4] It has not been possible to identify the methodology used to calculate the cost of missed deliveries and higher maintenance costs in the Trafficmaster reports - this is despite contacting Trafficmaster and is because Trafficmaster no longer produce the Motorway Congestion Index and there have been associated personnel changes.

Table 7.1 - Estimates of total cost of congestion in the UK and methods used

Source	Estimate	Methodology and comment
Glanville and Smeed (1958) [cited in Goodwin (2004)]	£125M per year in urban areas, £45M per year in rural areas, £170M per year total	Delay only, but no allowance for non-working time to have a value
CBI (1989) [cited in Goodwin (2004) and CBI email to authors]	£15 billion total per year for GB (£5 per week per household per year)	The authors have not been able to obtain a copy of this report. However, the CBI indicated that the estimate is based on a report produced for the OECD which estimated the cost of congestion as a share of GDP, suggesting it lay in a range from 2.6% to 3.1%.
Unknown	£20 billion per year (no date ascribed)	The CBI report that this often quoted £20 billion figure was produced "some years ago by updating the previous figure [the £15 billion CBI figure] to reflect movements in prices".
Newbery (1995) [cited in Goodwin (2004), Mumford (2000), Dodgson and Lane (1997)]	£19.1 billion per year for GB (1993 traffic levels and prices)	The authors have not been able to obtain a copy of this report. However, as reported by those who cite this study the method produces estimates of the cost of congestion for different road user types as well as a nationwide figure. The approach adopted has been criticised (e.g. by Dodgson and Lane) as providing an incorrect measure of the total cost of congestion as it "multiplies a marginal cost by a total volume".
Trafficmaster (1996) [cited in Santos (2000)] Trafficmaster (1997) [sourced from internet press release]	£2.1 billion for 4th quarter of 1996 (on motorways) £1.5 billion for 1st quarter of 1997 (on motorways)	Comparison of measured vehicle speeds in current year compared against measured vehicle speeds in the year in which the measuring devices became operational. Costs reflect wasted time, extra fuel, missed deliveries and higher maintenance costs [as reported by Santos]
Dodgson and Lane (1997)	£7 billion per year for GB (1996 traffic levels and prices)	Comparison of costs at freeflow and estimated current speeds – modelled using link based methodology. Time and vehicle operating costs (fuel and non-fuel).
Mumford (2000)	£18 billion GB total (1999 prices)	A 'mid-point' of the CBI's estimate, Newbery's estimate and Dodgson and Lane's estimate updated to 1999 prices.
Tweddle et al. (2003)	£15.2 billion GB total (1996 traffic levels, 1998 prices) £19.2 billion (1998 traffic levels, 1998 prices) £24 billion (2005 traffic levels, 1998 prices)	Based on a comparison of estimated speeds and freeflow speeds. Traffic levels for 1998 and 2005 estimated by growing 1996 traffic levels. Modelled using link based methodology. Time costs only.
Scottish Executive (2005)	£71M per year over 10 areas of Scotland's trunk road network (2003 prices and traffic levels)	Measured speed compared to measured freeflow speed. Time costs only

7.8 The Total Cost of Congestion approach, whilst being a reflection of the cost of congestion, has been criticised (e.g. Goodwin, 2004) as not being particularly useful from a policy perspective. Primarily this is because the measure appears to imply that the British economy will be, say, £20 billion better off, or in the case of the Scottish trunk roads £70 million better off, from alleviating congestion. Clearly this will not be the case as any policy associated with alleviating congestion will have a cost associated with it. Additionally any reduction in congestion will reduce the impedance of travel and result in an increase in travel demand and average trip length – which will not only increase the environmental, accident and maintenance burden but may also lead to an increase in congestion above the zero congestion level. The Total Cost of Congestion measure is also criticised for the arbitrariness of its baseline. This is because the baseline reflects speed limits. As such transport policy changes in speed limits (e.g. lowering speed limits in traffic management areas) can seemingly erase congestion, or correspondingly seemingly create congestion (e.g. raising speed limits on motorways) when in fact there has been no change in operating conditions.

The excess burden of congestion

7.9 The final approach to measuring the cost of congestion can be termed the Excess Burden of Congestion. Such an approach has an important role in the road pricing debate as it reflects the benefits associated with a reform of road prices. It is also associated with the challenge of identifying the level of transport infrastructure capacity that maximises economic output. The Excess Burden of Congestion approach differs from that associated with the Total Cost of Congestion as at efficient prices and at an optimum level of capacity (the baseline) it is highly likely that congestion will be present on the transport network.

7.10 The excess burden of congestion arises because the prices faced by road users are not optimal and therefore demand and congestion levels are also non-optimal. For example, if prices are too low then demand will exceed economically efficient levels and there will be too much congestion. Technically the excess burden of congestion is what economists term the deadweight loss. It therefore relates to a situation where capacity is fixed. Clearly if capacity is also sub-optimal then even at efficient (optimal) prices there maybe too much congestion. Once prices are efficient (i.e. reflect the full social costs of using the road) it is possible to develop simple investment rules to determine the optimal level of capacity: if the price for using the road is set above the cost of expanding capacity then this is a signal that capacity should be expanded (see for example Glaister and Graham, 2003; Dings et al, 2002). This is equivalent to the principle that the price for road use should be equivalent to short run marginal cost (i.e. a charge equal to the marginal external cost of congestion should be levied on road users) and investment decisions should be based on social cost benefit analysis (Nash, forthcoming p2; Dings et al, 2002). Clearly there is an explicit trade off between the cost of investment in additional capacity and the benefits that that extra capacity will bring. If the benefits of reducing congestion are less than the costs of providing extra capacity some congestion will be present at the optimal level of capacity even at efficient prices. That is some congestion will be present at the level of capacity and set of prices that maximise economic output.

7.11 Table 7.2 sets out some of the studies that give estimates of the Excess Burden of Congestion at UK level. There are also numerous other UK studies that have looked at this problem at a city level (e.g. academic related or government sponsored studies of London, York, Leeds, Edinburgh, Cambridge, Northampton, Hull, Lincoln, Norwich, Bedford, Hereford, Bristol, etc.) and there is also a substantial number of studies undertaken overseas. The primary difference between studies conducted at a national scale compared to those undertaken at a more local level is the nature of the modelling that underpins the study. The more tactical city wide studies typically use detailed network assignment models (e.g. Santos,

2000) whilst the more strategic national studies use the simpler link based form of modelling (e.g. Dodgson et al., 2002). Two things stand out from Table : the first is that the cost of congestion as measured by the Excess Burden of Congestion is substantial5. Whilst substantial it is however significantly less than that measured using the Total Cost of Congestion approach. The second is that, in a manner similar to the results from the Total Cost of Congestion approach, there is a substantial variation in the estimates of the cost of congestion. Such a variation cannot be explained purely by the different years the estimates relate to. The results regarding the cost of congestion under both methods can therefore be seen to be heavily dependent on the values assumed for the external costs and the methodology used to model vehicle delay.

7.12 The studies outlined above are based on estimates of 'first-best' prices. That is the prices reflect the full marginal external costs of road travel. In practice such a charging structure would result in a myriad of different prices and for implementation reasons a more simple pricing structure would be required (e.g. cordon charges as had been proposed for Edinburgh or zonal area charges as implemented in London). Such 'second-best' charges would not be expected to deliver the same level of benefit as first-best prices. Notwithstanding that it does appear that simplified charging structures if designed correctly can come close to delivering the benefits of a first best pricing scheme (see for example Shires (2006) for a discussion). There is also a substantial body of evidence that the manner that the revenue from a road taxation and pricing reform is used has strong implications for the efficiency, equity and acceptability impacts of the reform. Hypothecation of revenues to the transport sector appears to be one requirement for acceptability. A consequence of such hypothecation is that if there is a lack of good value for money transport projects, in which to invest revenue from road user charging, road prices may have to be set significantly lower than marginal external costs (to avoid generating surplus revenue). (see for example Tricker et al., 2006). The implication of these constraints on pricing reform imply that if the baseline for the Excess Burden of Congestion measure was defined to be a 'realistic' reform of transport prices rather than pure first-best prices, the cost of congestion estimates would be lower than those set out in Table .

7.13 None of the studies above have simultaneously considered transport pricing reform and investment in additional road capacity. The only study that has considered these issues simultaneously and within a rigorous framework at a national level is that undertaken by Dings et al. (2002) for the Netherlands. They demonstrate that for the Netherlands an optimal investment strategy would include a substantial investment in additional road capacity. Notwithstanding that they did find that the optimal level of capacity appeared to be lower than that set out in the Netherlands strategic plan (2010 to 2020). Their analysis also demonstrates that whilst capacity expansion does not increase welfare dramatically (once prices have been set to reflect the costs of congestion and on the environment) capacity expansion does bring about a substantial reduction in congestion (as measured by delays). Their results also demonstrate that some congestion would be present on the transport system at an optimal level of capacity.

[5] If the costs of revenue collection and enforcement had been included in the analysis the cost of congestion estimates would in fact be significantly lower. DfT (2004) estimate the cost of equipping the vehicle fleet with the necessary equipment would be £3 billion and the running costs of the pricing and enforcement scheme would be between £2 and £3 billion per year (or £5 billion per year including optimism bias).

Table 7.2 - Estimates of excess burden of congestion at the national level and methods used

Source	Estimate	Pricing reform only	Type of prices	Methodology to model delays	Impacts	Costs of revenue collection included	Revenue use
Dodgson et al. (2002)	£2 billion per year (England) (1998 prices and traffic levels)	Yes	Congestion charge additional to existing fuel and VED taxes. Congestion charge varies by area, time of day, vehicle type and link type. Reflects delay costs only.	Link speed/flow	Delay, reliability [(3)]	No	No constraint
Glaister and Graham (2003)	(a) £2.6 to £4.3 billion per year [(1)] (b) £2.9 to £3.8 billion per year [(1)](England) (2003 Prices and 2000 traffic levels)	Yes	(a) Fuel tax replaced by congestion and environmental charge that varies by area, time of day, vehicle type and link type (b) As (a) but mark-ups introduced to ensure revenue neutrality for the Exchequer	Link speed/flow	Delay, fuel, accidents, air pollution, climate change .	No	No constraint
DfT (2004)	(a) £9 to £10.2 billion per year [(2)] (b) £7.8 billion per year (Great Britain) (1998 Prices and 2010 traffic levels)	Yes	(a) Fuel tax replaced by congestion and environmental charge that varies by area, time of day, vehicle type and link type (b) As (a) but revenue neutral for the Exchequer	Link speed/flow with variable demand modelling	Delay, fuel and non-fuel vehicle operating costs, accidents, air pollution, climate change, noise.	No	No constraint
ECMT (2003)	€17 billion (=£11.7 billion [(4)]) (Great Britain) (2000 prices and traffic levels)	Yes	Fuel tax, VED, insurance tax replaced by congestion (including resource costs of parking) and environmental charge plus a charge that allows the government to recover lost VAT receipts. The charge varies by area, time of day, and vehicle type	Link speed/flow	Delay, fuel and non-fuel vehicle operating costs, accidents, air pollution and climate change.	No	No constraint

Notes to Table
1: Range depends upon assumptions associated with environmental costs (low or high)
2: Range depends on number of different charges. The larger the range of charges the greater the benefit.
3: Reliability benefits assumed = 25% of delay benefits
4: June 2006 exchange prices 1 Euro = £0.687

CHAPTER EIGHT DECOUPLING ECONOMIC GROWTH AND GROWTH IN TRANSPORT

8.1 One of the issues surrounding congestion and any measures that are taken to alleviate it is that of the relationship between economic growth and transport. It may be argued that reducing congestion and promoting economic growth are conflicting objectives – however the relationship is complex and a growing body of research has sought to provide both evidence on the relationship and propose measures to decouple transport growth and economic growth. Following the objectives set down in the EU White Paper (CEC, 2001), there has been increasing acknowledgement of the need to break this link, however, whilst decoupling was not the primary focus of the White Paper, it formed a headline objective for the EC Sustainable Development Strategy (CEC, 2001a). Despite this, it should be noted that decoupling is still not wholeheartedly embraced by all policy makers. As reported in Tight et al, 2004, whilst some parties believe it is not feasible in practice, there is a train of argument that market forces should just be left to prevail. Alternatively, those with a strong concern for the sustainability agenda believe that the continued promotion of economic growth is misguided.

8.2 The starting point for considering the need for decoupling is a strong evidence base of the links between road traffic demand, income and generalized cost. Work by Graham and Glaister, 2004 provides empirically observed elasticities that indicate that if congestion is reduced, then there will be a tendency for transport demand to increase. If incomes increase then there is also a tendency for vehicle kilometres (transport demand) to increase. A summary of the evidence in their paper is as follows. In terms of responses to changes in travel time, Car trips had a short run elasticity of -0.6, (Long run = -0.29) whilst Car veh-km short run elasticity was -0.74 (long run = -0.20). With respect to changes in income, Car veh-km had a short run elasticity of 0.3 and long run elasticity of 0.73. In the case for Scotland, work by Laird (2006) on wage rages and commuting in Scotland supports these findings. It is against this empirical evidence of the link between traffic demand, income and cost that research into the potential for decoupling has been carried out.

8.3 The concept of Transport Intensity is commonly used as an indicator of the relationship between the level of transport activity and the level of economic activity, defined as the ratio of 'gross mass movement' to GDP. In practice, this is often separated into passenger and freight intensity, using passenger kilometres and tonne kilometres respectively. The indicator may be expressed as elasticity, for example showing the ratio of percentage change in passenger kilometres to the percentage change in GDP over a period. This may be viewed alongside other related measures, such as the link between transport environmental impacts (see for example Tapio, 2005) or efficiency aspects (for example technology, organisational factors, see Bannister and Stead, 2002).

8.4 The EU White Paper agenda led to research at EU level, typically to produce historical evidence of decoupling (for example Tapio, 2005) and to propose measures that might be used to achieve decoupling (for example Tight et al, 2004). Tapio (2005) explores various definitions of decoupling using the transport intensity indicator as a basis and introducing concepts such as 'weak decoupling', 'strong decoupling' and 'recessive decoupling', depending on the direction of change and size of percentage changes. The research also extends the notion of decoupling to look at the relationship between economic growth (GDP) and road traffic emissions (CO2), with the proposition that decoupling may also take place between economic growth and the environmental impacts of traffic.

8.5 Tapio also presents quantified decoupling evidence for the EU15 countries, based on EUROSTAT and IEA statistics for 1970 to 2001. The results for road passenger growth indicate transport volumes closely followed GDP in the 1070's, exceeded GDP growth in the 1980's and grew rather slower than GDP in the 1990's. For freight a different pattern is presented – freight traffic volumes followed GDP growth in the 1970's, fell below GDP growth in the 1980's and showed a clearly higher growth than GDP in the 1990's. A more detailed individual country analysis is also reported. This is in contrast to similar analysis for the USA (Bannister and Stead, 2002), which indicate that in the US freight sector the tonne-kilometres carried have increased at a rate well below GDP, particularly, since 1985.

8.6 The general findings support the earlier work of Tight et al (2004). This also presented a short overview of evidence of decoupling in the EU15 context, but focused more on the potential for different transport measures to contribute towards breaking the link between transport activity and economic growth, through reducing travel demand, maintaining economic growth and enhancing environmental quality. In terms of the factors that may be used to explain or influence decoupling, some historical explanations for the case of Finland are given by Tapio, including the high cost of car purchase, income changes, green urban lifestyle and impacts of technology. The role of particular transport instruments formed the core element of the research by Tight et al, however, which gathered evidence on the potential effectiveness of instruments from experts across the EU and some international bodies. This was carried out using a questionnaire and panel group meetings - whilst some of the evidence collected had a subjective element, substantial parts was based on case studies, previous work and similar quantified evidence. Thirteen of the most promising measures were studied in detail, reporting their potential impact on transport intensity, environmental load, CO2 emissions and 'possible unexpected effects' – a 'reality check' with the expert panel was also included. Quantified evidence is given based upon specific country or local experience, but with an approximation to the EU-wide level (alongside acknowledgement of the difficulties in achieving realistic figures at that scale). The prevailing outcome was that packages of instruments would hold the greatest promise for decoupling, however the seven individual instruments emerging (in no order) were: urban road pricing, hydrogen fuel cell vehicles, controlled parking zones, car sharing as part of combined mobility, high speed rail, road pricing for freight traffic and combined measures relating to traveller attitudes/traffic behaviour.

8.7 According to Bannister and Stead (2002), the basic relationships between transport and economic growth are, however, far more sophisticated interdependencies. As a result, their work starts with the proposition that transport efficiency (reflected in modes, technologies, use of resources, prices and organisational structures) should be considered alongside the more traditional measure of transport intensity. In addition, they propose that the measurement of GDP should be extended in the production of indices. Illustrative analysis is presented for EU countries, giving summary indices for the EU alongside similar measures for the USA and Canada.

8.8 In discussing the basic interdependencies, the work starts from the findings of the influential SACTRA report (SACTRA, 1999), which was primarily concerned with understanding the link between transport and the UK economy, but also examined transport intensity. Bannister and Stead argue against the hypothesis that ultimately traffic intensity will decrease without intervention, as a result of the relationship between travel, car ownership and income. That hypothesis is based around traffic forecasts which are driven by growth in car ownership, not the distance travelled per vehicle. Car ownership forecasts are, in turn, driven by income levels and therefore related to GDP. The supposition is that car ownership levels will reach saturation level whilst income continues to growth and thereby intensity will decline in future. This is problematical - as SACTRA (1999) also states:

> '*the cross sectional evidence suggests that there are substantial differences in car use, which are not related to either car ownership or income'.*

8.9 As Bannister and Stead therefore propose:

> '*Income may be less important than other factors in driving the growth in travel…a clearer understanding is required for the motivations of car use apart from the costs. This could be a fruitful area of research in different national settings*'

8.10 To summarise, there is strong evidence that growth in vehicle-kilometres is a function of income and travel impedance or generalised cost as well as 'the need to travel'. Clearly transport policy that increases incomes and reduces travel impedance (e.g. reducing congestion) has to use other measures to prevent an increase in vehicle demand (e.g. road pricing can lock in the de-congestion benefits) or reducing the need to travel. Some of the measures needed to prevent the increase may be quite difficult to implement politically, such as road pricing. Despite this, evidence at EU level and internationally has suggested that decoupling of transport growth and economic growth has taken place historically, with differences seen between the passenger and freight sectors. Whilst the statistical relationship cannot give definitive evidence on causation, research has identified particular instruments which could be implemented to promote decoupling, seeking to maintain economic activity and achieve sustainability goals. These instruments are likely to have a more successful impact if implemented in packages. However, the underlying relationships are complex and further understanding of the demand for travel is needed before drawing firmer conclusions on the functional relationship with the economy.

CHAPTER NINE CONCLUSIONS

9.1 Whilst there is only a limited availability of literature on the locations of congestion in Scotland, a number of data sources exist that contain information on the impacts of congestion (delay, speed reductions and reliability problems). The information that does exist does not define congestion per se, nor does it define the point at which congestion is perceived to be a problem. On the available evidence therefore it is only possible to describe the locations where the impacts of congestion are greatest.

9.2 From the analysis of the available data a broad picture emerges. Whilst at the national level only a minority of trips (11.5%) are affected by congestion, this figure disguises large geographic, temporal and journey purpose variations. Congestion impacts are largest in the cities of Glasgow, Aberdeen and Edinburgh (where up to 42% of AM peak travellers experience congestion related delay and up to 49% of the AM peak network generates delays). The trunk road network that experiences the most congestion is that in the vicinity of these cities as well as on the approaches to the Forth estuarial crossings. The peak hours are more congested than the off-peak and commuting and business related trips are more affected by congestion than trips for 'other' trip purposes (no data is available on the impact of congestion on freight movements). Congestion is not however just confined to Aberdeen, Glasgow and Edinburgh and their vicinity, as congestion related delays are reported throughout Scotland, it is just that their frequency and incidence is higher in the large cities. Ultimately it only takes one over-capacity junction to impose a congestion related delay on travellers.

9.3 In seeking a definition of congestion in the literature, despite the past research and frequent use of the term, the state of congestion is often understood but not formally defined. Perceived congestion is an important factor alongside more objective definitions in driving the need for policy measures. Definitions vary according to two major dimensions – the traffic engineering perspective and the economic cost driven dimension which in fact relate to two major efficiency objectives i.e. system efficiency and economic efficiency. Users' perceptions are generally consistent with one or other of these dimensions. Congestion in urban areas can be distinguished from that in the interurban context as it can be recognised by the inability to exit a link within a traffic cycle. Congestion in an interurban context may be defined through speed of travel (or ultimately stopping). Both perceived and formalised concepts of congestion lend themselves to more objective measurement and indicators of congestion.

9.4 At the practical level of measuring congestion, more concrete indicators are needed. A wide number have been developed – some in the UK context but many in the USA, although literature suggests that only a small number form the basis for regular monitoring of the network. A number of common approaches exist. These are typified as travel time (or speed) based measures, volume based measures, area based measures and summary indices (or more complex model outputs). A comprehensive comparison of each of these using a single data source has not been found (and would be a topic for future research), so the relative advantages and disadvantages relate to their particular ability to reflect the objectives of measuring congestion and data requirements. In terms of use in practice however, research suggests that the simpler measures (LOS, volume/capacity ratio, delay) are more commonly applied than relatively complex measures. This is consistent with findings on users' preferences on congestion measures.

9.5 There are three economic terms that can be rightfully called the cost of congestion:

- marginal external cost of congestion
- total cost of congestion
- excess burden of congestion

9.6 The marginal external cost of congestion relates to the change in total congestion costs as a result of an extra vehicle-kilometre or trip. The total cost of congestion relates to the cost of congestion in relation to a situation with zero congestion, whilst the excess burden of congestion relates to the cost of congestion compared to a situation with optimal prices – optimal from the sense of maximising economic output. Clearly if capacity is also sub-optimal then even at efficient (optimal) prices there maybe too much congestion, therefore there may be an additional cost associated with sub-optimal capacity. Once prices are efficient (i.e. reflect the full social costs of using the road) it is possible to develop simple investment rules to determine the optimal level of capacity. The total cost of congestion measure is the easiest of the three measures to calculate but it is argued by some authors that it has the least policy relevance. Primarily this is because there is a cost associated with delivering the capacity necessary to alleviate congestion. As such the total cost of congestion measure, whilst being an economically valid measure of the cost of congestion, can never be delivered in its totality by any transport policy as a benefit. On the other hand the excess burden of congestion measure gives a cost estimate that it is possible to address using transport policy. Unfortunately it is more complicated to calculate as it requires variable demand transport models that can model the impacts of road user charging (i.e. transport models that can model the behavioural responses we would expect to occur as a result of a reform of road prices). Annex 3 contains a description of the data requirements of such models. Deriving the optimal level of capacity adds an additional degree of complexity and to this date we are aware of only one study that has attempted to do this at a national level.

9.7 The appropriate choice of measure of the costs of congestion will vary according to the end use of the data. For example, in cases where the aim is to consider road pricing measures, the marginal cost of congestion is normally calculated. To review the benefits of significant investment decisions, the total or excess burden of congestion may be calculated. The purpose of the research here has been to provide objective evidence on each based on the existing literature. The work will inform subsequent stages of research to be conducted by the Scottish Executive and at this point it is not possible to propose recommended methodologies until the nature of that programme is defined.

9.8 The methods used to measure costs of congestion can be typified as primarily static versus dynamic methods, with some approaches forming a hybrid between these. A dynamic approach iterates between supply, demand and cost whilst a static approach is based upon a 'snapshot' of the system through area-wide supply/demand curves for example. Within a dynamic approach to estimating the costs of congestion, a static or dynamic traffic network model may be utilized.

9.9 In terms of the data requirements, the calculation of all three variants of the cost of congestion require data on user impacts (some form of transport model) and estimates of the other impacts that congestion causes (e.g. pollution, accidents, etc.). Marginal costs for each of these impacts are also required (time, reliability, climate change, air pollution, noise, accidents). The evidence from empirical work in this area suggests that the results are sensitive to the transport models used and the values used for the costs of the impacts. Clearly the transport models that provide estimates of junction delay will give more robust results than those which exclude junction delay, particularly as congestion costs are most significant in urban areas. Uncertainty in the values to be ascribed to environmental impacts can also significantly affect the final estimates of the costs of congestion.

9.10 The individual nature of different geographic areas makes it difficult to transfer results from one geographic location to another, particularly in the context of urban areas. This stems from the different topologies, historic development of the network, functions of the network and economic activity in different areas. Extrapolating results from one area of the road network to other sections of the network or the whole network would therefore need to take cognisance of these sources of difference. Bespoke research would need to identify areas between which results can be transferred.

9.11 Considering the question of decoupling transport and economic growth, the starting point is the strong empirical evidence that growth in vehicle-kilometres is a function of income and travel impedance or generalised cost as well as 'the need to travel'. Clearly transport policy that increases incomes and reduces travel impedance (e.g. reducing congestion) has to use other measures to prevent an increase in vehicle demand (e.g. road pricing can lock in the de-congestion benefits) or has to reduce the need to travel. Some of the measures needed to prevent the increase may be quite difficult to implement politically, such as road pricing. Despite this, evidence at the EU level and internationally has suggested that historically the decoupling of transport growth and economic growth has taken place, with differences seen between the passenger and freight sectors. Whilst the statistical relationship cannot give definitive evidence on causation, research has identified particular instruments which could be implemented to promote decoupling, seeking to maintain economic activity and achieve sustainability goals. These instruments are likely to have a more successful impact if implemented in packages. However, the underlying relationships are complex and further understanding of the demand for travel is needed before drawing firmer conclusions on the functional relationship with the economy.

REFERENCES

Banister, D and Stead, D (2002) *Reducing Transport intensity*. EJTIR, 2, no.3/4, pp161-178

Bates, J. and Whelan, G.A. (2001) *Size and Sign of Time Savings.* Working Paper 561. Institute for Transport Studies, University of Leeds, Leeds, UK.

Bickel, P., Burgess, A., Hunt, A., Laird, J., Lieb, C., Lindberg, G., Odgaard, T. (2005) *State-of-the-art in project assessment*. HEATCO (Developing Harmonised European Approaches for Transport Costing and Project Assessment) Deliverable 2. Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart. [website] http://heatco.ier.uni-stuttgart.de/ [file] hd2final.pdf

Bickel, P., Hunt, A., Laird, J., Lieb, C., Lindberg, G., Odgaard, T., Jong, de G., Mackie, P., Navrud, S., Shires, J. and Tavasszy, L. (2006) *Proposal for Harmonised Guidelines*. HEATCO (Developing Harmonised European Approaches for Transport Costing and Project Assessment) Deliverable 5. Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart. [website] http://heatco.ier.uni-stuttgart.de/ [file] hd2final.pdf

Bouladon, G. *La Mobilité en Zone Urbaine: Apprendre l'Economie de Transport*, Document diffusion restreinte, Direction de l'Environnement, OECD – European Conference of Ministers of Transport (ECMT), Paris, 1991. Cited in Quinet (1994).

Bruzelius, N. (2001), *The Valuation of Logistics Improvements in CBA of Transport Investments: A Survey*. Report to the SAMGODS group, Swedish Institute for Transport and Communications Analysis (SIKA).

Button, K. (1993) *Transport Economics*. 2nd Edition, Edward Elgar, Aldershot.

CBI (1989) *Trade Routes to the Future*. London: Confederation of British Industry. Cited in Goodwin (2004).

CEC (2001) *European transport Policy for 2020: time to decide*. Com (2001) 370, Office for Official publications of European Communitites, Luxembourg

CEC (2001a) *Renewed Sustainable Development Strategy*. European Council DOC 10117/06

Department for Transport (2000) *Tackling Congestion and pollution: the Government's first report*. http://www.dft.gov.uk

Department for Transport (2000b). *A measure of Road Traffic congestion in England* http://www.dft.gov.uk

Department for Transport and Hedges, A (2001) *Perceptions of Congestion: report on qualitative research findings*. http://www.dft.gov.uk

Department for Transport, Hills, P, Schmoecker, J-D, May, T, Liu, R, Shepherd, S, Bates, J and Paulley, N (2001b) *Analysis of congested networks*. http://www.dft.gov.uk

Department for Transport (2001c) *NTM Appendix 1 Description of other European National Transport Models*. http://www.dft.gov.uk

Department for Transport (2003) *The reliability sub-objective. TAG Unit 3.5.7.* WebTAG guidance note. Department for Transport, London. http://www.webtag.org.uk/webdocuments/3_Expert/5_Economy_Objective/3.5.7.htm

Department for Transport, Brownfield, J, Graham A, Eveleigh H, Ward H, Robertson S, Allsop R (2003b) *Congestion and accident risk.* Road Safety Research Report No. 44, DfT. http://www.dft.gov.uk

Department for Transport (2003c) *The National transport model - detailed overview*. http://www.dft.gov.uk

Department for Transport (2004) *Feasibility Study of Road Pricing in the UK*. Department for Transport, London.

Department for Transport (2005) *Attitudes to congestion on motorways and other roads.* http://www.dft.gov.uk

Department for Transport (2005b) *FORGE The road capacity and costs model.* http://www.dft.gov.uk

Department for Transport (2005c) *Values of Time and Operating Costs. TAG Unit 3.5.6.* WebTAG guidance note. Department for Transport, London. http://www.webtag.org.uk/webdocuments/3_Expert/5_Economy_Objective/3.5.6.htm

De Jong, G. Kroes, E., Plasmeijer, R. Sanders, P. and Warffemuis, P. (2004a) 'The value of reliability', *Proceedings of the European Transport Conference, 2004.*

De Jong, G., Bakker, S., Pieters, M. and Wortelboer-van-Donselaar, P. (2004b), 'New Values of Time and Reliability in Freight Transport in the Netherlands', *Proceedings of the European Transport Conference, 2004.*

de Palma, A. and Marchal, F. (2002), 'Real cases Applications of the fully Dynamic METROPOLIS Tool-box: an Advocacy for Global Large-scale Mesoscopic Transportation Systems', *Networks and Spatial Economics* 2(4) pp347-369

Dijker, T, Piet H.L, Bovy R and Vermijs, G.M.M (1998) *Car following under non-congested and Congested conditions.* Tran. Res. Record, Vol 1644, pp20-28.

Dings, J.T.W., Leurs, B.A., Hof, A.F., Bakker, D.M., Mijjer, P.H. and Verheof, E.T. (2002) *Returns on Roads: Optimising Road Investments and Use with the User Pays Principle*. CE, Delft.

Dodgson, J. and Lane, B. (1997) *The Costs of Road Congestion in Great Britain: A NERA Briefing Paper*. National Economic Research Associates (NERA), London. http://www.nera.com/publication.asp?p_ID=752

Dodgson, J., Young, J. and J. van der Veer (2002), *Paying for Road Use,* Technical

Report, A report to the Commission for Integrated Transport, National Economic Research Associates (NERA), London, February. http://www.cfit.gov.uk/docs/2002/pfru/research/pdf/pfru-tech.pdf

ECMT (2003) *Reforming transport taxes and charges*. OECD Publications Service, Paris, France.

EU (2003) *Information Society Technologies for Transport and Mobility* Achievements and Ongoing Projects from the Fifth Framework Programme. http://cordis.europa.eu

Eliasson, J. (2004) 'Car drivers' valuations of travel time variability, unexpected delays and queue driving', *Proceedings of the European Transport Conference, 2004.*

Fowkes, A.S. (2001) *Value of Time for Road Commercial Vehicles*. ITS Working Paper 563, Institute for Transport Studies, University of Leeds, UK.

Glaister, S. (1981) *Fundamentals of Transport Economics*. Basil Blackwell, Oxford.

Glaister, S. and Graham, D. (2003) *Transport Pricing and Investment in England – Summary Report*. Department of Civil Engineering, Imperial College, London.

Glanville, W.H. and Smeed, R.J. (1958) 'The basic requirements for the roads of Great Britain', *Proceedings of Conference on the Highway Needs of Great Britain*, 1957. London: Institution of Civil Engineers. Cited in Goodwin (2004).

Goodwin, P.B. (2004) *The Economic Costs of Road Traffic Congestion*. Discussion paper. Rail Freight Group, Transport Studies Unit, University College London. http://eprints.ucl.ac.uk/archive/00001259/

Graham, D.J. (2005) *Wider economic benefits of transport improvements: link between city size and productivity*, A report to the Department for Transport. DfT, London.

Graham, D.J. and Glaister, S (2004) *Road traffic demand elasticity estimates - a review*. Transport Reviews, Vol. 24, No. 3, 261–274

Grant-Muller, S (2005) *Assessment Methodology report*. Project deliverable- Report 203754_MM_003

Hamer, R., Jong, G. De, Kroes, E.P. (2005) *The value of reliability in Transport – Provisional values for the Netherlands based on expert opinion*. RAND Technical Report Series, TR-240-AVV, Netherlands.

Highways Agency, Scottish Office development department, The Welsh Office, The department of the Environment for Northern Ireland (1997) *Design manual for Roads and Bridges, Traffic Flow Ranges for Use in the Assessment of New Rural Roads*. DMRB, Vol 5, Section1, Part 3. http://www.highways.gov.uk/

Hills, P J and Gray, P (2000) *Characterisation of congestion on an urban road network subject to road-use pricing - a fundamental review*. Presented to IATBR 2000 conference at Gold Coast, Queensland, Australia

Kocak, N. (2005) *TMfS Congestion maps* [Website]. MVA Ltd, Edinburgh http://www.TMfS.org.uk

Kouwenhoven, M., Jong, G.C. de and Rietveld, P. (2005a) *Reliability Ratio's voor het Goerderenveroer*. Final report to AVV. RAND Technical Report Series, WR-274-AVV, Netherlands.

Laird, J.J., Nellthorp, J. and Mackie, P.J. (2005) Network effects and total economic impact in transport appraisal. *Transport Policy* 12, pp537–544.

Laird, J.J. (2006) *Commuting costs and their impacts on wage rates*. Whitehall Placement scheme final report, ITS

Link, H., Dodgson, J., Maibach, M. and Herry, M. (1999) *The Costs of Road Infrastructure and Congestion in Europe*. Springer Verlag.

Link, H. and Stewart-Ladewig, L. (2006) *Report on the implementation of interurban case studies*, REVENUE Project Deliverable 4, Funded by 5th Framework RTD Programme, ISIS, Rome.

Lumsden, K. (2005) 'Transport Model For Scotland'. Paper presented at the *Scottish Transport Applications conference*, 25th April 2005 Glasgow Royal Concert Hall.

Mackie, P.J., Wardman, M., Fowkes, A.S., Whelan, G.A., Nellthorp, J. and Bates, J. (2003) *Value of Travel Time Savings in the UK*. A report to the Department for Transport. Institute for Transport Studies, University of Leeds, UK.

May, A.D., Liu, R., Shepherd, S.P. and Sumalee, A. (2002a) The impact of cordon design on the performance of road pricing schemes. *Transport Policy* (9) pp209-220.

May A.D, Milne D.S., Shepherd S.P, Sumalee A (2002b),Specification of Optimal Cordon Pricing Locations and Charges, *Transportation Research Record*, No. 1812, p60-68

McQuaid, R.W., Greig, M. Smyth, A. and Cooper, J. (2004) *The Importance of Transport in Business' Location Decisions*. Report to the DfT. DfT, London.

Milne D (2002) *Case Studies 7F - Urban Congestion Costs* UNITE (UNIfication of accounts and marginal costs for Transport Efficiency) Working Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, June 2002.

Mohring, H. (1976) *Transportation Economics*. Cambridge, Mass: Ballinger.

MORI Scotland, TNS Social Research and Scottish Executive, *Scottish Household Survey, 2003-2004* [computer file]. 3rd Edition. Colchester, Essex: UK Data Archive [distributor], December 2005. SN: 5020

Mumford, P. (2000) *The Road from Inequity, Fairer Ways of Paying the True Costs of Road Transport*. London: Adam Smith Research Institute. http://www.adamsmith.org/policy/publications/pdf-files/road-from-inequity.pdf

Nash (forthcoming) Transport Pricing a European perspective. ITS. University of Leeds

Newbery, D. (1988) 'Road User Charges in Britain'. *Economic Journal*, 98.

Newbery, D.M. (1995) *Reforming Road Taxation* The Automobile Association, Basingstoke. Cited in Goodwin (2004).

Newbery, D. and Santos, G. (2003), 'Area Speed-Flow Relationships and Urban Congestion Costs', presented at the *International Symposium on the Theory and Practice of Congestion Charging*, Imperial College London, August 18-20.

Noland, R.B. and Polak, J.W. (2002) 'Travel time variability: a review of theoretical and empirical issues' *Transport Reviews* 22(1) pp39-54

Ove Arup and Partners Ltd, Bates, J., Black, I. and Fearnon, J. (2003) *Frameworks for modelling the variability of highway journey times.* Report to the Department for Transport, UK.

Proost S., Van Dender K., De Borger B. et. al. (2002), How large is the gap between present and efficient transport prices in Europe?, in De Borger B., Proost S., eds., (2002), Reforming Transport Pricing in The European Union: A Modeling approach, EdwardElgar, 389-412

Quinet, E. (1994) 'The Social Costs of Transport: Evaluation and Links with Internalisation Policies'. In *Internalising the Social Costs of Transport*, Chapter 2, OECD - European Conference of Ministers of Transport (ECMT), Paris, 1994, pp. 31-75.

Rice, P. and Venables, AJ (2004). Spatial Determinants of Productivity: Analysis for the Regions of Great Britain. *Centre for Economic Performance Paper, 0642.* London School of Economics, London.

Robinson, C. (2006) *Delay per vehicle-kilometre in the TMfS* [Computer file]. MVA Ltd, Edinburgh.

Rosenthal, S.S. and Strange, W.C. (2004) Evidence on the nature and sources of agglomeration economies. In Henderson, J.V. and Thisse, J.F. (eds) (2004) *Handbook on Urban and Regional Economics Volume 4 Cities and Geography*. Elsevier, Oxford.

Sansom, T, Nash, C.A., Mackie, P. Shires, J.D. and Watkiss, P. (2001) *Surface Transport Costs and Charges: Great Britain 1998*. Report for DETR.

Santos, G. (2000) 'Road Pricing on the basis of Congestion Costs: Consistent Results from Two Historic UK Towns'. *Proceedings of 79th TRB Annual Meeting, Transportation Research Record, 1732*: pp25-31

Santos, G. (2004) 'Urban Congestion Charging: A Second Best Alternative'. *Journal of Transport Economics and Policy*, Vol 38, Part 3, pp.345-369.

Schrank, D. and Lomax, T. (2005) *The 2005 Urban Mobility Report*, Texas Transportation Institute, The Texas A&M University System, http://mobility.tamu.edu

Scottish Executive (2005) *Congestion on Scottish Trunk Roads 2003*. Scottish Executive, Edinburgh. http://www.scotland.gov.uk/library5/transport/congestion-00.asp

Scottish Executive (2006) *Scotland's National Transport Strategy: A Consultation*. Scottish Executive, Edinburgh. http://www.scotland.gov.uk/Publications/2006/04/20084756/0

Scottish Office (1998) *Strategic Review of the Trunk Road programme in Scotland*. The stationary office. http://www.scotland.gov.uk/library/documents

Shires, J. (2006) *Road congestion review*. Discussion note for GRACE project. Institute for Transport Studies, University of Leeds, Leeds.

Standing Advisory Committee on Trunk Road Assessment (SACTRA) (1999) *Transport and the Economy*, London: The Stationery Office.

Stateside Planning Scenario Synthesis. *Transportation congestion measurement and management*. Kentuky Transportation Centre, research report KTC-05-32/SPR303-05-iF

Steer Davies Gleave (2004) *Effects of road congestion on rail demand: technical report*. A report to PDFC.

Sumalee, A., May, A.D. and Shepherd, S.P. (2005). Comparison of judgmental and optimal road pricing cordons. *Transport Policy*, Volume 12, Issue 5 September 2005, pp384-390.

SUMMA (2004) *Sustainable Mobility, policy Measures and Assessment..* http://www.summa-eu.org/

Tapio, P (2005) *Towards a theory of decoupling: degrees of decoupling in the EU and the case of road traffic Finland between 1970 and 2001*. Transport Policy 12, pp137-151

Tight, M, Delle Site, P and Meyer-Ruhle (2004) *Decoupling Transport from Economic Growth: Towards Transport Sustainability in Europe*. EJTIR, 4, no.4, pp381-404

Trafficmaster (1996) *Motorway Congestion Index*. Trafficmaster Ltd, Cranfield, Bedfordshire.

Trafficmaster (1997) *Motorway Congestion Index*. Trafficmaster Ltd, Cranfield, Bedfordshire.

Tricker, R., Fereday, D., Pickup, L., Norheim, B., Bekken, J-T., Shepherd, S.P. , Laird, J.J., Nash, C.A. and Suchorzewski, W. *Report on the implementation of urban case studies*, REVENUE Project Deliverable 5, Funded by 5th Framework RTD Programme, ISIS, Rome, 16th January 2006.

Tweddle, G., Nellthorp, J., Sansom, T., Link, H., Stewart, L. and Bickel, P. (2003), "*Pilot Accounts - Results for the United Kingdom*", Annex 7 to "Deliverable D8 Pilot Accounts - Results for Tranche B Countries", UNITE Project (UNIfication of accounts and marginal costs for Transport Efficiency) Funded by the European Commission 5th Framework RTD Programme. ITS, University of Leeds.

Vandaele, E., Witlox, F. and Verleye, G. (2004), ‘The Use of Correlation Analysis to Explain the Monetary Value of Quality Attributes of Transportation’, *Proceedings of the European Transport Conference, 2004.*

Walters, A. (1961) ‘The Theory and Measurement of Private and Social Cost of Highway Congestion’. *Econometica,* 29, 676-99.

Wang W, Chen, H. and Bell, M.C (2005) *A Review of Traffic Incident Duration Analysis*. Journal of Transportation Systems Engineering and Information Technology 5, pp.127-140

Wardman, M. (2001) ‘A review of British evidence on time and service quality valuations’. *Transportation Research Part E* 37 pp 107-128.

Whelan, G.A. and Bates, J. (2001) *Values of Time by Market Segment.* Working Paper 565. Institute for Transport Studies, University of Leeds, Leeds, UK.

GLOSSARY OF ABBREVIATIONS AND ACRONYMS

AFFORD	Acceptability of fiscal and financial measures and organizational requirements for demand management
ANPR	Automated number plate recognition
ATM	Active traffic management
CBI	Confederation of British industry
CfIT	Commission for integrated transport
CO2	Carbon dioxide
COSMOS	Congestion management Strategies and methods in urban Sites
CRF	Congestion reference flow
CUPID	Co-ordinating urban pricing integrated demonstrations
DESIRE	Designs for interurban road pricing schemes in Europe
DfT	Department for transport
DIFFERENT	User reaction and efficient differentiation of charges and tolls
DRIVE	Community programme (EEC) in the field of road transport informatics and telecommunications
EU15	Countries in the EU before the accession of the new member states in 2004
FORGE	Fitting on of regional growth and elasticities model
GDP	Gross domestic product
GRACE	Generalisation of research on accounts and cost estimation
HEATCO	Developing harmonised European approaches for transport costing and project assessment
LOS	Level of service
LTS	Local transport strategy
MC-ICAM	Implementation of marginal cost pricing in transport – Integrated conceptual and applied model analysis
MECC	Marginal external cost of congestion
mph	Miles per hour
PETS	Pricing European transport systems
PROGRESS	Pricing regimes for integrated sustainable mobility
QUITS	Design and testing of an integrated methodology for the valuation of the quality of transport and systems and services in Europe
RECONNECT	Reducing cot Transport

RECORDIT	Real cost reduction of door-to-door intermodal Transport
REVENUE	Use of revenues from transport pricing
RR	Reliability ratio
RTP	Regional transport partnerships
RTRA	Road traffic reduction act
SACTRA	Standing advisory committee on trunk road assessment
SATURN	Simulation and assignment of traffic to urban road networks
SHS	Scottish household survey
SPECTRUM	Study of policies regarding economic instruments complementing transport regulation and the undertaking of physical measures
STAG	Scottish transport appraisal guidance
SUMMA	Conditions for sustainable mobility and transport
TCC	Total cost of congestion
TMfS	Transport model for Scotland
TRAM/DELTA	Traffic restraint analysis model/Development, transition, location, employment and air quality model
TRENEN	Models for the study of transport energy and environment policies
TWMV	Two wheeled motor vehicle
UNITE	Unification of accounts and marginal costs for transport efficiency
Veh-Km	Vehicle kilometre
Vehs	Vehicles
VOR	Value of reliability
VOT	Value of time
VTTS	Value of travel time savings

ANNEXE 1 SCOTTISH HOUSEHOLD SURVEY ANALYSIS (2003-04)

Table 0.1 - Journey purpose proportions

	Weighted Frequency	Percent
Travel during work	1,756	6.6%
Commuting	7,305	27.6%
Other non-work	17,393	65.7%
Total	26,454	100%

Table 0.2 - Proportion of trips delayed due to traffic congestion

	Weighted Frequency	Percent
Yes	3,037	11.5%
No	23,416	88.5%
Total	26,454	100%

Table 0.3 - Proportion of trips delayed by congestion by journey purpose

	Whether part of car/van trip delayed due to traffic congestion	
	Yes	No
Travel during work	17.0%	83.0%
Commuting	18.0%	82.0%
Other non-work	8.2%	91.8%
Total	11.5%	88.5%

Table 0.4 - Proportion of trips delayed by congestion by RTP (all trips)

ALL TRIPS

Regional Transport Partnership of trip destination	Whether part of car/van trip delayed due to traffic congestion	
	Yes	No
West of Scotland	13.5%	86.5%
North East Scotland	12.9%	87.1%
South East Scotland	12.4%	87.6%
Central and Tay	8.3%	91.7%
South West Scotland	7.1%	92.9%
Highlands and Islands of Scotland	5.6%	94.4%
Shetland	1.8%	98.2%
Total	11.5%	88.5%

Table 0.5 - Proportion of trips delayed by congestion by RTP (peak hour trips only)

PEAK HOUR TRIPS ONLY

Regional Transport Partnership of trip destination	Whether part of car/van trip delayed due to traffic congestion	
	Yes	No
North East Scotland	31.7%	68.3%
West of Scotland	28.1%	71.9%
South East Scotland	27.2%	72.8%
Central and Tay	19.4%	80.6%
Highlands and Islands of Scotland	13.2%	86.8%
South West Scotland	9.4%	90.6%
Shetland	2.9%	97.1%
Total	25.3%	74.7%

Notes to table
A peak hour trips is defined as one that either begins or ends during the morning peak (8am to 9am) or the evening peak (5pm to 6pm).

Table 0.6 - Proportion of trips delayed by congestion by RTP (off-peak trips only)

OFF-PEAK TRIPS ONLY

Regional Transport Partnership of trip destination	Whether part of car/van trip delayed due to traffic congestion	
	Yes	No
West of Scotland	9.9%	90.1%
South East Scotland	8.7%	91.3%
North East Scotland	8.4%	91.6%
South West Scotland	6.7%	93.3%
Central and Tay	5.5%	94.5%
Highlands and Islands of Scotland	4.0%	96.0%
Shetland	1.5%	98.5%
	8.2%	91.8%

Notes to table
A peak hour trips is defined as one that either begins or ends during the morning peak (8am to 9am) or the evening peak (5pm to 6pm).

Table 0.7 - Proportion of trips delayed by congestion by Local Authority (all trips)

ALL TRIPS

Council area of destination	Whether part of car/van trip delayed due to traffic congestion	
	Yes	No
Aberdeen City	19.4%	80.6%
Glasgow City	17.2%	82.8%
Edinburgh, City of	17.1%	82.9%
South Ayrshire	15.7%	84.3%
Inverclyde	14.8%	85.2%
Falkirk	14.6%	85.4%
Midlothian	13.6%	86.4%
West Dunbartonshire	13.3%	86.7%
East Dunbartonshire	12.9%	87.1%
North Lanarkshire	12.3%	87.7%
East Renfrewshire	11.9%	88.1%
South Lanarkshire	11.7%	88.3%
Dundee City	11.6%	88.4%
West Lothian	11.6%	88.4%
East Lothian	11.5%	88.5%
Renfrewshire	11.5%	88.5%
North Ayrshire	10.8%	89.2%
East Ayrshire	10.1%	89.9%
Stirling	8.5%	91.5%
Clackmannanshire	8.4%	91.6%
Moray	8.1%	91.9%
Fife	7.9%	92.1%
Dumfries & Galloway	7.1%	92.9%
Perth & Kinross	6.9%	93.1%
Angus	6.6%	93.4%
Scottish Borders	6.4%	93.6%
Highland	6.0%	94.0%
Aberdeenshire	5.6%	94.4%
Argyll & Bute	4.1%	95.9%
Orkney Islands	2.7%	97.3%
Eilean Siar	2.6%	97.4%
Shetland Islands	1.8%	98.2%
Total	11.5%	88.5%

Table 0.8 - Proportion of trips delayed by congestion by Local Authority (peak hour trips only)

PEAK HOUR TRIPS ONLY

Council area of destination	Whether part of car/van trip delayed due to traffic congestion	
	Yes	No
Aberdeen City	42.2%	57.8%
Edinburgh, City of	38.3%	61.7%
East Renfrewshire	33.3%	66.7%
Glasgow City	33.2%	66.8%
Midlothian	32.7%	67.3%
Falkirk	31.1%	68.9%
Renfrewshire	30.9%	69.1%
North Lanarkshire	29.1%	70.9%
East Lothian	28.4%	71.6%
South Lanarkshire	28.0%	72.0%
South Ayrshire	27.3%	72.7%
Dundee City	27.1%	72.9%
Inverclyde	25.0%	75.0%
East Dunbartonshire	24.8%	75.2%
Clackmannanshire	24.4%	75.6%
West Lothian	23.1%	76.9%
East Ayrshire	20.0%	80.0%
West Dunbartonshire	19.4%	80.6%
Fife	17.8%	82.2%
Angus	17.2%	82.8%
Aberdeenshire	16.9%	83.1%
Moray	16.7%	83.3%
Perth & Kinross	16.7%	83.3%
Stirling	16.4%	83.6%
Highland	15.4%	84.6%
North Ayrshire	15.3%	84.7%
Scottish Borders	12.5%	87.5%
Eilean Siar	10.7%	89.3%
Dumfries & Galloway	9.4%	90.6%
Argyll & Bute	8.3%	91.7%
Shetland Islands	2.9%	97.1%
Orkney Islands	0.0%	100.0%
Total	25.4%	74.6%

Table 0.9 - Average congestion delay

	All trips	Only trips experiencing delay
Delay (mins)	1.3	11.0

Table 0.10 - Reported congestion related delay per trip by RTP

Regional Transport Partnership of trip destination	Reported congestion related delay (mins)	
	Averaged over all trips	Averaged over only those trips experiencing delay
West of Scotland	1.37	10.6
North East Scotland	1.36	11.0
South East Scotland	1.25	10.3
Central and Tay	0.70	8.6
South West Scotland	0.53	7.7
Highlands and Islands of Scotland	0.45	8.5
Shetland	0.08	5.1
Scotland	1.1	10.3

Notes to table
Excludes trips where exclusion of reported delay from reported journey time would result in negative freeflow journey time or a freeflow journey time that would require an average speed of greater than 130 kph (80 mph)

Table 0.11 - Reported congestion related delay per trip by LA

Local Authority of trip destination	Reported congestion related delay (mins)	
	Averaged over all trips	Averaged over only those trips experiencing delay
Glasgow City	2.0	12.1
Aberdeen City	2.0	10.6
Edinburgh, City of	1.8	10.7
Midlothian	1.4	10.4
South Ayrshire	1.4	8.6
North Lanarkshire	1.3	11.6
Renfrewshire	1.3	11.2
Falkirk	1.3	8.7
East Dunbartonshire	1.2	10.2
West Lothian	1.2	10.8
East Renfrewshire	1.2	10.7
Inverclyde	1.2	8.5
South Lanarkshire	1.1	10.2
East Lothian	1.1	9.6
West Dunbartonshire	1.1	8.6
Clackmannanshire	0.9	11.6
Stirling	0.9	10.5
Dundee City	0.9	7.5
North Ayrshire	0.8	7.7
Fife	0.8	10.2
East Ayrshire	0.7	7.5
Scottish Borders	0.7	11.2
Aberdeenshire	0.7	12.5
Moray	0.6	7.7
Angus	0.6	8.3
Perth & Kinross	0.5	8.2
Dumfries & Galloway	0.5	7.7
Highland	0.5	8.1
Argyll & Bute	0.4	12.2
Eilean Siar	0.2	7.4
Orkney Islands	0.2	7.5
Shetland Islands	0.1	5.1
Scotland	1.1	10.3

Notes to table
Excludes trips where exclusion of reported delay from reported journey time would result in negative freeflow journey time or a freeflow journey time that would require an average speed of greater than 130 kph (80 mph)

ANNEXE 2 MARGINAL COST OF CONGESTION - VALUES

Table B.1 - Comparison of studies – values

Study	Values Measured	Values in 2003 Prices Pence
Sansom et al. (2001)	*Value Measured – Short run MEC: values without brackets are the low estimates & figures in brackets are high estimates.* *Central London:* Motorways: 53.75 Trunk & Principal: 71.09 Other: 187.79 *Inner London:* Motorways: 20.10 Trunk & Principal: 54.13 Other: 94.48 *Outer London:* Motorways: 31.09 Trunk & Principal: 28.03 Other: 39.66 *Inner Conurbation::* Motorways: 53.90 Trunk & Principal: 33.97 Other: 60.25 *Outer Conurbation:* Motorways: 35.23 Trunk & Principal: 12.28 Other: 0.00 *Urban>25 km2* Trunk & Principal:10.13 Other: 0.72 *Urban 15-25 km2* Trunk & Principal: 7.01 Other: 0.00 *Urban 10-15 km2* Trunk & Principal: 0.00 Other: 0.00 *Urban 5-10 km2* Trunk & Principal:2.94 Other: 0.00 *Urban 0.01-5 km2* Trunk & Principal: 1.37 Other: 0.00 *Rural:* Motorway: 4.01 Trunk & Principal: 8.84 Other: 1.28 *Unit – Per Car Unit Km (1998 prices & values – pence)*	*Value Measured – Short run MEC: values without brackets are the low estimates & figures in brackets are high estimates.* *Central London:* Motorways: 57.08 Trunk & Principal: 75.49 Other: 199.41 *Inner London:* Motorways: 21.34 Trunk & Principal: 57.48 Other: 100.33 *Outer London:* Motorways: 33.01 Trunk & Principal: 29.77 Other: 42.11 *Inner Conurbation::* Motorways: 57.24 Trunk & Principal: 36.07 Other: 63.98 *Outer Conurbation:* Motorways: 37.41 Trunk & Principal: 13.04 Other: 0.00 *Urban>25 km2* Trunk & Principal: 10.76 Other: 0.76 *Urban 15-25 km2* Trunk & Principal: 7.44 Other: 0.00 *Urban 10-15 km2* Trunk & Principal: 0.00 Other: 0.00 *Urban 5-10 km2* Trunk & Principal:3.12 Other: 0.00 *Urban 0.01-5 km2* Trunk & Principal: 1.45 Other: 0.00 *Rural:* Motorway: 4.26 Trunk & Principal: 9.00 Other: 1.36 *Unit – Per Car Unit Km*

Notes to table
Source: Shires (2006)

Table B.1 - Comparison of studies – values (Contd)

Study	Values Measured	Values in 2003 Prices and Values – Pence
Newberry & Santos (2003)	*Values Measured – MEC. 1st figures calculated from Area Wide Speed-flow Curves; Figures in brackets calculated using Saturn.* Northampton: 495 *(315)* Kingston Upon Hull: 209 *(166)* Cambridge: 80 *(71)* Norwich: 16 *(14)* Lincoln: 78 *(67)* York: 60 *(44)* Bedford: 12 *(11)* Hereford: 72 *(57)* *Unit-Per Car Unit Km (1998 prices & values-pence)*	*Values Measured – MEC. 1st figures calculated from Area Wide Speed-flow Curves; Figures in brackets calculated using Saturn.* Northampton: 525.64 *(334.50)* Kingston Upon Hull: 221.94 *(176.28)* Cambridge: 84.95 *(75.39)* Norwich: 16.99 *(14.87)* Lincoln: 82.83 *(71.15)* York: 63.71 *(46.72)* Bedford: 12.74 *(11.68)* Hereford: 76.46 *(60.53)* *Unit-Per Car Unit Km*
Milne (2002)	*Values Measured – MEC* Helsinki: 0.26 Edinburgh: 0.65 Salzburg: 0.92 *Unit-Per Car Unit Km (1998 Prices & values-pence)*	*Values Measured – MEC* Helsinki: 0.28 Edinburgh: 0.69 Salzburg: 0.98 *Unit-Per Car Unit Km*
May et al. (2002)	*Values Measured – MEC. 1st best pricing based on Saturn.* Top 10 links with uniform charges: 0.80 Top 10 links with two levels of charges: 0.50 & 2.00 *Unit-Per Car Unit/ Trip (2000 Prices- £s)* *Values Measured - Judgemental Cordons.* Inner 1 – 0.50 Inner 2 – 0.75 Outer 1 – 2.25 Outer 2 – 0.75 *Unit-Per Car Unit/ Trip (2000 prices & values- £s)*	*Values Measured – MEC. 1st best pricing based on Saturn.* Top 10 links with uniform charges: 83 *(7.9)* Top 10 links with two levels of charges: 52 & 208 *(5.0 &19.8)* *Unit-Per Car Unit/ Trip* *Values Measured - Judgemental Cordons.* Inner 1 – 52 *(5.0)* Inner 2 – 78 *(7.4)* Outer 1 – 234 *(22.3)* Outer 2 – 78 *(7.4)* *Unit-Per Car Unit/ Trip (Unit-Per Car Km)*

Notes to table
Source: Shires (2006)

Table B.1 - Comparison of studies – values (Contd)

Study	Values Measured	Values in 2003 Prices Pence
Santos (2004)	*Value Measured – MEC based on an optimal toll that maximises social surplus: defined as total utilities of all trips minus sum of total costs of all trips.* Northampton: 3.47 Kingston upon Hull: 3.73 Cambridge: 1.60 Lincoln: 1.07 Norwich: 0.80 York: 1.60 Bedford: 1.60 Hereford:1.60 *Unit – Optimal Toll Per Car Unit/Trip (2002 prices & values- £) for a single cordon scheme.* Northampton: 2.40 & 2.40 Kingston upon Hull: 3.20 & 0.53 Cambridge: 0.80 & 2.67 Lincoln: 0.80 & 1.07 Norwich: 0.80 & 0.80 York: 1.07 & 1.33 Bedford: 2.7 & 2.40 Hereford:1.07 & 1.07 *Unit – Per Car Unit/Trip (2002 prices & values- £) for a double optimal toll*	*Value Measured – MEC based on an optimal toll that maximises social surplus: defined as total utilities of all trips minus sum of total costs of all trips.* Northampton: 352 *(33.5)* Kingston upon Hull: 378 *(36.0)* Cambridge: 162 *(15.4)* Lincoln: 108 *(10.3)* Norwich:81 *(7.7)* York: 162 *(15.4)* Bedford: 162 *(15.4)* Hereford: 162 *(15.4)* *Unit – Optimal Toll Per Car Unit/Trip (Per Car Unit Km)* Northampton: 243 & 243 *(23.1 & 23.1)* Kingston upon Hull: 324 & 54 *(30.9 &5.1)* Cambridge: 81 & 271 *(7.7 & 25.8)* Lincoln: 81 & 108 *(7.7 & 10.3)* Norwich: 81 & 81 *(7.7 & 7.7)* York: 108 & 135 *(10.3 & 12.9)* Bedford: 274 & 243 *(26 & 23.1)* Hereford: 108 & 108 *(10.3 & 10.3)* *Unit – Per Car Unit/Trip (Per Car Unit Km)*
Santos (1999)	*Values Measured – MEC* Cambridge-Morning Peak: 61.4 Cambridge-Evening Peak: 51.0 York-Morning Peak: 48.9 York-Evening Peak: 49.9 York-Off Peak: 42.7 *Unit-Per Car Unit Km (1996 prices & values-pence)*	*Value Measured – MEC* Cambridge-Morning Peak: 65.20 Cambridge-Evening Peak: 54.16 York-Morning Peak: 51.93 York-Evening Peak: 52.99 York-Off Peak: 45.34 *Unit-Per Car Unit Km*

Notes to table
Source: Shires (2006)

ANNEXE 3 NOTE ON DATA REQUIREMENTS FOR COST CALCULATION

Extract from Nash, C.A and Samson, T. (1999) *Calculating Transport Congestion and Scarcity Costs*. Final Report of the Expert Advisors to the High Level Group on Infrastructure Charging (Working Group 2). ITS, University of Leeds.

Wherever possible, external road congestion costs should be estimated from a model which simulates the interaction of demand and supply on the road network. The model can then be used to approximate the marginal external costs of congestion by rerunning it with small changes in traffic volumes, and examining the effects on journey time for existing traffic. This model would ideally incorporate a detailed network description, with both speed/flow relationships and junction delays, and allow for user behaviour in terms of rerouting, retiming, changing destination or mode or changing frequency of travel, in order to obtain a new set of flows and journey times following imposition of a charge. Data is therefore required on the base O/D matrix, base generalised costs and responses to changes in these values. The calculation of generalised cost requires knowledge of operating costs, values of time and vehicle occupancy rates. Only when the charge is equal to the marginal external cost in this new position has the optimal level of charge and traffic been found.

Where this is not possible, we recommend that calculations are undertaken for typical inter urban or rural roads at alternative traffic levels and mixes of types of vehicle using link speed/flow relationships. Separate calculations will be needed according to the type of road (number of lanes; motorway or conventional road). Again, data on base traffic flows and generalised costs are needed, and traffic volumes should again be adjusted for the introduction of charges, if necessary by means of a simple price elasticity of demand, in order to obtain an equilibrium value.

For urban areas, the degree of interaction between roads means that such an approximation will be particularly crude. If a full network model is not available, the use of area speed/flow relationships relating to the entire network for central, inner and outer urban areas is likely to be preferable to link based speed/flow relationships.

Forecasting the impact of increased traffic on unreliability is more difficult, but given the importance of the issue it should be attempted wherever possible. A variety of approaches exists, including the use of micro-simulation models which model individual vehicles and can thus estimate the spread of journey times, and purely empirical approaches, which require data on unreliability and on traffic flows for a set of roads over time.

All the above relationships should relate to local conditions in the area concerned, and relate to conditions such as driving styles and typical speeds in that location. It would be counter-productive therefore to attempt to specify Europe-wide relationships, although results may with care be transferred from comparable situations elsewhere in Europe if local information is not available.