Appendix A Costs of Congestion – International Evidence

This section details findings from relevant international literature on congestion, its associated costs and methodological issues in calculation. In setting out relevant concepts, such as how to define congestion and how to calculate the costs, the section presents the context within which the framework for this study was developed and details how similar studies have been undertaken previously in a variety of international examples.

In particular it focuses on;

The Definition of Congestion - *How do we define what congestion is?*

The Measurement of Congestion - *When is a road congested?*

The Costs of Congestion - *What are the costs of congestion?*

International Findings - *What were the results of other congestion studies?*

A.1 Definition of congestion

Although the simple concept of congestion is a situation in which demand for road space exceeds supply, the literature studied for this review revealed that there is no single, precise definition of congestion, although the concept is commonly comprehended by academics and policy makers. The first step is to define the form of congestion to establish the frequency and predictability of congestion. Two main forms of congestion have been identified: recurrent congestion and non-recurrent congestion.[1]

Table 1: Forms of Congestion

Type	Forms of Congestion
Recurrent Congestion	Is generally the consequence of factors that act regularly or periodically on the transportation system, such as daily commuting or weekend trips. However, even recurrent congestion can display a large degree of randomness, especially in its duration and severity.
Non-Recurrent Congestion	Occurs at non-regular times at a site. It is unexpected and unpredictable by the road users and is normally due to accidents, vehicles breakdowns or other unforeseen loss of carriageway capacity.

[1] Brownfield et al. (2003) and the OECD (2007)

We need to define what that congestion actually represents in terms of traffic conditions. It is around this definition, of when a road is congested, that we see a variety of approaches in the literature. The following details a brief overview of a number of definitions and concepts which are utilised.

An early definition of congestion arose from a study on the topic by the Institute of Civil Engineers (1989) the definition they chose was '*because more people wish to travel at a given time than the transportation system can accommodate: it's a simple case of demand exceeding supply*'. Leonard (1993) then defined congestion in urban areas as '*the condition when the free movement of traffic through junctions starts to break down*'. The author proposed a five point scale ranging from grid lock to free-flow conditions. A more sophisticated definition was formulated by J.M. Dargay and P.B. Goodwin (ECMT Round Table Report, 1999) they suggested that the definition of congestion *'is 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'.*

Brownfield et al. (2013) suggested a definition for congested urban links '*where 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)'*. The assumption with this definition is 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 to capacity ratio.

Another definition of congestion relates to perceived congestion. 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 (DfT, 2001; DfT, 2005) have therefore looked at perceived perception (i.e. the state of the traffic system from the users' subjective interpretation.) These studies have led to several different definitions including *"loss of speed due to weight of traffic", "stationary or near stationary conditions" and "slow progress".* An encompassing definition of perceived congestion from the US Federal Highway Administration is *"Congestion is essentially a* *relative phenomenon that is linked to the difference between the roadway system performance that users expect and how the system actually performs"* (OECD ECMT, 2007).

The Highways Agency (DMRB, 1997) defined congestion as the situation where "*hourly traffic demand exceeds maximum sustainable hourly throughput of the link*". This is to say that as demand increases traffic flow will decrease, average speeds will decrease significantly and queues are likely to form. Some authors (Goodwin, 2004) have defined congestion as the relationship between vehicles and the impedance arising to other vehicles from an additional vehicle on the network. Brownfield et al (2003) on the other hand considered the relationship between congestion and accident risk for the Department of Transport in the UK. This study defined congestion on an interurban link 'when the point average speed taken over 3 minutes is below 50% of the speed limit'.

A.2 Measuring Congestion: The Level of Congestion

As the overview of the definition of congestion has demonstrated, there is no consensus approach as to what congestion is and how it should be represented. Strictly speaking, congestion could be viewed as any delay that one road user imposes on another. In other words, any road that has more than one vehicle on it is experiencing some degree of congestion. However, while this is congestion, this is not a useful definition, as it would mean that roads which are operating at well below capacity would be defined as congested.

A better approach is to identify the level of traffic at which the road would be operating at an optimal level, and to define congestion as the difference between actual, observed conditions and those optimal conditions. Definitions of congestion tend to have varying theoretical underpinnings and also link in different ways to measurement techniques. The first step in measuring congestion is to determine the optimal level of traffic of a road. That is, the volume of traffic on a road, above which we would say that the road is congested. When measuring congestion, this will be the counterfactual scenario which we will compare traffic levels against to calculate the costs of congestion.

In analysing the literature we find that there are two overarching theoretical arguments:

- The Economic View of Congestion
- The Engineering View of Congestion

The theoretical framework employed by economists and engineers differs. The fundamental difference is that economists typically equate congestion with the existence of externalities (when costs or benefits that are imposed on those who did not choose to incur them. In the case of congestion, the delay imposed by individual road users on others, the emissions imposed on society, etc) and therefore see congestion from the moment vehicles start to interact. The engineering view by contrast focuses on the capacity of the infrastructure and network.

Economic View of Congestion

The theoretical framework from economics underpinning the concept and definition of congestion focuses on individual users and the concept of externalities. This conceptual framework is typically discussed in the context of road pricing. The basic premise is that when a road user's individual cost of travel is lower than the cost imposed on all other users we arrive at a suboptimal point where there is excessive road use and congestion. As work by Grant-Muller and Laird (2006) demonstrated there are three economic concepts or terms that are traditionally employed. These are the marginal cost of congestion, the total cost of congestion and the excess burden of congestion.

Marginal Cost: The Marginal Cost of Congestion refers to the change in the whole network costs for a single additional trip (or vehicle-km). Marginal external costs are items of marginal cost that are not borne by the trip maker, (e.g. for road trips they include delay to others, road wear and tear, increased accident risk and environmental costs).

Total Cost: The Total Cost of Congestion approach refers to a system of zero traffic compared to the current system. It views all vehicle interaction as congestion and is linked to the concept of externalities.

Excess Burden: The Excess Burden Cost of Congestion occurs when prices faced by road users are lower than the marginal cost of congestion, leading to excess demand and congestion. It compares the current state of traffic to the state under a scenario with optimal prices in place and is thus associated with the challenge of identifying the optimal level of transport infrastructure or road pricing.

Thus, the economic view typically focuses on the impact that a single road user has on other road users. Typically the calculation implied by this view is a comparison between current conditions and the conditions that would arise in free flow (with no effect between cars on the road). The exception to this is the excess burden approach which attempts to build in the concept of an optimal flow of traffic and is more compatible with the engineering view. It can be argued that a pure economic definition which compares the current level of operation to that under free flow conditions overstates the level of congestion as it is unfeasible and likely sub-optimal to provide infrastructure at that level.

Engineering View of Congestion

The approach implied by an engineering view defines congestion as the excess delay and impacts caused when a road is operating above its maximum capacity. As such it focuses more on capacity and infrastructural supply rather than the individual impacts of road users.

The engineering approach can broadly be defined as being where the base situation is the speed associated with the maximum flow (vehicle throughput) on the road. When actual speed falls below this speed, the road is said to be congested. Congestion costs are thus equal to the difference between the time actually spent by vehicles on the road and the time these vehicles would spend if they were running at the 'maximum flow' speed. Therefore, the approach used under this viewpoint is to compare conditions currently to those that would be observed where the road was operating at capacity.

It could be argued that looking at a solely engineering definition (congestion at point beyond 100% volume over capacity) is underestimates congestion given that the design capacity of a road is typically between 70% to 90% volume over capacity rather than 100% (Wallis and Lipton, 2013). In addition, congestion as perceived by the user is likely to occur before the road reaches 100% volume over capacity.

Compatibility of Economic and Engineering View of Congestion

While the two approaches outlined have distinct differences, there is an overlap that can be identified and utilised in congestion analysis. Under the pure economic approach we measure current conditions against a scenario where the road's traffic levels are unfeasibly low and very likely sub-optimal. Under the strict engineering approach we compare current conditions to a scenario where the road is at its maximum capacity and again unlikely to be at an optimal flow. Given these extremities it is appropriate from a policy perspective to assess congestion as the difference between observed conditions and the optimal use of the road. This is similar in premise to the excess burden approach and falls between the economic and engineering definitions. This is the central approach utilised in this research paper although, as will be detailed, results based on an economic and engineering approach are also provided for clarity.

A.3 Measuring Congestion: Costs of Congestion

Having defined what the total level of congestion is, the final step is to apply a methodology to quantify what the cost of the estimated congestion is. The literature has defined a number of quantifiable impacts associated with congestion and these are highlighted below.

Travel Time Delay	Congestion's most noticeable impact is to increase the amount of time that those travelling on the network have to spend to get to their intended destination. This lost time is often quantified and monetised through an assessment of the value of lost time.
Cost of Emissions	In increasing the amount of time vehicles are active on the network, congestion increases the amount of emissions in a given transport setting. The resultant cost is quantified through the cost of carbon/emissions.
Vehicle Operating Costs	The increased length of time that vehicles spend on the network increases the vehicle operating costs for users.
Schedule Delay	A further cost is borne by transport users if the level of congestion causes them to alter their travel plans by leaving their origin either early of late so as to avoid congestion.
Reliability Costs	There is a further cost implied by a decrease in the reliability of travel times. If the time it takes to travel from origin to destination varies over time then there is a negative cost for users.

Wider Economic Impacts	A recent advance in transport appraisal is the inclusion and quantification of wider economic benefits such as agglomeration (the economic benefits of firms being located closer together). The presence of congestion and the reduction in the efficient operation of the network implies a negative impact in this regard.
Environmental Costs	In addition to the negative impact of congestion on emissions, there is also a negative impact on local air, noise and water quality.
Safety Impacts	Congestion also has an impact on safety levels on the road network given the increased volume of users and vehicles. Research points towards congestion increases providing safety benefits due to the reduction in vehicle speeds.

A.4 International Findings on Costs of Congestion

As referenced throughout this report, numerous studies have attempted to quantify the cost of congestion in other countries and cities. For reference, a brief description of some of the key studies is provided below in terms of methodology employed and overall result obtained.

Case Study 1: The Cost of Congestion in New Zealand

In 2013, the New Zealand Transport Agency released a research report estimating the cost of congestion in Auckland. The report presents an estimation of the cost of congestion in the city based on the difference between observed travel times and those that would occur at capacity. The study then estimated travel time delay costs, schedule delay costs and other costs such as emissions and vehicle operating costs. The methodology employed is thus similar to that undertaken in this report.

The results of the research were that **the annual cost of congestion in Auckland in 2012 is $250 million (NZ Dollars)**. The report also usefully states that the annual cost of congestion if calculated using the free flow methodology is $1,250 million, highlighting the extent to which this approach can potentially overestimate congestion.

Case Study 2: The Cost of Congestion in Canada

A report into the cost of congestion in Canada was published by Travel Canada in 2006. The review looked at 9 cities across Canada and estimated the cost of congestion. The cost was based on the difference between observed conditions and speed thresholds of 50%, 60% and 70% of free flow conditions. The calculated costs were delay costs, fuel costs and an imputed value for greenhouse gas emissions. The results of the study showed that the cost of congestion across the 9 cities was $3 billion (Canadian Dollars, 2012 prices, 60% Speed Threshold). The breakdown of costs per city based on the 60% threshold is shown in Table A.1 below.

Table A.1: Cost of Congestion in Canadian Cities ($ Million Canadian Dollars, 2002 Prices)

City	Cost of Congestion
Vancouver	516.7
Edmonton	62.1
Calgary	112.4
Winnipeg	77.2
Hamilton	11.3
Toronto	1,267.3
Ottawa-Gatineau	61.5
Montreal	854
Quebec City	52.3

Source: Travel Canada, 2006

Case Study 3: The Cost of Congestion in the UK, France, Germany and the USA

In 2014, the Centre for Economics and Business Research published a paper analysing the costs of congestion today and into the future in the UK, France, Germany and the USA. The assessment analysed both the direct and indirect economic and environmental costs in these countries. The review analysed the difference in travel times between current conditions and free flow conditions based on real time data. Thus, the methodology follows that of the economic definition of congestion, which, as previously stated, potentially overestimates the cost of congestion. The review then forecasted future congestion utilising a number of assumptions. The completion of this exercise yielded estimates of the current and future cost of congestion at a national and city level. The cost estimated included both direct costs, including value of time lost and fuel loss, and indirect costs, including the increased cost of doing business. As this report only considers the former, Table A.2 below presents the report's findings in relation to direct economic costs only.

Table A.2: Direct Cost of Congestion, $ Million

Country/City	2013	2020	2025	2030
UK	**12,649**	**15,865**	**18,264**	**20,937**
London	4,310	5,602	6,669	7,741
France	**12,881**	**14,780**	**15,984**	**17,158**
Paris	6,282	7,558	8,688	10,008
Germany	**21,684**	**24,224**	**25,929**	**27,702**
Stuttgart	2,054	2,287	2,496	2,694
USA	**78,519**	**97,099**	**109,550**	**120,695**
LA	13,213	17,305	20,074	22,294

Source: CEBR, 2012

Thus, this brief review of a couple of international case studies demonstrates that the issue of measuring the cost of congestion is something which has been done before in a variety of settings. The variations in methodology make comparisons more difficult. However, a brief comparative analysis will be provided in section A.4 to provide further context for this review's findings.

A.5 Previous Congestion Analyses in Ireland

The issue of congestion and its associated costs has been considered in an Irish context through a number of previous studies. This section briefly outlines some of this work in an effort to provide further context for this study.

In terms of calculating the actual cost of congestion, robust studies have been few in number in Ireland. A number of reports and statements have informally defined the level of congestion. In 1997, the Dublin Transport Office (DTO) stated that the annual cost of delay and extra fuel consumption as a result of congestion in Dublin was £500 million[2]. However, there is a lack of detailed and modelled estimations of congestion costs in the past.

One such analysis was undertaken by the National Roads Authority (NRA)[3] in 2015 with regard to the cost of congestion on the M50 in Dublin. This study estimated the cost of congestion by looking at the time delay observed between peak periods on the road and inter-peak or off-peak periods. The analysis considered the value of lost time only. The results of the analysis estimated that congestion on the M50 costs between €48 and €65 million per annum. It is worth noting that the methodology employed in the study differs from this study insofar as it defines congestion as the difference between peak and off/inter-peak rather than the difference between peak conditions and the estimated efficient operation of the network.

The European Commission's Joint Research Centre produced a report entitled 'Measuring the Costs of Congestion' in 2012. The report utilises real time data and defines congestion as the difference between current congestion and free flow speeds. In this regard, it may overestimate costs as previously mentioned. The report cites Ireland as having the highest level of congestion among EU Member States for roads where the free flow speed is less than 50km/h. In other words, when it comes to urban mobility within cities, the report estimates that congestion is highest in Ireland, which has the largest variation between observed and free flow speeds. The report also notes that Ireland is not seen as being particularly congested on roads that have a free flow speed on 80km/h or greater, meaning congestion is not estimated to be a particular problem on Ireland's motorway and dual carriageway network. It is also worth noting that Ireland has one of the lowest percentages

[2] http://www.irishtimes.com/news/cost-of-city-traffic-congestion-put-at-500m-1.109652
[3] NRA and RPA merged in August 2015 to form Transport Infrastructure Ireland.

of roads with speeds less than 50km/h (9.6% in comparison to an EU average of 17.5%) and this potentially impacts the analysis. The report summarises that the cost of congestion in Ireland is €1.8 billion or 1.1% of GDP. This is the fourth highest level of cost per GDP among EU Member States as demonstrated in Table A.3 below.

Table A.3: Estimated Cost of Congestion in EU Member States, 2012

Country	**Annual Cost of Congestion (€ Billion)**	**Cost of Congestion as % of GDP (2009)**
Austria	1.8	0.6%
Belgium	3.4	1%
Czech Republic	0.8	0.6%
Germany	24.2	1%
Denmark	1.5	0.7%
Spain	5.5	0.5%
Estonia	0.1	0.8%
Finland	1.4	0.8%
France	16.5	0.9%
United Kingdom	24.5	1.6%
Hungary	0.7	0.8%
Ireland	**1.8**	**1.1%**
Italy	14.6	1%
Lithuania	0.5	1.7%
Luxembourg	0.3	0.7%
Netherlands	4.7	0.8%
Poland	4.8	1.6%
Portugal	1.2	0.7%
Slovakia	0.3	0.5%
Sweden	2.6	0.9%
Total EU	**111.3**	**1%**

The analysis presented by the European Commission points towards congestion being a particular problem in Ireland's urban areas. Although the methodology employed in that study is different to this one, it does provide some further context towards congestion in Ireland.

Finally, a number of comparative congestion indices are produced to estimate the relative level of congestion across international cities based on real time data. These studies typically rely on a comparison between current traffic conditions and free flow. Given the methodological issues these studies arguably do not present a definitive and robust assessment of the relative congestion in Dublin. However, they do present further evidence in this area. Two primary studies are detailed below in addition to their relevant findings for Ireland.

Firstly, the INRIX Urban Mobility Scorecard[4] is an annually produced research project which compares international cities and countries in terms of congestion. In 2014, the scorecard ranked Ireland as the 9th most congested country in Europe with 24 hours wasted per person annually. The scorecard estimated that congestion increased by 14% between 2013 and 2014. Secondly, the TomTom Traffic Index[5] measures congestion across the globe. Based on 2014 data, the index estimates that Dublin is the 18th most congested city in the world and the 9th highest in Europe. This is based on Dublin's travel times increasing by 38% between peak and free flow scenarios. These two indices rely on real time data from their various commercial elements and in addition rely on a different methodology to that employed here.

In conclusion, there are a number of studies that have been carried out in an Irish context. However, the number of in-depth and focused studies has been small and the majority of comparative studies have focused on the definition of congestion being the difference between observed traffic flows and what would occur during free flow, which may overestimate the true cost of congestion based on the definition employed in this research.

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[4] INRIX Urban Mobility Scorecard 2014: http://inrix.com/scorecard/

[5] TomTom Traffic Index 2014: https://www.tomtom.com/en_ie/trafficindex/#/