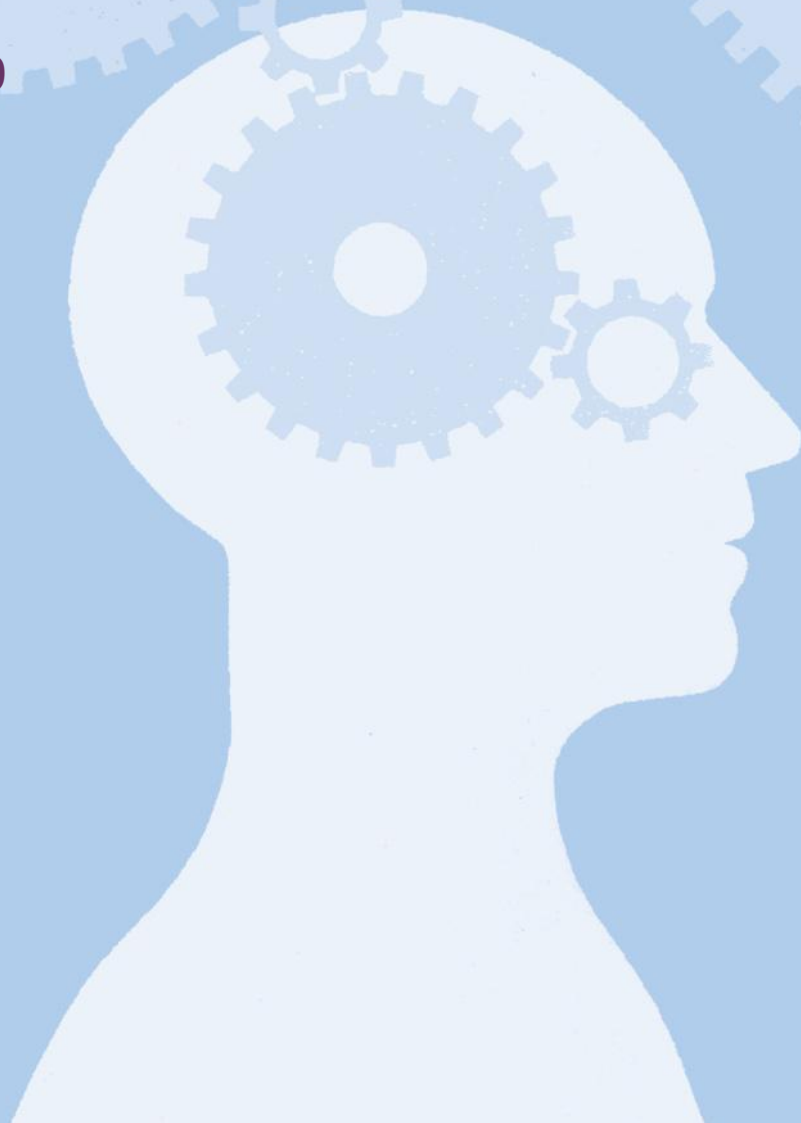


Understanding the theory of international connectivity

**Prepared for the
Department for Transport**

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1 Introduction

This report, prepared by Oxera for the Department for Transport (DfT), offers an analysis of the theory of connectivity. It addresses the research objectives posed by the DfT, both in terms of gaining an understanding of the concepts involved and in determining whether and how they might be applied to transport modelling and appraisal. These objectives were to:

- review the literature and audit existing connectivity measures;
- develop a clear definition of connectivity;
- set out the mechanisms through which connectivity affects transport user behaviour and economic performance;
- determine the extent to which these impacts are already captured in New Approach to Appraisal (NATA).

Although the report is grounded in first principles from network theory and transport economics, it has also been informed by the literature review accompanying this report. The review provides some useful thoughts and sources of data for measurement, but also raises many issues.

This report does not offer a concise single operational definition of connectivity, but instead suggests a hierarchical approach. It first offers a broad overarching definition that aims to encapsulate all the relevant concepts to be introduced, before breaking it down into two key components. It then suggests appropriate measures that capture these components for use in particular contexts.

The report addresses many of the issues of measurement that have been raised in the literature review, some of which are conceptual and some more practical. Where possible, a recommendation of the most robust way of overcoming these issues is offered; however, a large number of them are very much context-specific.

In order to assess how the concept of connectivity should be handled in appraisal and other analytical contexts, it is necessary to consider the mechanisms through which it may affect transport and the economy. Based on the concepts and measures put forward in previous sections, Oxera analyses whether the relevant features of connectivity are captured in existing approaches such as transport user benefits, locational choices and improved competition, or whether additional features are required.

It is worth noting that in appraisal, connectivity is being considered on a marginal basis. It is an inherent part of any transport system, since by definition a transport movement is a form of connection. Therefore, appraising changes in connectivity cannot be undertaken on a network level since the presence or otherwise of connectivity is not a binary concept. Instead it may be relevant for the consideration of specific schemes such as new deep sea ports or enhanced capacity at airports.

Certain features of the report are worth noting up front. First, it discusses international connectivity but is framed in the context of the UK. As an island nation, there are no international surface transport links, with the exceptions of the land border to the Republic of Ireland and the Channel Tunnel. This leads much of the discussion to be focused on the aviation and maritime sectors. The report allows for both passenger and freight users to be considered.

Another key feature of international transport is that, for passengers, it almost always occurs on communal transport. Therefore, the provision of a service by a commercial operator is nearly always required in a different way to the use of a private vehicle on a road. This is an

important distinction that is discussed at several points throughout the report when considering realised supply and demand.

The remainder of this report is structured as follows:

- section 2 looks at the general concepts and definitions of connectivity;
- section 3 looks at some of the conceptual issues;
- section 4 discusses some of the practical issues of constructing a measure;
- section 5 looks at the impacts on the economy and implications for the DfT's appraisal guidance.

2 Concepts and definitions

One of the DfT's fundamental research questions is: 'What is connectivity?' Underlying this, the DfT has indicated its concern that the theoretical foundations of connectivity are not fully understood. This section addresses this issue. In order to clarify the theory, Oxera has reviewed the underlying mathematics as well as the fundamental principles of transport economics to determine the most important components of connectivity.

The literature review accompanying this report shows that there is no neat single operational definition of connectivity that has been widely adopted. Oxera therefore sets out a hierarchical approach to definition in this section, starting with a general definition, then breaking this down into the key analytical components of connectivity, and finally identifying possible approaches to measuring them in practice.

2.1 General definition

A clear definition of connectivity is important because, without it, no meaningful analysis of its impact on transport and the economy can be undertaken, and measurement becomes essentially arbitrary. Fundamentally, connectivity relates to the ability and ease with which destinations (Ds) may be reached from potential points of origin (Os) and vice versa. It captures how they are linked, both spatially and temporally. The more destinations that can be accessed, the greater the potential to supply transport services between these destinations—and the more frequent the services to the destinations in question, the greater the level of connectivity. However, the value (demand-side impacts) of connectivity is affected by other characteristics, such as the relative importance of the destinations served and the cost of accessing them. It is not straightforward to incorporate all these factors into a single definition.

A review of the relevant literature suggests that connectivity has a multi-dimensional nature (see section 3.5 of the review). Accepting this means that it is difficult to offer a precise single definition that can be operationalised for detailed analysis. However, it is possible to suggest a general definition that captures the key concepts involved and can be used to guide the choice of more detailed analytical concepts and measures. Oxera offers the following general definition:

Connectivity is the availability of transport that enables people and goods to reach a range of destinations at a reasonable generalised cost.

This definition is very generic and, on its own, is insufficient to be converted into a specific measure or measures of connectivity. In order to do that it is necessary to break it down into key analytical components. To begin to do so, and to understand the fundamental principles involved, it is worth rehearsing the fundamental mathematical theory on connections—graph theory.

2.1.1 Graph theory

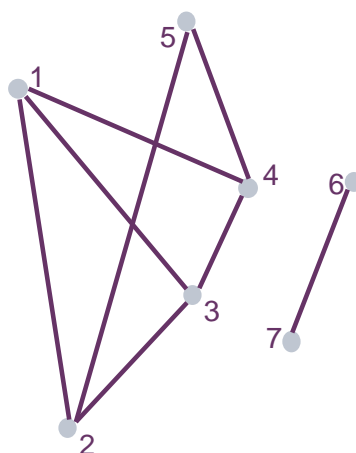
A branch of mathematics, graph theory analyses connections between entities, and hence forms the basis of connectivity analysis in different contexts. A good understanding of the concepts that it incorporates is important to help inform more practical measures and assessment of connectivity in the context of transport.

The term 'graph' has a precise definition in this literature, and is quite different to the generic use of the word to describe charts and figures. Essentially, graphs are a collection of nodes and the links between them. The precise terminology varies, depending on the context, with different names given to the two types of principal components: nodes (also called points or

vertices) and edges (also called links or connections).¹ In the transport context these nodes can be thought of as potential Os and Ds, such as airports, ports, stations or cities. The links between them, or edges, are roads, railways, shipping paths or air routes. Graphs themselves are sometimes referred to as networks, as in the case of transport.

Figure 2.1 shows a representation of a graph using dots for nodes and lines for edges. In this example, the set of nodes has seven elements (nodes 1–7), and the set of edges connecting the various nodes has eight elements.

Figure 2.1 A stylised graph



Source: Oxera.

If there is a *path*² between two nodes, they are described as *connected*. If every pair of nodes in the graph is connected then we say the whole graph, or network, is connected. In Figure 2.1 the whole graph is not connected because there is no path from nodes 7 and 6 to any of the other five nodes, but nodes 1–5 form a connected graph.

As stated above, however, connectivity is not simply a binary concept. The concept of paths leads to several measures that can be used (both theoretically and practically) to measure the degree of connectivity between two nodes. This involves counting the number of edge-independent paths or the number of node-independent paths: paths between the two nodes that do not share an edge or a node respectively. The greater the number of independent paths between two nodes, the more connected they can be said to be. A practical example in the transport context might be the number of different road routes between two cities. The number of nodes in a connected network is a measure of the connectivity of the nodes/places within it.

For a further range of possible connectivity measures based on graph theory, see the literature review, Table 3.1.

In the transport context, it can be helpful to work with an enhancement to the basic graph concept, such as a *directed* graph. In this case, each edge is ordered, so that it reflects the direction in which traffic may flow. Specifically, in particular transportation problems, graph theory can assume that there is one specific node which has no incoming edges (the O), and a specific node with no outgoing edges (the D). This is a level of sophistication which may be relevant in some contexts, particularly certain modelling exercises.

¹ The formal mathematical definitions of graphs use set theory, whereby a graph is a pair of sets (A and B). One set (A) is a collection of nodes (usually assumed to be non-empty) and the other set (B) is a collection of two-element sub-sets of the first set (A). These two-element sub-sets are edges.

² Formally, a path is a sequence of distinct nodes such that there is an edge between each consecutive node in the sequence. For example, in Figure 2.1, the sequence of nodes 5, 2, 1 is a path.

Looking at the number of connections in the way suggested by graph theory, and the number of nodes within a connected network, is a useful starting point for constructing a definition of connectivity. However, it does have limitations. A disadvantage of taking a definition from graph theory, such as the number of node-independent paths, for use in relation to transport connectivity, is that it provides limited or no information about the strength of each connection. For example, it does not indicate how frequent a service on a given connection is, or how direct some of the routes are, and how long the different journeys would take or cost.

2.2 Components of connectivity

The general definition of connectivity suggested in section 2.1, and the principles underlying graph theory and transport economics, suggest two main components of connectivity. Considering an individual at a point of origin, these principles suggest that how connected they are can be broken down into, first, the range of destinations physically available and, second, the generalised cost of accessing each one.

Any other definitions (such as catchment area, which has been used in the literature, see section 3.3 of the literature review) would appear to be derivatives of these two main components. Catchment area, for example, may simply reflect a type of weighting on the range of destinations.

2.2.1 Available destinations

The range of available destinations is clearly a component of connectivity. In terms of graph theory it captures the number of nodes available with edges between them and the origin of interest. To understand where the value of additional destinations comes from, it is helpful to realise that each destination has a different basket of characteristics. These include factors such as the number of businesses located there, the population, the tourist attractions and the climate. The more destinations that are available, the more likely it is that there will be a destination that has the appropriate basket of characteristics which would offer a net benefit to an individual who travelled to that destination.³

There has been some debate as to whether more variety is always better. Some behavioural economists have argued that excessive choice causes confusion and leads to reduced overall demand.⁴ Whether this would occur in the context of international journeys is unclear, and thus proceeding using the classical assumption that more options are always better seems appropriate.

The contribution of the number of destinations to connectivity may also be highly complex and non-linear. There may be a declining marginal benefit of additional destinations, either in general or to similar types of destinations. For example, from a given O if many connections to European destinations already exist, a connection to an East Asian destination may have a much greater benefit than a further European one. Similarly, a connection to a holiday resort may be better than a connection to another city. This relates closely to the possibility of weighting destinations (see section 4.1).

The number of destinations is a measure used in the literature, see section 3.1 of the review.

However, the number of available destinations on its own may give an incomplete assessment of this aspect of connectivity because not all potential destinations may be of equal importance. The importance of each connection to a potential destination ideally needs to be defined and measured. This relates to approaches in transport modelling whereby trip

³ It is intuitive that granting an individual a greater set of choices, which includes the original set, cannot make the individual any worse off. They can at least choose what they would have chosen before (whether that is a specific destination or not to travel at all). In microeconomic theory, this intuition is known as the weak axiom of revealed preference.

⁴ See, for example, Iyengar, S.S. and Lepper, M.R. (2000), 'When Choice is Demotivating: Can One Desire Too Much of a Good Thing?'

generation is inspired by the attractiveness of available destinations. More attractive destinations are likely to have a higher value associated with a trip to them, and hence more traffic between them. How to account for the importance of destinations is discussed further in section 4.1.

2.2.2 Generalised cost

A destination may be available in principle, but the assumption implicit in the definition in section 2.2.1 is that it is available at reasonable generalised cost⁵—otherwise nobody would ever make use of it. There may be few (or no) places that an individual cannot get to in principle, but some might require many changes or different modes to reach them, and in practice the generalised cost may be prohibitive. This suggests that the degree of connectivity between particular O–D pairs reflects the generalised cost of travelling between them. Journeys with high generalised costs will therefore contribute less to connectivity than less expensive journeys. A number of papers use generalised cost, or components of it, as their preferred connectivity measure—see section 3.2 of the literature review.

Generalised cost can therefore be used to represent the strength of a connection. In terms of graph theory this might be thought of as a missing feature in the earlier discussion about the strength or thickness of each edge. In the context of *gravity theory*, transport demand is likely to reflect both the economic importance or size of the O/Ds concerned (a positive relationship) and some measure of separation, such as distance or generalised cost (a negative relationship). Transport models which incorporate a degree of separation can take into account factors such as service frequency (through generalised cost) and can thus indicate that, even if two nodes are connected, the connection may be quite weak (eg, a ferry service running once a week). Parameters from such models could be used to measure the strength of particular connections, either in a binary fashion (based on threshold levels) or as an ordinal measure of connectivity. Such measures could use some combination of time, distance and cost as the measure of separation.

Another component of generalised cost is journey time reliability, and in this context the number of different routes between particular Os and Ds—the edges in graph theory—may be relevant. The more routes available, the less unreliable journey time may be, because options are available to switch routes when others become more congested or unreliable. This may be important for some aspects of international connectivity—for example, when alternative routes are available for air travel between cities. This is discussed in sections 4.3 and 5.5.

The key for analysing international connectivity is deciding which elements of generalised cost are most relevant in practice. There are other issues around applying generalised cost in this context—for example, whether a threshold should be used to define available destinations, and how to compare generalised cost for passengers and freight. See section 4.2 for further discussion.

2.3 Specific measures

The conclusion from this section is that a sensible general definition of connectivity can be broken down into two key components: the number of available destinations and generalised cost. The next layer in the definitional hierarchy is the choice of empirical measures to reflect these key components operationally in analysis. However, before these possible measures can be determined, some specific issues need to be resolved. These are discussed in greater detail in sections 3 and 4.

⁵ Generalised cost is a concept that represents the entire cost of a given journey. At a conceptual level it includes the financial cost, the value of travel time, frequency, wait-time, interchange time, access time and reliability of a service. In practice, different combinations of its components are usually included in a non-systematic way.

3 Conceptual issues

This section covers some specific issues that need to be addressed before any general definition of connectivity can be narrowed down, or before measures can be selected. The likely answers to these issues will probably depend on one over-arching question:

What is the purpose of the definition? Is it for descriptive or analytical purposes? What is the context and what type of analysis is being considered?

Without first knowing the answer to this it may not be possible to answer some of the more detailed questions. This is the context in each of the sub-sections that follow. The diversity of measures identified in the literature review is in part a reflection of this context specificity.

3.1 Who or what does connectivity apply to?

3.1.1 Is it for O–D pairs, particular places, or whole networks?

In this context:

- connectivity for particular O–D pairs is relevant to analysis of travel between them and for other consequential effects;
- connectivity of particular places is relevant to location decisions for businesses and people, and to economic characteristics such as degrees of competition and openness to trade;
- connectivity of networks or sub-sets of networks has a bearing on policy decisions and priorities.

The literature review identifies examples covering all these different forms of connectivity which have been used for analytical purposes. This distinction is made in the discussions of measures and mechanisms later in this report (section 5)

Incorporating accessibility to transport hubs, such as airports or ports, may be an important dimension of connectivity in some contexts. Therefore, the concept of international place connectivity, for example, may need to incorporate elements of domestic connectivity. A London resident may be relatively indifferent to the choice between using Gatwick or Heathrow Airports, but the internal connectivity of London itself is relevant to the international connectivity of the city.

At an individual decision-making level, it may seem unlikely that the connectivity of particular networks affects many transport decisions, but it may influence mode choice to some degree, particularly when inter-modal connections are not straightforward.

3.1.2 Are all transport users included in the definition? Do they receive the same treatment?

In principle, connectivity is of general relevance to all potential users. For example, a connection to New York may be particularly valuable for business travel, but in addition there is value for leisure travellers and freight. In practice, the value of connectivity may differ by journey purpose (eg, leisure or business) and by user type (eg, people or goods).

Sometimes one may wish to use a narrow definition of connectivity for particular pieces of analysis, focusing perhaps on just one transport user type. However, this will most likely give an incomplete measure of connectivity and thus will not be appropriate in other analytical

contexts. For example, using something like the Business Connectivity Index (BCI)⁶ would appear to fully account for the value of connectivity to leisure travellers.

3.1.3 Are all modes relevant to connectivity?

All modes are relevant to a proper assessment of connectivity for any of the three types set out in section 3.1.1, but connectivity provided by a specific mode may be particularly important in some contexts. As stated above, connectivity provided by individual modes may affect mode choice for particular journeys, and some modes may in practice dominate for some types of travel. For example, aviation will dominate passenger transport to distant places, and shipping will dominate for the transportation of containers. It is possible for passengers to travel long-haul on ships, but with the exception of cruises, few will choose to do so due to the additional journey time. This is a feature of the generalised cost of each mode in the relevant context, and may affect the need to cover all modes equally in practical connectivity measures.

3.2 Ex ante or ex post measures

A distinction can be made between ex ante and ex post measures of connectivity, or potential versus actual connectivity. The distinction arises from the difference between what is possible and what actually occurs. Ex ante connectivity means that the infrastructure is in place to support the relevant type of connection. Ex post connectivity would then occur if an actual connection takes place—for example, if an airline actually operates a service, given sufficient demand.

The distinction is particularly marked for international connectivity. One of the main features of international connectivity is that (with relatively few exceptions) most transport users require a specialist service provider such as a ferry company, an airline or Eurostar to operate. For international connectivity, users travel mainly on communal transport. From the point of view of the general public, an operator is required for an international connection to exist for them; whereas with domestic road-based connectivity, most users provide a private vehicle to create their own route and make their own journey at a time of their choosing.

To see the difference between ex ante and ex post, consider two airports. Ex ante, the infrastructure may exist for a flight between two airports, and that may influence economic behaviour, but ex post the airports may remain unconnected for most people while there is insufficient demand to support a service. The two definitions will coincide in some cases, however, where private planes or boats are available, or where chartering is feasible and competitive, although this will not be an option for most users.

In principle, both types of connectivity may influence travel and economic behaviour. But which approach is most suitable in particular contexts?

For most transport users, ex ante measures are of limited value because they do not indicate whether a connection is feasible for them in practice. The mere existence of infrastructure, such as an airport or a port, is less relevant to them for connectivity than the existence and number of services, although they may be attracted to the prospect of living and working in a location if they foresee the prospect of growth in demand and the possibility of services in the future.

Ex ante measures may be relevant for other users—for example, sizeable companies wishing to transfer locally produced goods to overseas markets or to import materials. They are the type of user that may be able to employ charter transport or to use their own vehicles. The greater the scope for services to be chartered, the more flexibility users have, and the greater the connectivity they enjoy.

⁶ The BCI is an index of connectivity produced by York Aviation. See section 3.5.1 of the literature review for further discussion of the index.

There are also limits to some ex post measures, such as service capacity (ie, the numbers of passengers who are able to travel on particular services), as they may simply reflect realised demand and not the quality or availability of services. Operating larger-capacity aircraft may not imply better connectivity (from an individual's perspective) if it simply reflects greater demand on a route. If capacity and the demand of others increase equally and simultaneously, there may not be an effect on a given individual's ability to use a connection. By the same token, if total traffic movements are similar on different routes, it does not follow that they are equally strong connections.

This section has discussed the ex ante ex post distinction mainly in terms of the availability of destinations or services. However, the generalised cost dimension is also relevant, although perhaps less so for particular services or routes.

3.3 Is connectivity an ordinal or a cardinal concept?

A further issue that arises when attempting to define connectivity is whether it is an ordinal or cardinal concept. That is, can connectivity be compared only between places and across time, or is it possible to measure variations in it?

Ordinal measures are useful for comparative purposes, as they may provide insight into differences across places or countries or across time. However, they would be less useful for use in appraisal where an absolute value may be required.

In practical terms, ordinality is unlikely to be sufficient. In theory, a locating firm or individual may choose between two places according to their relative connectivity, but it is quite possible that, as no two places are identical, and all decisions will involve trade-offs between factors, cardinality will be needed so that it can be incorporated with other factors in the calculation.

However, it seems unlikely that there will be a linear relationship between overall connectivity and some of the components of it. For example, doubling the number of routes between an O–D will not necessarily double the connectivity. Such a feature may make devising a cardinal measure, or estimating behavioural relationships, difficult.

Cardinality is particularly relevant to the construction of a multi-dimensional measure. If each dimension of connectivity is only ranked ordinally, it may not be appropriate to combine the various dimensions. This is because the ranks of each dimension will be treated equally, although the underlying difference in magnitude of connectivity may be very different across dimensions.

4 Practical measurement issues

This section looks at some of the more practical issues to be considered before any specific measure can be implemented. As in the previous section, the question has to be asked: 'what is the purpose of this measure/definition?'

Many of the issues discussed are purely empirical, and Oxera has indicated this at the end of each section where this is the case. Any additional empirical research is beyond the scope of this study.

4.1 Should destinations be weighted, and if so how?

Section 2 has shown that the number of destinations is a crucial component of connectivity. However, it may not be appropriate to treat each destination in the same way. Some destinations may be of greater importance than others.

Some of the measures covered in the literature review involved weighting destinations. See, for example, the discussion of the paper by Fan (2006) and York Aviation (2009).

4.1.1 Should they be weighted?

Weighting destinations may well make an important difference to the usefulness of a connectivity measure. It seems clear that connections to certain destinations are more valuable than others, in the sense that trips to that destination are potentially more valuable to the user than to the other destinations, and this is likely to be reflected in realised demand. For example, New York–London is a relatively 'thick' route, suggesting that the connection is important in pure passengers-carried terms, in turn no doubt reflecting the two cities' high positions in studies of global city importance. Conversely, if few people wish to visit a location, the value of connecting to it is relatively limited.

Thus, the main issue is *how* to conduct the weighting, rather than *whether* to do so. It is important to ensure that weighting is undertaken as objectively as possible to avoid problems of circularity. For example, weighting a destination by traffic throughput would not meet this criterion, whereas weighting by population or economic activity would because the latter are drivers of transport demand and not outturns. It is also important to be clear about the purpose of the analysis; the weightings used in some measures, such as York Aviation's BCI, are clearly focused on the importance of destinations to business travellers, ignoring leisure travellers.

4.1.2 Weighting by population, GVA, or something else?

There are different ways in which a weighting could be implemented, each of which is likely to reflect different journey purposes. For example, weighting by population would provide a relatively generic measure capturing the overall size of a destination. However, using population does not capture the value of labour and markets located there, which might best be captured by incomes and/or employment.

For business travellers, and some goods transport, gross value-added (GVA) may be a more appropriate measure of destination value. Freight will normally be travelling to destinations where it can either become part of a production process (if it is an intermediate good), or where it can be retailed (if it is a final product). GVA seems a natural choice in this case.

Clearly, more specific weighting factors might be preferred for certain journey purposes. For example, leisure travellers may weight destinations by resort facilities. Steel manufacturers might weight destinations by the amount of construction activity.

4.2 Components of generalised cost and thresholds

Connectivity is improved when the generalised cost of a given trip is reduced (further) below the potential value of that trip. This may lead to trip generation or switching. It may or may not lead to trip lengthening.

Given the importance of generalised cost to travel decisions, it is essential to measure it appropriately. This is a concept that incorporates different components, and in principle all are relevant for a connectivity measure. However, it may not always be possible or appropriate to include them all in practice, and this section reviews possible approaches.

4.2.1 What components of generalised cost should be included?

The two principal components are travel time and the financial cost.⁷ The relative importance of financial cost compared with other measures may also depend on the precise context. The financial cost may be relatively low for something like light mail, but connectivity may be crucial. Where possible it would seem appropriate to include financial cost, provided that data is available.

Scheduled journey time between any two destinations should be readily available for inclusion. Assumptions are needed for the value of time if it is to be combined into a single measure, and this can be taken from sources such as the DfT's WebTAG.⁸ Whether these values are entirely appropriate for international travel could be examined with an additional piece of empirical research. It is plausible that travellers value, and budget for, international travel time in a different manner than for travel time for more regular journeys.

An appropriate measure of the value of time is also needed for freight. There is a general problem that different users of different modes have different values of time, and that using a simple average is a considerable over-simplification. The preferred approach will once again be context-specific. However, the general conclusion is that value of journey time is an essential component of generalised cost and should generally be included in any measure of connectivity.

It may be desirable if possible to include some measure of access and egress time for the point of international departure. For maritime freight transport, access time may depend on the loading facilities available at the port and the speed at which a service can be embarked (either for Ro-Ro⁹ or Lo-Lo¹⁰). For passenger aviation it may include the average time taken to reach the airport, pass through security checks and wait for take-off. The situation is similar for egress.

Journey time reliability is also relevant, and is discussed in section 4.3 in the context of the number of available routes.

4.2.2 How should frequency be allowed for in measuring generalised costs?

One aspect of generalised journey time is service frequency. The frequency of a transport service affects generalised journey time because, unlike private transport, the departure time for communal transport depends on the service provider rather than the transport user. There is often, therefore, a degree of waiting time involved in an individual's journey that ought to be included along with overall trip length. As frequency increases, average waiting time decreases.

⁷ The measure of financial cost will almost always have to be an average, although price discrimination means that different fares are often available for transport users using particular services.

⁸ WebTAG is the DfT's detailed guidance on the appraisal of transport schemes and wider advice on scoping and carrying out transport studies. It is available online at <http://www.dft.gov.uk/webtag/>.

⁹ Roll-on, roll-off.

¹⁰ Load-on, load-off.

For international transport, how frequency should be taken into account is not immediately obvious. Clearly, on most occasions, international travellers do not turn up at a departure point and wait for the next service in the same manner that they might for local bus or train services. However, even if not waiting at a port or airport there may still be a penalty for infrequency because of the potential inability to match a service to desired departure times.

International travel has features which differ to some degree from more standard domestic travel. Reasons include the following.

- Pre-booking—international travellers almost always have to pre-book their tickets, whereas for more local transport, such as bus and local rail travel, they can simply turn up. This may be in part because passengers acknowledge that the bus or train will operate with reasonable frequency, but it may mean that waiting time bears a less straightforward relationship with service frequency.
- Adjusting to departure time—international transport users may be able to tailor their desired journey to departure time more easily than domestic travellers. In general, international travel is undertaken less often than regular journeys such as commuting.

The relevance of these features will depend on journey purpose and the extent to which a journey is discretionary. Journey purpose is therefore likely to be a factor in determining the extent to which frequency is important.

- Leisure travellers may not be concerned by infrequency. A traveller planning six months in advance may not care how frequent flights to their chosen holiday destination are, as long as there is one available with sufficient capacity. They can book this and tailor their journey to it.
- Alternatively, there will be some cases where frequency is paramount and time between services is as important as the journey time itself. This may be the case for the transportation of perishable goods, or for business people who have to attend meetings at short notice.

Therefore, there is a spectrum of importance for frequency in connectivity, depending on the extent to which the travel is discretionary. This suggests that it should be included as a separate variable in measures of connectivity, rather than as an element of waiting time within a more comprehensive measure of time costs.

4.2.3 Should generalised cost thresholds be used?

One method of measuring connectivity could take the form of examining the number of destinations within reach of a certain generalised cost threshold. The choice of threshold is somewhat arbitrary, however, but may be a useful way in some contexts of combining availability of destinations and generalised cost within a single connectivity measure. It would be possible to explore the empirical relevance of several variant measures—ie, number of destinations within various thresholds. Section 3.3 of the literature review discusses a paper by Prud'homme and Lee (1999) which takes this approach. However, there is no guarantee that each of these measures will preserve the ranking by connectivity across places. Although preservation of ranking may be a desirable quality, if rankings do change then the thresholds at which they do so may provide insight into the nature of each place's relative connectivity.

The use of thresholds therefore depends entirely on the context of the measurement required. Even if it is appropriate, the range of thresholds will depend on who or what is being transported—for example, a threshold is likely to be lower for the transport of milk than for televisions.

4.3 How to incorporate the number of routes/services?

Section 2.2.2 stated that the number of routes available may contribute to connectivity.

4.3.1 Is the number of routes as important as the number of destinations?

For international connectivity, from the UK at least, the majority of links are via sea or air. In these cases there are fewer constraints from infrastructure regarding the precise number of routes available, although there are still flight and sea paths that cause restrictions. Perhaps, therefore, the equivalent concept in international travel for the number of routes is the number of providers on a given route—eg, the number of airlines flying between places. This may affect connectivity in several separate ways. First, more competition on a route may reduce prices, although this should be captured in generalised cost; second, it may mean greater capacity; and finally it may affect the reliability of a service.

Typically, an individual will take the shortest/cheapest route, and in many cases there will be a clear first choice. However, the existence of alternatives is important for reassuring a traveller that a journey is possible. The main value of multiple routes/services between an O–D pair therefore comes from the option value that it provides to users.

The greater the possibility of disruption on a given route (through, for example, industrial action, of the sort experienced by British Airways in early 2010), and the greater the need for a trip, the greater the value of multiple routes. In some circumstances, multiple routes will be of particular importance—for example, if service frequency by individual carriers is low and an individual's journey is essential (eg, travel for medical reasons or travel to special events).

The propensity of an individual to travel a given journey may be affected by the extent to which there are alternative routes available for that journey. Some individuals may be more inclined to arrange a visit if they know that there are different ways of getting there—for example, a journey to Lima, Peru, from the UK can be taken by flying via the Caribbean or via Madrid—and therefore that the risk of disruption is reduced.

A change in the risk of disruption or the variability of costs will be one of the factors determining whether there has been an improvement in connectivity. However, the relationship with route or operator numbers is likely to be highly non-linear, because beyond a certain point these are likely to make little difference to reliability. How important they are will depend on how essential the journey is and how much the risk of disruption is reduced.

4.4 Whether/how to construct indices which capture the multi-dimensional nature of connectivity

The focus of this report has so far been on demonstrating that connectivity is a multi-dimensional concept. This raises a key issue of how to incorporate the different dimensions and how to value them against each other.

There is no a priori logic for giving greater weight to one component of connectivity than another. In UNCTAD's LSCI (reviewed in section 3.5.1 of the literature review), five different components were given equal weight and combined into a single index. It may be possible to obtain a set of weights based on consumer or business surveys if respondents are able to indicate the components they value the most.

Combining the different elements could be undertaken in a number of ways. For example, the use of a threshold generalised cost to determine the number of available destinations is one method, as described earlier. The precise method and weighting system which is appropriate will depend on the particular connectivity indicators being used, and ideally the weights should be determined empirically in estimation of the behavioural relationships involved.

4.5 Implications for different modes

Table 4.1 sets out the possible implications of the preceding discussion for different modes of international transport. The intention is not to be overly prescriptive, but to suggest a broad approach that can be implemented for each mode.

Table 4.1 Implications for different modes

Issues	Aviation		Maritime	
	Passenger	Freight	Passenger	Freight
Ex ante or ex post measures most relevant?	Generally ex post services	Generally ex post, although where chartering is possible ex ante may be more appropriate (eg, infrastructure)	Generally ex post	Generally ex post, although where chartering is possible ex ante may be more appropriate (eg, infrastructure)
Should the number of destinations be included?	Yes, in general. Most relevant will be the number of direct services	Chartering may diminish its relevance	Yes, in general. Most relevant will be the number of direct services	This is complex, depending on the amount of chartering. Chartering may diminish its relevance as the existence of suitable ports at origin and destination is the key (regular services relevant to a minority)
How should destinations be weighted?	Weighting could depend on a suitable measure of economic value ¹ and touristic value of destination	Weighting could depend on a suitable measure of economic value ¹ of the destination	Weighting may depend on some measure of touristic value	Weighting may depend on a suitable measure of economic value ¹ of the destination
Which components of generalised cost should be included?	Journey time and average fare are likely to be important, as are access and egress costs	Financial cost and journey time both likely to be important	Potentially, financial cost will be the most important, and proximity to a port may be of minor relevance	Potentially, financial cost will be the most important, along with cost/distance to port
Should frequency be included as a separate variable?	Potentially highly relevant for business users, as a separate variable, and somewhat less so for leisure travellers	Likely to be relevant for time-sensitive freight, as a separate variable	Possibly somewhat relevant	Likely to be insignificant
Are generalised cost thresholds relevant?	In order to combine generalised cost and available destinations into a single measure, one method would be to use parameters from transport models or gravity theory. An alternative is to use thresholds. However, thresholds are a relatively crude way of weighting destinations by generalised cost/distance			

Note: Implications for connectivity via the Channel Tunnel and via the land border between Northern Ireland and the Republic of Ireland are omitted as special cases.

¹ GVA is the most comprehensive measure of economic value; however, population, incomes or employment may all be suitable proxies if GVA is difficult to obtain.

Source: Oxera.

4.6 Conclusion

This section has discussed some of the practical issues that arise when measuring connectivity. The broad conclusion is the same as that of section 3—that the appropriate answers to these issues depend on the purpose and use of the measurement that is being made.

5 Impacts on the economy and implications for appraisal

One of the objectives of this study is to provide an understanding of how connectivity affects transport and the wider economy, and thereby to assess the implications for transport modelling and appraisal. This section addresses the following questions about connectivity.

- How does it affect transport and the economy?
- How should this be captured in appraisal, and are methodological changes needed?
- What are the implications for modelling?

In order to answer these questions, it is first necessary to consider the responses to connectivity changes that are suggested by theory.

5.1 How does connectivity affect behaviour?

The literature review accompanying this report suggests that changes in connectivity may have effects on:

- transport user benefits;
- the location of people and businesses;
- the degree of competition in markets;
- employment, productivity and trade.

These are considered in turn below, starting with a discussion about the impacts on transport users which underlie all the above effects.

The effects on behaviour may arise as a consequence of changes in either or both of the two key components of connectivity outlined in section 2.2. For example, for transport users:

- the addition of an extra destination may imply:
 - generation of new trips to that specific destination;
 - abstraction of trips from existing destinations;¹¹
 - possible changes in the overall number and length of trips.
- a reduction in generalised cost may imply:
 - time/cost savings for existing users;
 - generation of new or longer trips (some new, some abstracted);
 - mode switching.

The impact of reductions in generalised cost has been widely covered, in both appraisal and modelling of transport user benefits. The methodology is well developed and well understood. This section therefore concentrates on the impacts on transport users of changes in the other component—the number of available destinations—and the wider consequences that follow. It is helpful to start from basic microeconomic theory to illustrate how these effects arise. Figure 5.1 illustrates the impact of a new destination or route becoming viable and thus serving some previously latent demand.

¹¹ Note that any passenger switching trips must be doing so because of a higher consumer surplus from the new route than the old ones.

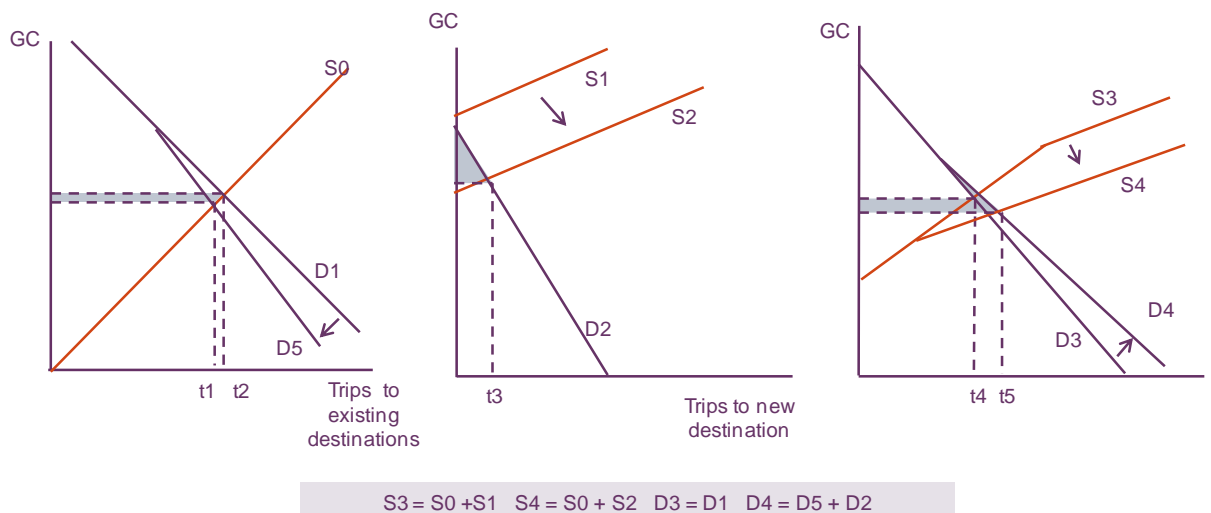
The example used could be that of international passenger flights to a destination that was not previously served—ie, where demand was latent. The three panels in Figure 5.1 show demand and supply to existing destinations; the new destination; and all destinations. The demand and supply curves in the third panel of the diagram are the horizontal sum of those for the routes in the two previous panels.

In the first panel of Figure 5.1, the effect shown is a decrease in demand to existing destinations as a result of some abstraction to the new destination. If supply does not change, as shown here, there may be a reduction in generalised cost.

The second panel shows trips to a new destination with relatively low demand. The supply shift shown is an illustrative way of representing a new destination becoming available. The existing supply (S1) is the previous supply of indirect flights. With the addition of direct flights there is a supply shift to the new supply (S2) which offers trips at a much lower generalised cost. At this level of supply, travel to the destination becomes feasible for passengers and some trips (t3) occur.

The third panel shows what happens to total trips with the addition of direct flights to the new destination. There is both a demand and a supply shift outwards, such that the total number of trips increases (t4 to t5). The demand shift occurs because consumer choice is increased by the addition of new transport opportunities. It is likely to incorporate both generative (the addition of D2) and abstractive effects (a movement from D1 to D5 in the first panel) which will act in offsetting directions. Thus the demand increase (t4 to t5) will be less than the total trips to the new destination (t3) due to the extraction effect. The impact on average generalised cost associated with this increase in output is ambiguous in principle.¹²

Figure 5.1 Addition of a new destination



Note: GC = generalised cost. Blues shaded areas represent consumer surplus. The diagram is stylised to illustrate the issue and therefore horizontal summation is not exact. There is a distinction between the demand for the new destination shown in the middle panel and the demand shown in the third panel. There is an expansion of demand in the third panel as this shows what could be termed 'effective' demand, demand for routes that are viable. Whereas the demand for the new destination could be thought of as 'fundamental' or latent demand in the initial case. Source: Oxera.

Increases in output of the type shown in Figure 5.1 will be associated with increased consumer (and producer) surplus. However, as discussed below, the welfare benefit is not simply related to the change in generalised cost, it is also related to changes in demand.

¹² It depends on the precise shapes of the demand and supply curves.

It is also important to note that the degree of substitutability between various destinations and routes will affect the outcome. For example, adding more and more routes will not increase demand indefinitely, because there is a limit to how much individuals can travel. The same applies to price reductions. Therefore, as the number of destinations increases, demand changes are likely to become increasingly abstractive rather than generative. This is apparent from time constraints that will ultimately limit individuals' propensity to travel. Whether such a point has yet been reached is unclear (this is discussed in section 5.2.2). In addition, the demand for new routes may well be quite low. This is difficult to assess, but it may be noted that if it were high, there would have been a strong incentive for suppliers to be serving the market already.

The changes in travel patterns described above clearly imply benefits to transport users, but how they can be quantified in practice is not straightforward. The issues around quantification of benefits may not be issues solely relevant to analysis of connectivity. They may apply also for any assessment of transport demand where the scope of transport opportunities is significantly enhanced without necessarily altering the costs involved. It may also affect how revised transport user behaviour indirectly affects the wider economy.

It is now necessary to consider the types of impact currently covered in appraisal and the mechanisms through which connectivity may affect them. Having done this, whether existing appraisal and methodology may need to be adjusted to take connectivity effects fully into account will then become apparent.

The following sections look specifically at where connectivity impacts are picked up in WebTAG, the DfT's appraisal guidance.

5.2 Transport user benefits

5.2.1 Calculating consumer surplus

The DfT's approach to appraising transport user benefits is set out in TAG unit 3.5.3, and is implemented in the DfT's standard economic appraisal package, the Transport User Benefits Appraisal (TUBA) model. The calculation of consumer surplus can in principle be undertaken relatively easily, either from estimation of demand curves or simply from knowledge of the previous price and demand and the new price and demand. The relationship between demand and generalised cost is the fundamental building block on which demand modelling is based.

The likely impact of additional destinations—the other component of connectivity, which is not as familiar and well developed as generalised cost in existing transport appraisal methodology—is set out in section 1.1 and Figure 5.1 of this report. The key conclusion is that transport users would be likely to gain additional welfare benefits that are not associated with generalised cost reductions because increased consumer choice would result in an outward shift in the demand curve. This is broadly accepted in WebTAG, with the following statement about variable demand:

any change to transport conditions will, in principle, cause a change in demand.¹³

The standard guidance in WebTAG and TUBA does not appear to routinely incorporate the possibility of demand changes from additional destinations. Changes in consumer surplus are assumed to be driven by generalised cost changes using the 'rule of a half'.¹⁴ This is illustrated in Figure 5.2, taken from TAG unit 3.5.3, which illustrates the effect of a reduction in generalised cost due to a supply increase on a given route. The increase in consumer surplus is equal to:

¹³ DfT (2006), Variable Demand Modelling: Preliminary Assessment Procedures TAG Unit 3.10.1', June, para 1.2.1.

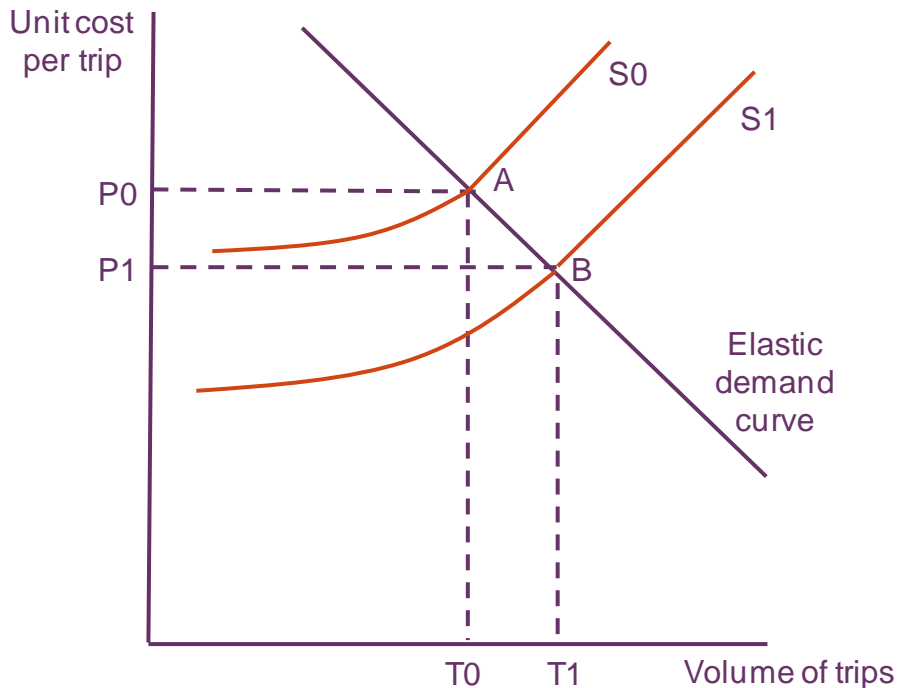
¹⁴ The rule of a half is a name for Equation 5.1, which estimates the change in consumer surplus for changes in supply if demand is fixed.

$$\frac{1}{2}(T_0 + T_1)(P_0 - P_1)$$

Equation 5.1

In Figure 5.2 this is defined by the four points P0, P1, A and B. Conceptually, the increase is made up of two components: first, those existing users who were paying P0 and are now only paying P1; second, that T1 – T0 users can now travel at price P1, whereas they did not wish to travel at price P0.

Figure 5.2 Consumer surplus in WebTAG



Source: Based on DfT (2010), 'Transport User Benefit Calculation TAG Unit 3.5.3', draft, Figure 2.

However, the analysis of connectivity in the previous section suggests that the situation is more complicated in situations where the demand curve shifts as well as the supply curve, as may be the case with the addition of new destinations. In these cases the consumer surplus calculation needs to be thought about carefully.

Nellthorp and Hyman (2001) consider alternatives to the rule of a half in appraisal in some detail in different circumstances.¹⁵ WebTAG/TUBA address the issue of variable demand and how it should be modelled (see, for example, TAG unit 3.10). However, Oxera's initial review of the guidance has not uncovered explicit reference to the impact of an increase in available destinations on demand and how this should be translated into transport user benefits. This is something that may have a benefit in being addressed, if it is not already, because in order to implement the more complex method for computing consumer surplus that is required, it is necessary to determine the demand shift involved empirically. This is discussed further in the next section.

In addition to the above discussion of consumer surplus, changes in producer surplus should be taken into account. Producer surplus is an equally important element of social welfare. Changes in producer surplus will be significant only in situations of imperfect competition; otherwise, if prices equal costs then producer surplus is zero.

Before moving on to the next section, two other aspects of the impact of increased connectivity on transport users need to be considered briefly. The first is the impact of

¹⁵ Nellthorp, J. and Hyman, G. (2001), 'Alternatives to the Rule of a Half in Matrix-based Appraisal', Proceedings of the European Transport Conference, 2001.

additional routes on journey reliability, as discussed in section 4.3, and the second is the additional options which greater connectivity provide (section 5.6). These are covered in the wider appraisal context in TAG units 3.5.1 and 3.6.1. The latter in particular is in need of further methodological development, but both in principle provide guidance on approaches which can readily be applied in the connectivity context.

5.2.2 How is the number of ‘trips generated’ determined in models?

Because of the potential importance of impacts of additional destinations on demand and transport user benefits, Oxera has examined briefly the functioning of some domestic and international models used by the DfT. There is a significant amount of material about domestic models, and while these are of less direct relevance to this study of international connectivity, they are relevant to the concept of connectivity in general.

Most (domestic/urban) transport models follow a four-stage structure:

- trip generation;
- trip distribution;
- mode choice;
- route assignment.

It is the trip generation element that is of particular relevance. In this context there are two main types of transport model for trip generation: O–D models and producer–attractor models.

- In O–D models, trips are described by the place they start and the place they end.
- In producer–attractor models, trips are described according to where they were produced from and attracted to—ie, a return trip from home is described as the home producing two trips.

O–D models tend to be used for modelling supply, and producer–attractor models tend to be used for modelling demand.¹⁶ In producer–attractor models, adding more attractors but not influencing the producer does not necessarily imply that any additional journeys are made. This may not be appropriate if demand changes, as the discussion in section 5.2 has shown.

The National Trip End Model (NTEM) is a multi-modal model that can be used to produce traffic forecasts. Its outputs are used in the National Transport Model (NTM) and in TEMPRO. The process of generation of trips in the NTEM is based on trip rates from the National Travel Survey. These trip rates are assumed constant and hence trip-end growth comes only from growth in population.¹⁷ This process of trip generation would not seem to incorporate connectivity effects of the type discussed above, since the availability of destinations does not appear to be a factor in the generation of trips. This is, however, a domestic model and focused primarily on car use. It is not therefore necessarily appropriate for use in this context.

For modelling international transport, Oxera has briefly reviewed the National Air Passenger Demand Model.¹⁸ The methodology can be broadly described as follows.

- **‘Unconstrained’ demand is determined.** This assumes that there are no constraints on airport or airline capacity. As such, it could be consistent with an approach in which some notion of underlying demand to all places may exist, but actual supply determines whether it remains latent or is actually served. However, given that it takes the form of econometric models based on past realised air travel, it would seem that, strictly

¹⁶ WebTAG unit 3.15.2.

¹⁷ WebTAG unit 3.15.2, para 3.3.5.

¹⁸ As described in DfT (2009), ‘UK Air Passenger Forecasts and CO₂’, December.

speaking, so-called unconstrained demand actually just assumes the same degree of constraint as found in past behaviour. There is no sign of the availability of destinations being used as an explanatory variable in determining (realised) demand.

- **Unconstrained demand is allocated.** The model then allocates unconstrained demand to destinations or airports, also based on past relationships—specifically with journey purpose and generalised cost.
- **Demand is constrained.** The final stage places constraints on this demand where there is limited capacity at airports, so that passengers are reallocated between airports accordingly.

It is not clear that availability of destinations features in this model in an explicit way that would enable analysis of connectivity effects in appraisal and other contexts. All such effects appear to be implicit.

In addition to the National Air Passenger Demand Model, Oxera has reviewed the supporting documentation for SPASM, the DfT's passenger allocation model used for forecasting the number of passenger and aircraft movements at UK mainland airports.

In SPASM it appears that demand growth is based on the former DETR's Air Traffic Forecasts 2000, with an allowance for growth rate differentials between regions.¹⁹ This does not appear to leave scope for changes in connectivity to affect the level of demand.

Oxera has been unable to examine models of shipping demand or demand for transport through the Channel Tunnel.

5.2.3 Conclusion

Assessing transport user benefits from changes in connectivity is not as straightforward as it may initially seem. The assessment of connectivity impacts relies on models being able to accurately capture the response of transport users to changes in connectivity. This includes capturing any demand shifts that may result from these connectivity changes.

From an initial assessment of air transport models it is not clear that any account is taken explicitly of the value of additional destinations in generating overall demand for travel. However, Oxera's examination has not been exhaustive. Further empirical evidence on this is likely to be beneficial, particularly the extent to which overall propensity to travel internationally has changed over time, while controlling for other factors.

In addition to the need for models to fully account for all demand and supply effects, the actual consumer surplus calculation needs to be undertaken carefully. In situations of connectivity changes causing both demand and supply shifts the appropriate calculation is likely to be more complicated than the 'rule of a half'.

If it can be determined that changes in the number of available international destinations do indeed cause shifts in demand, then there may be a case for reviewing whether current appraisal methods for international trips need to be extended.

In addition to this, passenger maritime and freight models ought in principle to incorporate the number of available destinations.

However, simply examining direct benefits gives an incomplete view of the total effect of connectivity changes. There are several other effects that broadly fall under wider economic benefits that can be considered. Incorporating their effect will largely be captured under improvements to transport models suggested above.

¹⁹ DfT (2004), 'Rules and Modelling: A User's Guide to SPASM Edition 2'.

5.3 Place competitiveness

The connectivity of places will affect their competitiveness.²⁰ Places effectively compete with each other to be attractive for people and businesses to locate and invest in.

Industries that operate in globalised markets must be well connected internationally in order to compete successfully. On the output side, they need to be able to efficiently transport goods and services to market. On the input side, greater connectivity allows them to draw on a wider source of labour, skills and capital. International connectivity is not a guarantee of a competitive globalised industry, sector or region, but it is often a necessary condition.

The level of international connectivity may affect the investment decisions of foreign and domestic firms. People and businesses are more likely to locate in places which are well connected, internationally and domestically. This factor will have a stronger impact on consumers and the economy if there are agglomeration benefits from the co-location of several firms or industries.

The effect of place competitiveness can be picked up in appraisal through several mechanisms including land use and the resulting impacts on employment. Land Use Transport Interaction (LUTI) models are needed to assess this, as suggested in TAG unit 2.8 and the current consultation draft guidance on Wider Economic Benefits (TAG unit 3.5.14).²¹ This will feed into assessments of transport user benefits, as discussed in the previous section; for example, TAG unit 3.16 considers appraisal in the context of new housing development. There does not appear to be an equivalent to this unit for new commercial and industrial developments, although the impact on these developments will also feed into an assessment of agglomeration and other wider economic benefits (see below).

In principle, much of this aspect of connectivity's effect on the economy should therefore already be captured in existing appraisal guidance. However, the key is how international connectivity effects feature in LUTI models used for this purpose. A more detailed examination of these models would be required to determine if there is any need for coverage of this in the guidance to be looked at further.

5.4 Wider economic benefits

Many of the other impacts of increased connectivity on the economy can be grouped under the heading wider economic benefits. The present consultation guidance on appraising these is provided (in consultation form) in TAG unit 3.5.14.

5.4.1 Agglomeration benefits

Agglomeration benefits may arise as a result of increased international connectivity through the attraction of people and businesses to the places concerned, as discussed in section 1.3, and the resulting impacts on productivity. Some papers in the literature have suggested that job creation is the main method through which connectivity may affect the economy.²² Increasing the size of an international product market available to a firm may help to increase its output and thus affect its demand for labour. Equally, the decisions of firms to locate in specific areas will affect the number of jobs available in those areas. Agglomeration benefits can arise in these circumstances as a result of higher employment density, with more business interaction, more efficient matching of workers to jobs, and greater market efficiency more generally, leading to higher average productivity.

²⁰ In addition, competitiveness of specific nodes is relevant for infrastructure owners—eg, an airport owner will have an interest in maintaining the airport's reputation as being competitive.

²¹ DfT (2009), 'The Wider Economic Impacts Sub-objective, TAG unit 3.5.14', draft for consultation.

²² See section 4.4 of the literature review.

This is covered in the guidance on wider economic benefits (TAG unit 3.5.14, section 2), although the discussion about employment density—the key driver—is primarily in terms of generalised costs. As noted, connectivity involves other mechanisms which need to be included in modelling employment changes. However, the basic guidance on the scale of such effects is equally applicable in the connectivity context.

5.4.2 Labour market effects

Section 4 of TAG Unit 3.5.14 provides guidance on the welfare effects arising from labour market changes caused by a transport change. These effects result from the fact that some people may be able to move to more productive jobs, and more people may choose to participate in the labour force as a result of transport improvements. Evaluation of these effects needs to reflect the tax wedge on wages—ie, the difference between the cost of labour to the employer and a worker's take-home earnings.

The discussion of labour supply in the guidance focuses on the impact of changes in generalised costs, and specifically commuting times. However, this is unlikely to be of much relevance to international connectivity, as only a limited number of individuals will choose to regularly commute on an international route. The more general approach to location decisions outlined in section 5.3, with well-specified LUTI models incorporating international connectivity effects, is required to estimate likely employment impacts and the options for better paid work. As noted, this needs further examination, but such effects are certainly relevant in the context of connectivity.

5.4.3 Imperfect competition effects

One potential economic benefit of increased connectivity is an increase in competition in both product and labour markets. The increase in competition could arise from widening the geographic size of the market. For example, transport connections to other agricultural markets allow competition between domestic and international producers. Such competition should lower prices for consumers.

Competition effects are often assumed to be relatively small, due to the UK having a relatively well connected internal network. As such, they are not considered explicitly in the guidance on wider economic benefits in TAG unit 3.5.15. The Eddington Transport Study claims that the impact of transport on changes in competition is difficult to measure and, therefore, ambiguous:

the contribution that transport improvements at the margin can make to competition, and therefore productivity, is difficult to measure.²³

However in the case of international connections there may be more scope for connectivity to have a competition impact, because the existence (or not) of a connection is often more of a step-change than it may be for domestic transport schemes. This would obviously apply mainly in the case of internationally traded goods and services. There may however be some limited impacts on non-traded goods, due to changes in travel patterns around nodes of departure from the country, but these are likely to be minor.

The guidance on wider economic benefits includes a section on impacts in imperfectly competitive markets (section 3), which applies equally to connectivity. WebTAG recommends that the additional benefits arising from consumers valuing extra outputs by more than the costs involved can be measured as a fixed proportion (10%) of the increase in benefits to business users.

It is beyond the scope of this study to consider the appropriateness of this methodology in detail. However, competition benefits from improved connectivity arising from lower

²³ Eddington, R. (2006), 'The Eddington Transport Study', 1, para 2.45.

generalised cost should be captured in appraisal and should be updated in the same way as for other transport improvements.

The literature review accompanying this report found that there is little empirical evidence on the existence and scale of competition effects from increased connectivity, despite the theoretical case for them. While in principle there is a case for including them in appraisal guidance, it is not a strong one. This could be the subject of further work to provide clearer evidence of the magnitude of these effects.

This leaves a potential omission in appraisal of competition benefits arising from increasing the number of destinations, which could increase the size of the market. How the benefits might be captured is unclear. Attempts could be made through making assumptions about the current form of imperfect competition. For example, there may be a clear oligopoly structure to the existing market, and an extra route may feasibly expand that market by one producer. If so, a broad assumption that the market was characterised as a Cournot oligopoly could allow the increase in output and fall in price from an additional consumer to be estimated. In practice, however, there are unlikely to be few such routes which, if added to the UK, would bring about significant changes in competition.

5.5 Option values

Option values occur in situations where there is uncertainty about the availability of transport or, in particular, the availability of a given mode or route, as discussed in section 4.3. They reflect the value placed on the existence of a route that they do not intend to use initially, but will use if their primary method of transport is unexpectedly unavailable, or if there are other unforeseen circumstances limiting their mode choice.

For example, there is a degree of option value on the existence of the Eurostar and flights between London and Paris. If one is unexpectedly unavailable (eg, aviation due to volcanic ash, or Eurostar due to adverse weather conditions, both of which occurred in 2010), the user can use the alternative.

The discussion of option values relates to the discussion of the importance of the number of routes in section 4.3.1. As indicated, the size of option values will vary depending on the frequency of disruption to the primary mode and the extent to which a given journey is discretionary. As suggested in section 5.2, the guidance on this is in need of further methodological development, but in principle the current approach can readily be applied in the connectivity context. The current approach is tailored towards assessment of local schemes and may therefore need to be amended.

5.6 Network effects

Network effects arise when the addition of a marginal connection to a network has a greater-than-marginal impact on the network as a whole.

In terms of international connectivity, the addition of an extra international connection may lead to increased travel within the domestic network as well. This may be as a result of increased feeder services to the origin of the new international connection. This can lead to both benefits for consumers (consumer surplus from extra travel) and producers (producer surplus from extra travel).

This is an under-explored area of empirical research in transport, although network effects clearly exist. It is likely that such benefits are, in practice, wrapped up in macro-estimates of productivity and employment. They do not appear to be considered explicitly in WebTAG, but are likely to feature in transport models. These effects are often seen in other industries such as telecommunications. In these sectors, however, the emphasis tends to be on network externalities for consumers, whereas in transport such externalities exist for both consumers

and transport suppliers. Literature and analysis from other sectors would be a sensible starting point for any further work on the topic of network effects.

5.7 Conclusion

The main conclusion of this section is that most of the direct and wider effects of connectivity are picked up somewhere in existing appraisal guidance (Table 5.1 below sets out a summary of this).

There does not, therefore, appear to be a need for an additional section in the guidance explicitly for connectivity. Indeed, to add such a section would risk the double-counting of many of these benefits. However, there are some areas where the guidance may need clarification to ensure that all aspects of connectivity are captured.

The estimation of impacts on consumer surplus in assessing transport user benefits requires particular care. The key question about the completeness of the existing approach is whether the transport modelling underpinning appraisal explicitly allows for generative demand effects from connectivity improvements that are not simply movements along a demand curve due to reductions in generalised cost, but are shifts outward in demand due to a greater number of destinations available and the increase in consumer choice which that implies.

Existing models used by the DfT do not appear at first sight to effectively address such effects, although Oxera has not been able to undertake an exhaustive assessment. For freight and passenger maritime services it is unclear how the number of trips is determined in transport models. This issue needs to be examined further.

One additional point that should be highlighted is that much of the existing guidance is focused on appraisal of domestic/local schemes. Additional aviation or maritime services are likely to be undertaken by private enterprises and do not necessarily require appraisal. However, any changes in infrastructure supporting international services are likely to be large and therefore may well require their own individually customised appraisal.

Table 5.1 Summary table of where connectivity may be captured in WebTAG

General mechanism of effect on economy	What is the specific benefit?	Where it may be captured	Where does it appear in Appraisal Summary Table?	Comments/potential improvements
Transport user benefits	Increased consumer surplus	TAG units 3.5.2 and 3.5.3	Transport Economic Efficiency	Enhance consumer surplus calculation to account for demand shifts
Place competitiveness	Higher-value land use, increased attractiveness to locational decision-makers	–	Wider Economic Impacts, Land-Use Policy	Existing methodology appears adequate provided that LUTI models capture international effects
Agglomeration	Productivity improvements from higher density	TAG unit 3.5.14	Wider Economic Impacts	Existing methodology appears adequate
Competition effects	Increased competition should lower prices and increase output	TAG unit 3.5.14	Wider Economic Impacts	Existing methodology appears adequate
Employment effects	Job creation	TAG unit 3.5.14	Wider Economic Impacts	Incorporate international connectivity into LUTI models, if not already
Option values	Existence of alternative in times of disruption	TAG unit 3.6.1	Option Values	Amend for international context
Network effects	Increased travel on the domestic network (producer and consumer surplus)	–	-	Identify if effects are genuinely captured in models

Source: Oxera.

6 Conclusion

This examination of connectivity has shown that it is not a straightforward concept to analyse and that, crucially, it is multi-dimensional. This is supported both by the theory and the diverse range of approaches that the literature review has uncovered.

Even defining connectivity as a concept is challenging, although this report has attempted a hierarchical approach to doing so. In practice, data limitations and limitations caused by the way people behave lead to an inability to recommend a universal measure for connectivity. Crucially, the specific mode and journey purpose under consideration will affect the recommended method of measurement.

Care should be taken when proclaiming the benefits of connectivity. Connectivity is an inherent part of transport and therefore is clearly beneficial to the economy. However, there is a risk of double-counting these benefits if it is accounted for explicitly.

The analysis of modelling and appraisal in this report has suggested that, in general, the effect of connectivity on the economy and transport users is captured elsewhere in appraisal. The main potential shortcoming of current modelling appears to be derived from lack of clarity over whether increases in demand, caused by an expansion in the number of available destinations, are allowed for in models. Aside from this significant issue, many of the features of connectivity appear to be adequately accounted for elsewhere.

6.1.1 Options for further analysis

There is still significant scope for further research in this area and, in particular, on some of the issues that are relevant to appraisal. Further work could include:

- a comparison of measures of connectivity in a specific appraisal to assess the impact of the measure on appraisal outcomes;
- a comprehensive review of current DfT international transport models, focusing on trip generation;
- an empirical analysis of the propensity for international travel among both leisure and business passengers. This could attempt to answer the question of the existence of market saturation and the degree of substitutability between destinations;
- a review of values of time for international travel and particularly for freight;
- an empirical examination of the magnitude of competition effects.

The priority of these would appear to be the second bullet point. Allowing for demand shifts in the calculation of consumer and producer surplus should be a fundamental part of appraisal, and its inclusion could potentially have a material impact on appraisal outcomes.

The value that such research could add to policy decisions would be through clarifying the role of connectivity in the economy, and ensuring that it is neither omitted from, nor double-counted, in policy decisions.

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