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To Timbuktu, and back again: why transport connectivity is important

The term 'connectivity' is often talked about in transport, but what is it and how should it be used in appraising new transport schemes? In particular, the benefits associated with connectivity can be significant, to the point of even altering the outcome of an appraisal, thus helping to determine the socially optimal level of investment in transport schemes

The ability of passengers and freight to travel to a wide range of destinations is vital not only for network users (passengers and freight customers), but also for the wider economy since transport allows businesses to function more efficiently. The existence of transport connections that enable users to make these journeys is therefore valuable, and so any assessment of whether to enhance existing or build new infrastructure —for example, a new runway or rail line—should take into account all the benefits associated with these connections. Connectivity is frequently mentioned in the transport literature, but is used to mean a number of different things. What does the concept actually mean and when is it appropriate to use it to test or appraise whether schemes should proceed?

What is transport connectivity?

There is no universal definition of transport connectivity. Fundamentally, it refers to the ability of passengers and freight to move between a wide range of destinations, as well as the 'strength' of these connections (where 'strength' incorporates factors such as the frequency, journey time and capacity of a service). It captures how places are linked, both spatially and temporally. The more destinations that can be accessed and the greater the supply of transport services between them, the greater the level of connectivity. There is a large literature on connectivity[1] and a summary of the theory behind it is provided in the box below.

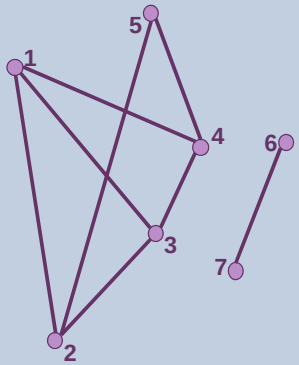
Very few places could be considered totally unconnected, since it is usually possible to travel to and from any destination by some means. For example, there are currently no scheduled flights from the UK to Timbuktu, Mali. This restricts the ease of visiting Timbuktu from the UK since one has to either change flights at Bamako, Mali, or travel overland. This illustrates that even the most remote destinations are accessible, but the ease of reaching a given destination differs from place to place and incorporates various factors such as travel time, reliability issues and financial cost. These factors are captured in the

The theory of connectivity

From first principles, connectivity (including outside of transport) can be represented using a branch of mathematics called *graph theory*. This theory formalises places and their connections into nodes (points in the network—the numbered dots in the figure on the right) and connections (discrete links between nodes—the lines in the figure). In a transport context the nodes might represent ports and the connections scheduled ferry crossings.

Formalising a network into these components can help to measure the connectivity of a node or network and permit objective comparisons across networks. Measures of connectivity are various, and can include the number of connections between two places, the total number of connections in a network, the average number of connections from a given node, and even the ratio of a network's total number of connections to the total number of possible connections.

The theory can be developed further by adding direction to the connections to reflect the direction of traffic flow, or weighting connections to reflect their relative strengths.



concept of *generalised cost*, which places a financial value on a journey that incorporates the ticket price, the monetary value of the journey time, the monetary cost of infrequency, and costs associated with any interchanges. Improvements in generalised cost will therefore generally improve connectivity.

The availability of destinations and the generalised cost of a journey are therefore the primary components 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. For example, a small airport with services to New York and London may be considered more connected than one with the same number of services but no connections to 'world cities'. The value of each connection will therefore change depending on the places connected.

Using connectivity to justify transport schemes

We now turn to whether, and how, connectivity might be used to justify when to spend money on enhancing transport networks.

An assessment of the net benefits of a transport scheme should include not only direct financial returns but also, in the case of government investment, the wider effects that transport facilities have on the economy—such as on employment, business activity and competitiveness. So, for example, a private sector entity's business case may include only benefits in terms of the profits it gains as a result of additional passenger revenue, but a government's assessment should also include those factors that cannot be captured by the private sector, such as wider economic impacts.

This highlights that the importance of connectivity is related to the perspective from which it is viewed—ie, that of a user, operator or funder of the transport network. For the user, connectivity is important because it enhances their ability to get from A to B, or to reach a destination that was previously inaccessible. Project funders can be split between the private sector and governments, the latter usually being interested in social welfare. From a private sector perspective, connectivity is important in so far as it makes a commercial strategy (for example, a hub-and-spoke model) feasible; while from a public policy perspective, connectivity is more complex due to the wider economic impacts that it induces.

How does connectivity affect user behaviour?

A key aspect that both private sector business cases and government appraisals need to capture is how transport users' behaviour is likely to change as a result of any proposed scheme. Depending on how the appraisal system is arranged, these changes may be accounted for separately in the appraisal, or included under 'transport connectivity'. Either way, it is important that they are captured only once (ie, avoiding double counting). Some of the potential effects that a change in transport connectivity might have on users' behaviour are as follows.

- The addition of an extra destination may cause:
  - the generation of new trips to that destination;
  - some trips switching from existing destinations to the new destination;
  - possible changes in the overall number and length of trips.

- A reduction in generalised cost may cause:
  - time or cost savings for existing users;
  - the generation of new or longer trips (some new, some abstracted);
  - mode switching.

Clearly, each of these effects will have further impacts—for example, on the environment and crowding. These effects are not discussed further here, but any appraisal or business case would need to consider them in detail.

Mechanisms through which connectivity affects the wider economy

In general, an improvement to connectivity will make transport users better off through the savings it brings or the additional journeys it enables. However, there are other, wider economic impacts that policy-makers should take into account.

Connectivity between places and people or firms facilitates the functioning of the economy by allowing more opportunities for people and goods. In making use of these opportunities the additional journeys benefit third parties as well as the users themselves. The wider mechanisms through which connectivity can help the economy include the following.[2]

- Place competitiveness—places that are well connected are more attractive for firms that conduct a significant amount of trade, and hence may receive more investment.

- Agglomeration—agglomeration occurs where groups of companies cluster together in the same geographic area. Benefits can arise in these circumstances as a result of higher employment density, with more business interaction, faster exchange of ideas, more efficient matching of workers to jobs, and generally greater market efficiency, leading to higher average productivity.

- Labour and product market competition—the easier it is to travel to a particular place, the more firms are able to compete effectively in that area. This in turn increases efficiency and should lower prices and increase output. A similar effect arises with having a larger pool of labour that competes for jobs.

- Option values—firms and individuals may value the option to travel, even if they choose not to exercise it, or they may value the availability of an alternative to their preferred mode. Enhanced connectivity may therefore be valued, even if the opportunities it brings are not used.[3] For example, there is a degree of option value on the existence of Eurostar and flights between London and Paris. If one option is unexpectedly unavailable (such as flying due to volcanic ash, or taking the Eurostar due to adverse weather conditions—both of which occurred in 2010), the traveller can use the alternative.

- Network effects—adding connections can increase the traffic on the whole network by more than the new connections themselves—ie, adding an international flight to or from a country's main airport may increase passengers on domestic flights into or out of that airport who are connecting with the new international flight.

Measuring each of these factors can be challenging—in particular ensuring that there is no double counting—but in principle they should all be assessed.[4] Having identified the relevant mechanisms through which connectivity affects the economy (as in the examples above), the next step is to determine how the assessed enhancement affects these mechanisms relative to how they would have been without it—ie, to establish the mechanisms both under the enhancement and under a relevant counterfactual. This is the relevant monetary value that can be attributed as the benefit of the enhancement.

Does the value of these connections change?

Understanding that these effects exist is important, but someone conducting an appraisal will want to know if they are material. In particular, there is a question as to whether all improvements in connectivity have the same value. Is there a declining marginal benefit of new connections, and is connectivity important only where significant step changes are made, such as a new port or high-speed rail line? How would the value of an additional connection at a small regional airport compare with one at an already busy large international airport?

The answer to these questions will depend on many factors, but in general improvements in connectivity will be smaller for larger airports because more destinations are already available, costs are lower, and frequency is higher. Nevertheless, the benefits associated with connectivity improvements at a location will be greater the larger the existing network to which it already belongs. Even small improvements can be highly valuable if used by a large number of individuals.

Examples of connectivity in appraisals

It is important that connectivity is somehow incorporated into transport appraisal. The way the UK appraisal guidance is shaped results in the effects of connectivity being captured in other parts of the process (eg, under direct time savings and agglomeration), rather than under a heading of 'connectivity' per se.

The business case for Crossrail is an example in which the wider economic aspects of enhanced connectivity were particularly significant.[5] Crossrail is a proposed major infrastructure project involving a new east–west rail service across London, part of which would be underground. The connectivity benefit of Crossrail primarily arises from reduced travel times and enhanced frequency when crossing London from east to west, or vice versa.

The latest business case for Crossrail quantified the user benefits—ie, the direct benefits discussed in section 2—and derived a 'conventional' benefit–cost ratio (BCR) of 1.9:1, which equates to 'medium value for money' for government expenditure.[6]

To complete the evaluation, the wider economic impacts were also evaluated and found to be significant, at £7 billion–21 billion in 2010 prices. These wider benefits have not been disaggregated in the most recent business case, although an earlier version valued agglomeration at £3 billion.[7] This agglomeration value was determined on the basis of estimates of increases in central London employment and an elasticity of productivity to employment density, taken from research by the DfT and Imperial College London. When these wider economic impacts were included in the business case, the BCR changed from 1.9:1 to 2.7:1, and the scheme went from providing 'medium value for money' to providing 'high value for money'. This demonstrates how accounting for all the connectivity impacts can be important when analysing a transport scheme.

Another recent business case that has incorporated the wider economic impacts of improved connectivity is that of HS2 (the proposed high-speed rail line between London and Birmingham). The main benefit of HS2 is time savings, forecast to be £29 billion over 60 years and mainly accruing to existing users of the equivalent current lines, in particular business passengers who have a high value of time. The business case for HS2 also included wider economic

impacts of agglomeration of £2 billion and enhanced competition of £1.6 billion, both over a 60-year period.[8] The agglomeration benefits are relatively small because they are based on an inter-regional methodology whereby the benefits decay quickly over long distances such as those covered by HS2.

Not all schemes have been as concrete in their inclusion of these impacts. The UK DfT's Impact Assessment of adding capacity at Heathrow concluded that:

> it is recognised that it might be very difficult to quantify such benefits, and there could be some negative impacts to partially offset the benefits. Hence no estimate of wider economic benefits is included in the monetised benefits calculations.[9]

This highlights that although connectivity (or its resulting impacts, if they are measured separately) ought in principle to be included in appraisals, it is not always straightforward to generate robust estimates of its factors. However, given the size of the impacts, and their potential to alter the outcome of a business case, simply disregarding them because of their computational difficulty risks resulting in sub-optimal investment in transport infrastructure.

Conclusion

Transport connectivity is important for a number of reasons, which vary depending on the user's perspective. For users of transport services, such as passengers and businesses, connectivity enables easier transport of people or goods to a wider range of destinations. For private sector providers of transport services (train network operators, airlines, ports or airport operators), connectivity has implications for commercial strategy, while for governments, it is important because of the impacts on the productivity of the wider economy.

Connectivity is a concept that has been widely used and is often poorly defined. The effects of changing connectivity can be manifested in a number of ways, which makes it particularly important that those involved in assessing or writing business cases purporting to capture connectivity clearly define what they are measuring. Without such a definition, there is a risk that either the impacts of connectivity will not be sufficiently reflected in business cases—with the consequence that transport schemes that have a positive (net) impact on social welfare will not be constructed—or the different aspects of connectivity will be double counted—in which case the provision of transport schemes will be less than socially optimal.

[1] See, for example, Black, W.R. (2003), *Transportation: a Geographical Analysis*, The Guilford Press; Geenhuizen, M. van (2000), 'Interconnectivity of Transport Networks: a Conceptual and Empirical Exploration', *Transportation Planning and Technology*, **23**:3, pp. 199–213.
[2] For a comprehensive, UK-based example, see WebTAG Unit 2.8, available from www.dft.gov.uk/webtag.
[3] For more details see Oxera (2003), 'Real Option Valuation', October; or Cartea, A., Meaney, A., Riley, C., Worsley, T., and Zamani, H. (2008), 'Using Real Option Techniques in Appraisal to Value the Options provided by Transport Networks', *Papers and Proceedings of the European Transport Conference*, Leeuwenhorst, Netherlands, October.
[4] Oxera's work for the Airport Operator's Association discusses these issues in detail. See Oxera (2009), 'What is the Contribution of Aviation to the UK Economy?', November.
[5] Cross London Rail Links Ltd, Strategic Rail Authority and Transport for London (2003), 'The Crossrail Business Case – Summary', September, p. 20.
[6] Crossrail (2010), 'Crossrail Business Case Summary Report', July.
[7] Crossrail (2005), 'Economic Appraisal of Crossrail'.
[8] High Speed Two Limited (2010), 'High Speed Rail: London to the West Midlands and Beyond', Figure 4.2b.
[9] DfT (2009), 'Adding Capacity at Heathrow: Impact Assessment', January, Annex 2.

If you have any questions regarding the issues raised in this article, please contact the editor, Dr Gunnar Niels: tel +44 (0) 1865 253 000 or email g_niels@oxera.com

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