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A Methodological Basis for the Definition of Common Criteria regarding the Identification of Bottlenecks, Missing Links and Quality of Service in Infrastructure Networks

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Why the UNECE Inland Transport Committee undertook this study

There has been increasing European interest for some years in international planning and coordination of developments in transport infrastructure. Geopolitical developments in the 1990s, the growth of the European Union and the increasing importance of trading links to Asia have all contributed.

Transport planning on this scale is not straightforward. Both technically and politically it is important to have a shared understanding of key concepts in order to support coordination efforts.

Two particular concepts that are regularly referred to in policy discussions are *bottlenecks* and *missing links*. High-level infrastructure planning is often presented essentially as an exercise in identifying problems caused by bottlenecks and missing links in existing systems and then addressing them.

However, the formal definitions of both these terms are less clear than might be expected. This creates the potential for misunderstanding and inconsistency in policy discussions. The present study was commissioned in order to examine the various ways in which bottlenecks and missing links have been identified and to recommend, for each of the major inland transport modes, ways in which consistency of definition could be sought.

What the UNECE study has found

While broadly shared intuitive understanding of the terms *bottleneck* and *missing link* level is relatively easy to establish, shared understanding at a technical level is much more elusive.

With a prime focus on international traffic, this study sought to identify definitions of the two terms that are theoretically grounded, clear, comprehensible to a range of stakeholders, and capable of being operationalized. However, the search was not fully successful. Technically rigorous definitions were difficult to establish and, in some areas, lack of data is still a significant barrier to implementation.

The study has identified a growing number of investigations of bottlenecks in international transport networks. However, there is only limited consensus about the means by which bottlenecks should be identified and all adopt different definitions depending upon mode of transport. Most have a more or less explicit understanding that both bottlenecks and missing links are manifestations of inadequate quality of transport service. This may be understood through an assessment against design standards, through a capacity analysis comparing traffic volume with capacity, or through an outcome-based analysis against policy-based expected performance indicators.

Quality of service, after a certain point, deteriorates more or less continuously as traffic volume increases but there is normally no unambiguous single point at which quality of service changes from acceptable to unacceptable and therefore the label *bottleneck* is essentially a matter of judgement. In this respect, missing links may be seen simply as extreme cases of bottlenecks, where the quality of service on the relevant link is extremely low.

While recognising that network policy development through identification of missing links and bottlenecks cannot be a substitute for rigorous, model-based transport planning, it does have a role to play, provided it is carefully implemented, for example, ensuring that common forecasting assumptions are made between countries and across modes. The study proposes a way forward developed from this perspective that envisages separate analyses for the different modes, building on and developing identified best practice procedures.

It is clear that such an approach is a potentially useful way to stimulate debate and innovative thinking about network development at an international scale of operation. However, network design simply through the process of identifying bottlenecks and missing links is not sufficient. It must be complemented by rigorous, model-based project appraisal.

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1. INTRODUCTION: WHY EXPLORE THESE ISSUES?

Why do we need a clearer understanding of bottlenecks and missing links?

The term ‘bottleneck’ is in common use in discussing our day-to-day experience of using transport networks. According to the Oxford English Dictionary, it is:

(a) A narrow entrance to or stretch in a road, comparable to the neck of a bottle in shape; a narrow or confined space where traffic may become congested; or

(b) Anything obstructing an even flow of production, etc., or impeding activity, etc.

“Missing link” is also intuitively quite well understood, although not so often used in describing transport networks, other than by professionals or those charged with taking a design overview of a network. Again, the Oxford English Dictionary defines ‘missing link’ as:

(a) A thing lacking to complete a series or to form an intermediate between two things, especially in an evolutionary process, and ‘link’ as:

(b) a means of connection or communication.

The UNECE report TRANS/WP.5/R.60 (p. 6)[1] offers: “… a situation in which the quality of service has extreme low values due to the fact that no direct link exists between two points”.

So far, so good. It is useful to have the two terms “bottleneck” and “missing link” available to facilitate discussion of investment or policy changes at various locations in an infrastructure network and in a way that strikes a chord with people’s intuitions about their own experience of delay and congestion.

But a note of caution is required: once description of a situation or possible situation starts to morph into analysis of a problem and possible policy or action, precision in definition and language becomes more significant. Clear, unambiguous communication is important.

If experiencing a bottleneck is usually an unpleasant or frustrating experience, then it is temptingly self-evident that the identification of a bottleneck in a network requires a response. Similarly with respect to a missing link; when reviewing a network in relation to traffic flows between nodes, it is easy to argue for adding a link to allow a direct connection to replace an indirect one, where the deviation above straight line distance is a substantial proportion and/or where the flows are large.

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[1] References in this report use the Harvard convention, except in relation to UNECE Inland Transport Committee papers, which are referred to in the text by their UNECE reference numbers which in turn may be identified in terms of their title and date in the Reference section of the paper

Increasingly, ‘bottleneck’ and ‘missing link’ are becoming part of standard discourse at the policy and professional levels. They are frequently referred to in discussions about transport network planning, with the strong, though usually implicit, assumption that identification of bottlenecks is an important step along the way to defining investment and other strategies for investment in and/or management of networks. Similarly, but to a lesser extent, the same pertains to “missing link”. It is important to bear in mind also a range of pertinent external factors which are changing and influencing thinking about transport infrastructure provision, for example, the explosion of container traffic, especially to and from East Asia, increased concerns about the effect of transport on the environment, and important changes in transport sector deregulation and infrastructure pricing with consequent implications for demand.

But both terms, while superficially attractive, are not easy to pin down technically. What precisely, in transport engineering or planning terms, is a bottleneck? When does a bottleneck exist and when does it not? When is a link missing? In reality, the vast majority of direct links are missing in infrastructure networks. In a network of n nodes, of the $n(n+1)/2$ links that could be present, typical road network densities, for example, would have only about $1.5n$ extant in a developed country (Chorley and Haggett, 1969, ch. 1).

Initial ideas about definitions

The thinking behind this current paper is simply that, if these words, bottleneck and missing link, are commonly applied in policy discussions and thus become concepts that start to shape significant decisions, then:

(a) they should be theoretically founded, clearly defined and understood in terms that key stakeholders feel comfortable with;

(b) it should be clear in normal circumstances they can be operationalized, particularly with regard to data availability;

(c) professionals must be clear that the terms align sufficiently with the identification of properly analysed priorities for investment and/or policy change that to focus policy discussion using the two concepts is helpful to eventually securing transport policies rationally based on the stated needs and priorities of key actors.

Perhaps, however, this is an over-demanding stance. Especially if comprehensive definitions are not available, or if time constraints or lack of data mean that fully rigorous analysis is not practicable, an inability fully to pursue (a) and/or (b) does not necessarily mean that the whole process should be abandoned. Even if we cannot agree rigorous, theoretically founded definitions, then there can still be value in sharing ways of operationalizing the ideas of “bottleneck” and “missing link”, so that communication about network planning may be clearer and more consistent.

This paper derives from earlier work undertaken on behalf of the UNECE Inland Transport Committee, notably reports TRANS/WP.5/R.44 and TRANS/WP.5/R.60 and the 2005 *Trans-European Motorway (TEM) and Trans-European Railway (TER) Projects’ Master Plan* (UNECE, 2005a).[2] As such, its concern is with international flows at a pan-European level, with due attention paid also to flows to major trading partners outside Europe. It is not concerned with urban networks or congestion, except to the extent that urban conglomerations with their commuting and similar flows may affect international movements. It concentrates on the three key inland modes: road, rail and inland waterway, but recognizes also the increasing importance of multi-modal transport and so pays some attention to this area also.

The purpose of the present work is to build on this earlier experience to suggest an approach that will permit an overview of existing bottlenecks and missing links, based on national planning mechanisms but nonetheless supporting thinking which is pan-European in its scope. The approach must be practicable and support policy makers and professionals in concentrating attention on those locations in the overall network where investment or policy changes will have the most beneficial overall effect. It suggests procedures that will support decisions validated ultimately through other processes. It will not itself make clear-cut decisions about where investments should be made, or not; about where administrative procedures should change, or not.

The paper develops as follows: in section 2, some of the policy background is briefly summarized, to provide a fuller overall context. Section 3 first examines what theoretical underpinnings there are to the tasks of identifying bottlenecks and missing links Then, largely through a review of existing attempts to establish methodologies to fulfil these tasks, it seeks to establish what can be done in practice. Section 4 proposes ways in which the Inland Transport Committee of UNECE might like to consider moving forward in this regard.

2. POLICY BACKGROUND AND HISTORY OF PREVIOUS WORK

Previous UNECE work has not developed fully rigorous definitions

The Inland Transport Committee of the UNECE has been concerned about infrastructure network missing links and bottlenecks since at least 1992 (TRANS/WP.5/R.44), largely in the context of developing efficient and effective trans-European transport networks. For example:

> "The Working Party felt that before commencing another phase of activity, which includes:
>
> The identification of investment priorities on major international transport routes;
>
> The establishment of a timetable for the realization of the infrastructure investments;
>
> The assessment of the costs for improvement of this infrastructure and appropriate financing arrangements,
>
> there was a need for a closer analysis of such terms as bottlenecks, missing links and quality of service of transport infrastructure networks." (TRANS/WP.5/R.60, p. 5).

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[2] The latter was also subsequently reported in the academic literature in Tsamboulas (2007).

Nonetheless, the work undertaken for TRANS/WP.5/R.60 is a very valuable contribution, both in terms of its emphasis on practicality and its clarity about definitions of important relevant terms, see especially annex 3 of that report.

The explicit reference to quality of service is picked up in the formal terms of reference for the current piece of work and is an important reminder that the identification of whether there exists or not a "bottleneck" or a "missing link" is ultimately a judgement formed against a real or expected or perceived quality of service performance of the network in meeting a demand for movement.

Since TRANS/WP.5/R.60 in 1994, a number of attempts have been made to identify bottlenecks and missing links but problems of definition and methodology have been a recurring theme. A recent but important and ambitious piece of work, mentioned above and accomplished through UNECE, aimed to develop master plans for the Trans-European Motorway (TEM) and Trans-European Railway (TER) networks, using, among other ideas, practical interpretations of the concepts of bottleneck and missing link, based on TRANS/WP.5/R.60, to help formulate those plans (UNECE, 2005a).

In the 2005 study, special emphasis was given to identification of bottlenecks and missing links in relation to major international flows. Following the approach outlined in TRANS/WP.5/R.60, for the Trans-European Motorway system (TEM), bottlenecks were identified using an approach that related forecast traffic flows (adjusted for vehicle mix and terrain type) to typical design capacity of a road of the type in place. For the Trans-European Rail network (TER), it was not felt practicable to identify bottlenecks in any rigorous, evidence based way within the time and resources available to the project, and instead analysis was restricted to identifying missing links, nominated on the basis of expert judgement.

Subsequent work (TEM, 2005) identified the series of sections of the Trans-European Motorway network that appeared likely to emerge as bottlenecks up to the year 2020. Explicitly recognizing that there is no uniform, generally accepted definition of bottlenecks, it based its identification on the US *Highway Capacity Manual*, TRANS/WP.5/R.60, and work by the Conference of European Directors of Roads (CEDR, 2004).

Although the *TEM and TER Master Plan* work was restricted to road and rail, other work, including TRANS/WP.5/R.44 and TRANS/WP.5/R.60, has also considered inland waterways. For example, the Inland Transport Committee Working Party on Transport Trends and Economics at its nineteenth session in September 2006 considered information identifying perceived bottlenecks relating to all three terrestrial modes and in 2005 it received a report, *Inventory of Most Important Missing Links in the E Waterway Network* (UNECE, 2006b) in which bottlenecks and missing links were identified for a wide range of countries' inland waterway systems. See also TRANS/SC.3/159 and TRANS/WP.5/2006/2.

UIC has undertaken important work in relation to rail network capacity

A further stream of work with a single mode focus is that undertaken through the International Union of Railways (UIC) looking at railway infrastructure capacity. Leaflet 406 (UIC, 2004b) suggests a methodology for capacity estimation of rail links which may then in turn be set against estimates of demand to identify bottlenecks, e.g., the EURAILINFRA report on capacity analysis and bottleneck estimation, UIC (2004a) and the *Capacity Management* summary report (UIC, 2004c). This methodology is relatively demanding in data and processing time, being based on simulations of line sections. More recently, a simpler UIC methodology has been developed and applied in the 2008 ERIM report (UIC, 2008). It is used for the assessment of plain lines and provides a good general overview although less accurate than the full Leaflet 406 analysis. This methodology has been applied to produce a list of likely capacity constrained sections on the main rail corridors for 2020.

Studies through the ECMT and European Commission have also studied bottlenecks

The European Conference of Ministers of Transport (now the International Transport Forum) has also for some time taken an interest in infrastructure planning at the pan-European level for road, rail and inland waterway. It does not seem to have undertaken any published work on the definition of bottlenecks or missing links, but has reported work identifying bottlenecks in individual countries and convened conferences where the terms “bottleneck” and “missing link” have very much been part of the language in terms of which the need for infrastructure and other improvements are identified. Moreover, it is clear from this work that the same type of language and thinking is common in the policy making of individual nations – Germany, Italy, the United States of America and the United Kingdom, for example.

Bottlenecks and missing links (network “sections”) have also become part of the established language in European Commission (EC) discussion of infrastructure network development, especially in the development of the TEN-T. TEN-T were initially conceptualized in 1996 to address transportation issues at a European level and guidelines to promote development were promulgated (Decision No 1692/96/EC of the European Parliament and of the Council of 23 July 1996 on Community guidelines for the development of the trans-European transport network, Official Journal L 228, 09/09/1996 P. 0001 – 0104). Subsequently, concern about speed of progress lead to the issue of a revision to the Guidelines in 2001 in which a somewhat greater focus on addressing bottlenecks and missing links was introduced. Further revision took place in 2004.

In this work, although there are references to documents in which assertions are made about the extent of congestion expected on European networks (for example, the 2001 Transport White Paper, OM (2001) 370 suggests that 10% of the road network was even then daily affected by jams; and 20% of the rail network is regarded as bottlenecked) clear understanding of what is meant by the term is not explicit. Nor is there much reference to the “missing link” concept.

In 2006, DG-TREN commissioned a pilot study, *The Northern Transport Axis* study, later reported in December 2007 as WSP (2007). This study had a strong focus on bottleneck identification and was underpinned by a reasonably rigorous methodology.

If, for reasons of data unavailability, model deficiencies or politics, it is not feasible to construct an overall, multi-national model-based approach, then typically two main traditional approaches to bottleneck identification have been used. One is *design-standard* based and simply sets a design standard for each relevant link based on its classification or similar, and then identifies bottlenecks as any sections or locations where the design standard is not met. The second is based on *capacity analysis* and compares traffic volume on a link or at a node to capacity (either for the present or some future time) and identifies as bottlenecks locations where demand exceeds capacity. Most of the studies referenced elsewhere in this section are based on one or other of these approaches.

The Northern Transport Axis study, however, argues for what it terms an *outcome-based* analysis. Essentially what this does is to broaden the list of performance indicators by which the existence or otherwise of a bottleneck might be identified to include not only capacity questions but others, primarily with a quality of service orientation. Quality of service is, of course, a key feature in the terms of reference for this present report also. Relative to the proposals in TRANS/WP.5/R.60, these proposals can be seen as an extension in scale, but not in principle. For example, in TRANS/WP.5/R.60 for roads, a wide range of quality of service performance indicators are listed (p. 12), but it is recommended (p. 14) that only a capacity indicator and a speed indicator are used.

Separate analyses were conducted in the *Northern Transport Axis* work for border crossings, railway links and road links, but linked by the common use of five broad criteria, which are then defined more specifically in ways to make them operationalizable for the three different cases. The evaluation criteria used reflect: level of regulatory harmonization; mobility and/or line speeds; capacity utilisation; road safety; and environment. Not surprisingly, the data availability challenges of such an approach are considerable and are noted in the report (pp. 36-8).

The *Northern Transport Axis* report argues that an outcome-based evaluation approach avoids some problems inherent in capacity analysis. While this is true, it should be recognized that outcome-based evaluation of the type proposed is not without its problems. One is data needs, as above. A second is that the profile of each bottleneck is assessed against indicators of achievement of policy objectives. How these latter are defined will be critical, especially if different countries set different policy objectives. A third is that some of the criteria, as currently applied, require assessment by expert judgement, which would be inherently difficult to keep consistent across the wider range of jurisdictions and geographies that the present work focuses on, compared with the (relatively) specific focus of the *Northern Axis* work.

That said, however, this is an interesting piece of work, broadly consistent with the TRANS/WP.5/R.60 approach and has the virtue of having been applied in practice recently and in the light of current modelling practice, data availability and policy needs.

In May 2007 the European Commission also issued an invitation to tender for a project, *Traffic Flow: scenario, traffic forecast and analysis of traffic on the TEN-T, taking into consideration the external dimension of the Union*, one element of which relates to the identification of bottlenecks affecting traffic flows and where, at least by omission, there is an implication that precisely how a location is identified as a bottleneck is a part of the research to be undertaken. It is relevant that the scale of this work is quite substantial, with some 300 person days devoted to bottleneck identification, with methodological development being a non-trivial component. The report from this study is scheduled to be submitted in October 2008.

In the same vein, in relation to the important emerging topic of developing effective multi-modal logistic networks for Europe, a recent EC announcement (http://www.ec.europa.eu/transport/logistics/overview/doc/2006_06_28_communication_en.pdf) is seeking to identify bottlenecks in freight transport logistics at least in part through bottom-up, industry-driven nomination of bottlenecks.

A stream of somewhat more theoretically founded, logistics orientated work, which although not designed for this purpose can to an extent be used for bottleneck identification and readily incorporates transhipment at border crossings or between modes, has been developed and applied by ESCAP (2003), following the work of Beresford and Dubey 1990) and Banomyong (2000). Essentially, by plotting cumulative travel time against distance, it highlights transshipment bottlenecks, but appears to require expert judgement and further ad hoc assessment to list the bottlenecks themselves. Details are available in ECE-ESCAP (2008), pp. 151-2.

A similar, but more sophisticated, approach has also been adopted in Arnold (2005). It works in terms of plotting travel time and travel cost against distance, recognising the effects of border crossings and other administrative delays on the efficiency of the overall supply chain. It further introduces considerations of reliability and flexibility to offer a multicriteria view of corridor performance.

But there have been some suggestions of over-reliance on too simplistic an approach

The developing emphasis on using the identification of bottlenecks and missing links to specify transport plans is, however, not uncontested and is certainly not apolitical. Jack Short, then Secretary General of the ECMT, expressed some concern about the role of bottleneck identification in shaping European Union (EU) transport planning (Short, 2001). Turró (1999, ch. 3) has commented on the politicization of EU priority lists which purport to address bottlenecks. Peters (2003) argues that EU transport investments lack consistency and sustainability due to the existence of partially complementary, partially competing development objectives, with missing links and bottlenecks sitting alongside cohesion and polycentricity as rationales for action and with transport network investments having to satisfy a range of policy objectives related to growth, competitiveness, cohesion and sustainability. Rathery (2007) accepts that infrastructure networks are undoubtedly “part of the problem”, but suggests that they may be over-emphasized relative to institutional reform.

None of the above is an argument for abandoning “bottleneck” and “missing link” from the thinking that underpins efforts to plan the development and administration of transport infrastructure networks at the pan-European level. What it does do, however, is begin to shape an approach to the investigation that this paper reports.

Firstly, it suggest that, at least at the international, pan-European level, there seem to be no widely available and agreed definitions of what constitutes a bottleneck or a missing link. Secondly, identifying bottlenecks and missing links is not a substitute for rigorous infrastructure planning; rather, it is a potentially useful step along the path from problem recognition, through analysis to action; it supports the process through which specific concerns are recognized and discussed. Thirdly, there are concerns about the interface between the political process at the pan-European level and the "rational" planning process, with a view that it can be too easy to adopt the simplistic view that removing bottlenecks and building missing links will in some way automatically optimise network configuration.

Overall, however, reviewing the relevant literature suggests that it is UNECE Inland Transport Committee that has worked longest and most deeply on *methodologies* for bottleneck and missing link identification, multi-modally and internationally. The recently completed *Northern Axis* work complements this approach. Therefore it is reasonable to take these two streams of published work as a good approximation to the state of the art and to use them as a starting point for a fuller consideration of what might be done in this regard.

UNECE has developed a comprehensive set of studies based on identification of bottlenecks and missing links

At its meeting held in September 2006, the UNECE Inland Transport Committee Working Party on Transport Trends and Economics discussed replies to its questionnaire on bottlenecks and missing links and specifically the document TRANS/WP.5/R.60, *Methodological basis for the definition of common criteria regarding bottlenecks, missing links and quality of service of infrastructure networks.* Recognizing the value and unique content of the document, nonetheless it felt that the methodological basis and analysis might be outdated. It therefore asked the secretariat to convene a small informal group of experts to undertake the task of revising and updating the document in the light of new methodological developments, evolution and the current practice of ECE member countries. This current work is the report for the activity requested by the Working Party.

Previous UNECE work is primarily reflected in two documents.[3] The first of these, TRANS/WP.5/R.44 prepared in 1993, reports the outcome of a country-by-country questionnaire survey that sought information on four matters: current capacity problems; regulatory measures to alleviate bottlenecks; infrastructure measures to relieve bottlenecks; and financing of up-grading and construction of infrastructure. Some difficulty was experienced in securing a good response rate to the questionnaire and, where responses were received, information was not always complete or in sufficient detail.

In TRANS/WP.5/R.44, bottleneck identification appears to have been done individually by each country, without reference to any shared definition or parameters. Bottlenecks were identified as being induced by either inadequate capacity relative to demand or by poor quality of maintenance, meaning that practical capacity was below the level it could otherwise be. Typically, at the time of the report, poor maintenance was associated with countries in Eastern Europe and with

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[3] A fuller summary of the immediate background to the current work is set out in annex 1.

railway links. Lack of capacity was more often a roads phenomenon and occurring in Western Europe. Nodes, as well as links, induced bottlenecks especially in rail systems; border crossings were also a problem. The inland waterway network functioned as a network only in certain very specific geographic areas and was generally less fully reported on than road or rail.

Reporting of missing links was not directly requested in the questionnaire, but TRANS/WP.5/R.44 contains an analysis based on the study “The Cost of Inadequate Transport Infrastructure in Europe”, undertaken in 1990/1991 for the European Parliament. This study took a network-based, Europe-wide approach and sought to estimate demand levels for road passenger and freight, rail passenger, rail freight and inland waterway and to then relate these to existing network capacity. The fundamental difficulty encountered was the lack of a definition of “adequate” when assessing whether or not service levels provided met expected standards (since this in turn would influence whether there was a case to argue that a link was indeed “missing”). The study therefore applied its own quality standards, attempting to estimate what would be seen as “adequate” by European users of the infrastructure, framed both in terms of the structure of networks and service quality over them.

Overall, it is clear from the report that, both for identifying missing links and bottlenecks, a major issue was a lack of adequate benchmarking in terms of either a relationship between traffic density and required infrastructure or an understanding of what quality of infrastructure (service) would be seen as adequate. A separate addendum to the report (TRANS/WP.5/R.44/Add.1) suggested a study of the definition of common criteria in relation to bottlenecks, missing links and quality of service on infrastructure networks.

The second major UNECE document, dated 1994, is TRANS/WP.5/R.60, which is essentially the response to that suggestion for a further study.

This paper first of all discussed the three inter-related concepts, bottleneck, missing link and quality of service, recognizing that previous work had, for pragmatic reasons, not sought to establish or apply agreed definitions but had rather relied primarily upon national estimates of where bottlenecks, in particular, existed. It also recognized that establishing internationally common understandings of these terms would not be straightforward and that any efforts in this regard must of necessity also have regard to operational issues such as data availability and uncertainties in traffic forecasts. At the time, most nations had developed their own, individual ways to identify bottlenecks.

Nonetheless, the group brought forward recommendations for standarization of criteria, although in some regards, in relation to the choice of values for thresholds, no specific numerical recommendation was made, because of the need for wider discussion before alighting on any particular figure.

The group was also very clear that the identification of bottlenecks and missing links represented only one (early) stage in the progress towards any decision to invest in new infrastructure or to change traffic management or other arrangements. Such decisions should only be finalized following a full evaluation process involving project design and economic and other forms of social appraisal. The existence of a bottleneck is in itself neither a necessary nor a sufficient condition for there being a case for investment or policy change. For example, geographical barriers, such as mountain ranges, may well mean that direct investment in a congested link may be impossible or hopelessly expensive.

The report considered the inter-relationship between bottlenecks, missing links and quality of service in terms of capacity, quality of transport service and traffic flows. It argued that each of these inter-relationships needs to be examined separately for road, rail and inland waterway networks. The ranges of factors leading to less than adequate quality of service were sufficiently distinct that generalization across the modes offered little help.

In general, the phenomenon of less than adequate quality of service in a transport network is a complex one. For example, judgements have to be made about what is an adequate quality of service; assessments are needed of the extent to which existing quality of service levels are leading to suppressed demand, or demand that is shifted in time, route choice, or mode from where it would otherwise fall. Technical capacity (the flow that a link could in principle accommodate in 24 hours, say) can be quite different from what it can actually service, given variations in travel demand through the course of a day.

The report recognizes that, while it is important to base the assessment of bottlenecks, etc. on as sound an evidence base as possible, the scale of the required analysis for Europe as a whole dictates that procedures must be relatively straightforward to implement.

Standardized and reliable data are a core requirement for any analysis, with as much as possible agreement on issues such as reference time periods for traffic flow and capacity assessments; uniform classification of vehicle types; differentiation of freight from passenger traffic; and information on variations across time in traffic patterns.

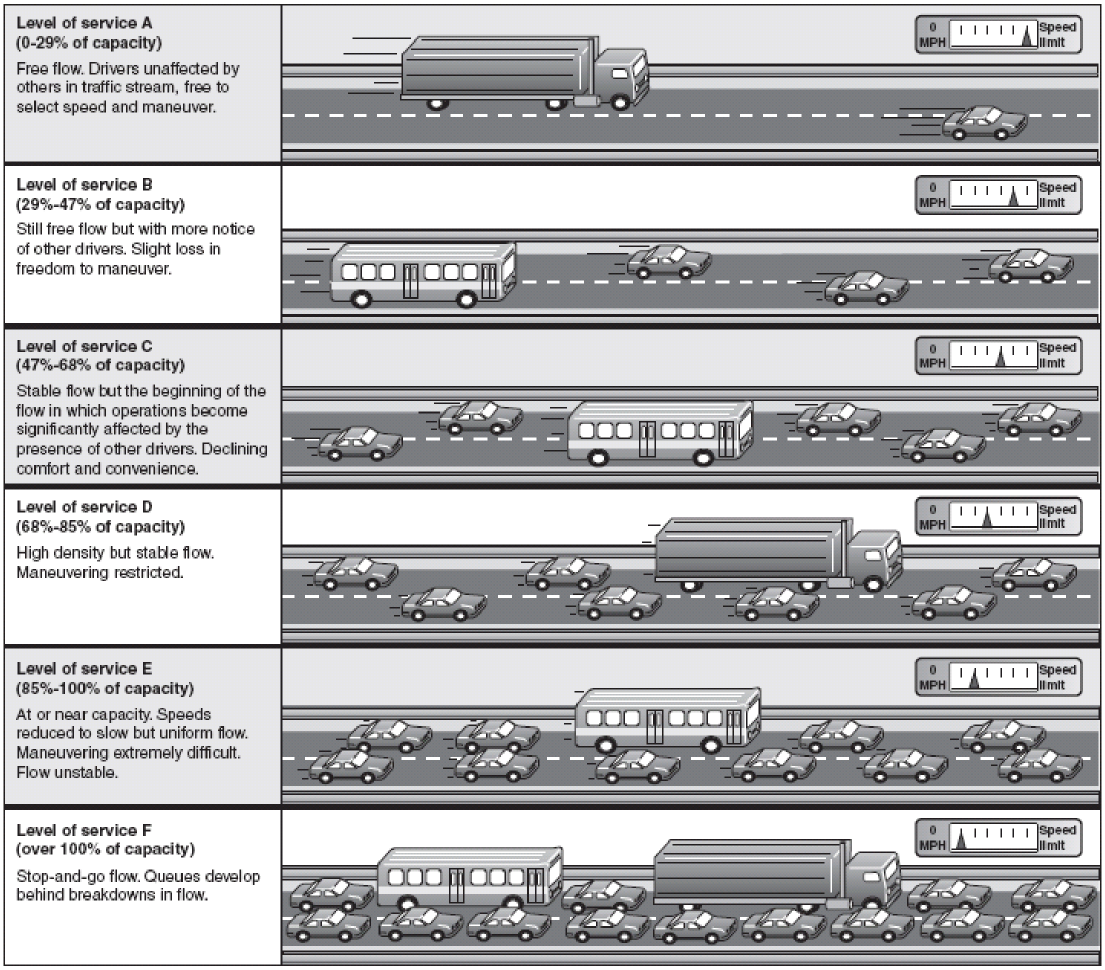
It is important also to make assessments relative to an agreed set of traffic forecasting assumptions and with a common understanding of broad policy developments – e.g., medium- and long-term policy regarding road/rail balance.

The report then offers recommendations separately for each of the three modes for indicators against which a section of network could reasonably be assessed as a bottleneck.

Applications to roads

Quality of service on roads can be manifested in many ways, but speed is typically well correlated with many of them and is an established indicator of quality of service. In turn, traffic volume and travel speed are inversely correlated for any given infrastructure configuration (see Figure 1). Capacity of a road link relates to the maximum number of vehicles that can pass in a given time period, which, among other things, depends on the required quality of service.

Figure 1: Representation of levels of service on a two-lane highway



Source: United States Government Accountability Office (2007).

TRANS/WP.5/R.60 suggests that bottleneck identification might be based on the relation between road capacity and demand. Specifically, it recommends using daily data (because of data limitations for more disaggregated data) and calculating a weighted total traffic demand for each link in passenger car units (pcu) (goods vehicles and buses are weighted more heavily) and comparing this demand-side calculation with estimates of daily capacity (in turn dependent upon the type of road considered) which are available from highway capacity manuals.[4] It further suggests that a bottleneck might be argued to exist if demand exceeds capacity on at least 80 – 120 days of the year.

For missing links, it argues for computing for all regional centre to regional centre pairs the speed of travel as a ratio of time taken to crow-flies distance. If this speed falls below a 60–

[4] TRANS/WP.5/R.60 leans heavily on the US Department of Transport Highway Capacity Manual. Since publication of TRANS/WP.5/R.60, a new edition of the manual is available (TRB, 2000).

100 km/hour range (depending upon whether the distance between centres is short or long), then it is deemed that the relevant link is missing. This is independent of traffic volume, but does need to be refined in the case that there may be significant geographical barriers.

Applications to rail

For rail, speed and comfort are seen as the prime quality of service indicators, but these in turn depend upon many parameters in relation to the construction of the line itself and to operating procedures. Similarly, defining capacity is a complex business. In practice, capacity, measured as number of trains per day, was often computed simply from a knowledge of the track configuration (single vs double) and some knowledge of the traffic mix using the line. It is acknowledged, however, that other, “nodal” factors, such as marshalling yard capacity, stations, etc. could have a significant influence on capacity levels also.

As a practical indicator, TRANS/WP.5/R.60 suggests simply identifying bottlenecks by assessing whether the anticipated demand exceeds 60–80 trains per day for a single-track main line and 2 x 100–200 trains per day for a double-track main line. No specific recommendation in relation to missing links was made.

Applications to inland waterways

For inland waterways, speed is typically less of a consideration in terms of quality of service. Additionally, capacity of the network as a whole is significantly influenced by the fact that inland waterways are constructed to very different specifications with marked differences in capacity. The UNECE, for example, identifies seven different categories (I through to VII).

There are thus major, structure-dependent bottlenecks to use of certain types of craft. However, the cost-effectiveness of measures to tackle such issues is always likely to be problematic. In TRANS/WP.5/R.60 bottlenecks induced by inadequate lock capacity were seen as the prime bottleneck issue for inland waterways and a procedure for calculating lock capacity was given. In TRANS/SC.3/159, two types of bottleneck were distinguished: *Basic Bottlenecks*, which are sections of E waterways whose parameters are not in conformity with the requirements of European Inland Waterways, Class IV; and *Strategic Bottlenecks*, which are other sections satisfying the basic requirements of Class IV but which nonetheless ought to be modernized to improve the structure of the network or to increase the economic capacity of inland navigation traffic. This work has since been taken forward further by the UNECE Working Party on Inland Transport (SC.3) as part of its work on the AGN (see annex 2).

Overall, although TRANS/WP.5/R.60 did work through some case studies for each mode of construction projects aimed at relieving bottlenecks, in no case was there a direct application of any bottleneck identification procedure. The report did not proceed as far as recommending a specific methodology for bottleneck identification, which it saw as further development work to be done, but simply set out arguments for the indicators noted above as potentially practicable guides to identify where bottleneck issues may be present. It was, however, quite clear and explicit (section 6) about the potential value, if achievable, of definitions of bottleneck and missing link criteria, based on a quality of service concept and sharing a common methodology that could be internationally applied.

In this regard it is also interesting to note a paper reviewed at the nineteenth session of the UNECE Working Party on Transport Trends and Economics held in September 2006 (UNECE 2006a). This paper, together with associated documents, reports the responses to a questionnaire, using the criteria suggested in TRANS/WP.5/R.60 by 15 countries associated with the AGC, AGR and AGN networks, and shows that devolved requests for bottleneck and missing link identification based on such criteria are, at very least, capable of being acted upon. Without some meta-analysis, this does not directly establish accuracy or consistency, but it is broadly supportive of this style of approach.

3. A WAY FORWARD

There is increasing interest in international transport planning

Recent socio-political developments, notably the expansion of the EU and changing trade patterns with the East, have brought about, and arguably will continue to bring about, significant re-orientations of traffic flow. Given the long time lags typically involved in major transport infrastructure building and in securing international agreements on changing traffic regulations and similar matters affecting the efficiency of international transport, there is a strong argument for continuing to develop “master plan” style planning for transport networks. Growing environmental concerns, the role of inter-modal transport and the potential for substantial modal shifts stemming from this cause reinforce this argument.

Planning at the European master plan scale of operation is difficult, because of the size and complexity of the analysis required, because of differences between the ways different national transport agencies function, and because of data variability and deficiencies. Of course, these difficulties would apply to any analytical approach to transport planning, whether framed in terms of the identification of bottlenecks and missing links or not.

A review of the literature, touched upon in the previous section of this report, has revealed no major theoretical breakthroughs since TRANS/WP.5/R.60. There have been developments, for example a new *Highway Capacity Manual* (TRB, 2000), the work by the UIC on rail link capacity calculation (UIC, 2004b) and the *Northern Axis report* (WPS, 2007), but these have been essentially methodological and at the link level of analysis. There has, as well, certainly been an expansion of discussion in the policy arena in which the concepts of bottleneck and missing link continue to figure prominently.

The new *Highway Capacity Manual* has an approach to capacity estimation which is essentially the same as its predecessor. The UIC (2004b) work on rail link capacity, on the other hand, represents a significant departure from what was available previously. It uses link-specific simulations to assess the true maximum working capacity of links using realistic estimates of the demand mix which the link is likely to face. This provides the opportunity for much more realistic link capacity estimates than had previously been accessible.

More directly applicable for rail in the context of European-level planning is the recent ERIM report (UIC, 2008) which looks at up-grading needs and potential investment costs for 2020 target year traffic projections. This work is simpler in some ways than earlier UIC approaches, comparing average daily number of trains recorded with the theoretical link capacity. Assuming a 20% improvement in load factors and using 70% of 24-hour link capacity as a benchmark for what would constitute full utilisation of link capacity, it has identified that 32% of current provision will be at capacity or above by 2020.

Overall, however, the request from the September 2006 Inland Transport Committee Working Party on Transport Trends and Economics meeting to re-consider and up-date the methodological basis for the identification of bottlenecks and missing links seems timely and appropriate.

But an approach based theoretical analysis alone is insufficient

In section 1, it was argued that, if, ‘bottleneck’ and ‘missing link’ are terms commonly applied in policy discussions and thus start to shape significant decisions, then the terms should have a theoretical foundation, should be capable of being operationalized, particularly with regard to data availability; and should align sufficiently with the identification of properly analysed priorities for investment and/or policy change.

“Bottleneck”, in particular has come in recent times sometimes to be prefixed by terms such as “environmental” and “social”. However, in this report, bottlenecks are principally assessed in relation to traffic flow and quality of service, although it is recognized both that there can often be an association between negative traffic quality of service impacts and other concerns and that, on occasions, there will be other, say localized environmental, impacts that may underpin an argument for significant investment or policy change in the transport system.

A key question, then, is, for *traffic* bottlenecks or missing links, are there any theory-based drivers that can inform practice in a useful way? The focus of the commissioned work is, quite rightly, ultimately on methodology, not theory. It is concerned with how the concepts of bottleneck and missing link can best be operationalized to help achieve wider economic, social and political goals in relation to infrastructure development. Nonetheless, if there were a theoretical underpinning then clearly it would be important to identify it. Methodology that is inconsistent with an underlying theoretical base could be difficult to defend.

It is initially an attractive proposition to believe that such a theoretical underpinning for the identification of bottlenecks and missing links should exist and could be used to guide application. In practice, this is only true to a limited extent.

In the case of bottlenecks, there are at least two impediments to establishing a clear theoretical foundation. The first is that in a road network, traffic will in general, following

Wardrop's principle,[5] equilibrate. Without relatively sophisticated demand modelling and forecasting, it will be difficult to know from link-level data where bottlenecks really exist, because traffic will try to avoid them. Secondly, what constitutes a bottleneck on an individual link is, to a degree, a matter of preference and judgement, rather than absolute definition. How much delay is too much? There is no single answer: it will depend upon the trip purpose, the individual, the value and nature of the commodity for freight traffic and so forth.

This is not to say that, for rail and road links at least, there are not some theoretical guides. There are points on speed-flow curves on links, for example, where significant increases in congestion and hence delay start to occur and these are, to an extent, identifiable in a theoretically founded way.

An over-riding concern, moreover, is that such theoretical under-pinning as there is operates at the individual link level; however, the ultimate concern is with the network and the performance of the whole is not simply the sum of the performances of the individual parts.

A further influence which is difficult to incorporate in a way that is theoretically founded but practicable concerns pricing. For rail, but increasingly for road, direct user charging is in place. Thus the level of use of a link and the degree to which evidence of a bottleneck emerges depends not just on the level of demand and the physical characteristics of the link, but will also be influenced by the level of charges, on the individual link concerned and potentially on other links also (see Figure 2). Thus, for example, by setting price high, a link operator can eliminate any immediate suggestion of there being a bottleneck, although there may well be bottleneck consequences elsewhere and/or in some way a "societal bottleneck" in the sense that in terms of socially optimal provision there is an inadequacy that has not been identified and/or or addressed.

Similarly with missing links, as discussed earlier, most links are missing in most networks. There is no straightforward piece of theoretical analysis of networks that states that a particular link *should* be present. That judgement is one that requires some element of meta-analysis. Indeed, a key issue is that such theory as there is is entirely at the link level, whereas what is needed for master plan work must take a broader view which combines links.

In summary, a fully rigorous, theoretically founded basis for identifying bottlenecks and missing links in networks that directly and prescriptively informs network-level analysis, is not available. However, for road, there is at the link level some theoretical underpinning for the identification of bottlenecks and for forecasting at what level of traffic flow a link might begin to be seen by users as a bottleneck. Similar judgements are possible for rail links, although arguably rather more empirically founded.

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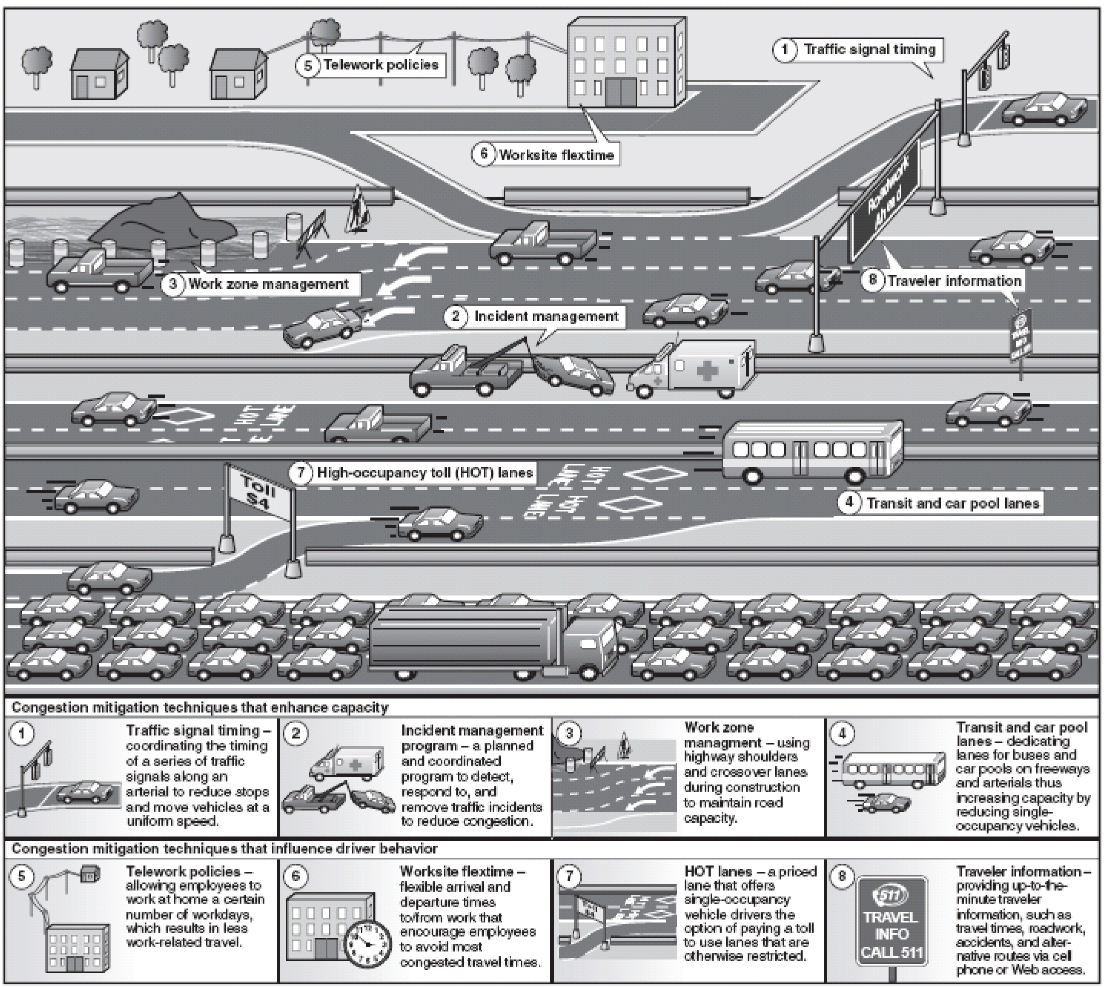
[5] Wardrop first enunciated the principle that traffic flowing over a network between an origin and a destination will seek to use the shortest/cheapest available set of links and, in seeking to pursue this goal, a set of users would ensure that all paths between any given origin-destination pair would have the same equilibrium cost/time, since any difference would be nullified as users sought to use any cheaper/shorter route and thereby undermine its advantage through the extra congestion their use of the relevant links would induce. This fundamental behaviour also has implications for marginal cost road pricing and for demand modelling and forecasting.

The lack of a fully theoretical foundation does not, however, invalidate the approach of seeking to understand where bottlenecks and missing links exist or may occur in future. The day-to-day familiarity to non-specialists of the terms “bottleneck” and “missing link”, and their intuitive appeal as identifying “causes of concern” commend them; and, indeed, the continuing use of these terms in policy discourse in many contexts supports the argument that they have value. The basic notion of a (congestion-induced quality of service) bottleneck as the consequence of transport conditions leading to travel times that are unacceptably long for either passenger or freight traffic continues to be fundamentally valuable. In some ways, it makes the present piece of work even more important, in that the need to establish consistent and defensible methodologies is that much the greater. This is essentially the aim for the remainder of this report.

Figure 2: Select Congestion Management Techniques that Enhance Capacity and Influence Driver Behaviour and Demand



Source: United States Government Accountability Office (2007).

Development and application of the UNECE style of work offers a practicable way ahead

UNECE has:

(a) A focus on international traffic flows and a wish to guide and co-ordinate, internationally, transport infrastructure development so as to facilitate traffic flows;

(b) A concern minimally to look at pan-European flows and, increasingly, to improve links to peripheral countries also.

Previous UNECE work has:

(a) Encountered some significant conceptual difficulties in defining bottlenecks and missing links;

(b) Adopted an approach that has largely devolved data gathering to individual countries and has relied on their existing data sources;

(c) Found problems of inconsistency of data across member countries and of incomplete or inconsistent completion of questionnaires.

Within this context, the preceding review and analysis has raised the following points pertinent for recommending a way forward that supports UNECE's overall ambitions for this stream of work:

(a) Simply combining link-level identification of bottlenecks or missing links will not of itself directly lead to transport infrastructure optimization at the network level;

(b) But bottlenecks and missing links are useful concepts if used carefully to initiate, focus and support discussion of network planning, especially with non-specialists;

(c) Any full proposal for infrastructure investment would nonetheless have to be taken through a meta-process, above the link level of aggregation that involves transport modelling, economic, environmental and social appraisal, and engagement with the broader policy process;

(d) The processes for identifying bottlenecks and missing links are different from each other;

(e) The processes for assessing the presence or otherwise of a bottleneck, while fundamentally linked to quality of service in all three cases, must nonetheless be undertaken using different methodologies for the three modes, road, rail and inland waterway;

(f) A separate focus on purely international traffic is difficult to achieve and arguably inappropriate since bottlenecks and missing links affect all traffic;

(g) Nonetheless, by avoiding micro-modelling of the physical network and by careful choice of thresholds and time intervals in regard to bottleneck definition, undue influence of smaller scale, peaky and often urban congestion can be diminished. Bottlenecks that are caused primarily by relatively short periods of commuter congestion, which affect primarily short-distance intra-urban car traffic which is not the focus of this study's concern and which in many circumstances international traffic will avoid by using major arterial highways can be kept out of the analysis. Similarly, short-term bottlenecks caused by accidents, road works or unusual weather conditions can be filtered out;

(h) There is no absolute judgement to be made on whether a bottleneck exists or not; these are relatives, context dependent, a judgement that needs to be parameterized and against an understanding of why this is being done in the first place. What is seen as unacceptable congestion in one user or social context can be regarded as tolerable in another; there is no "magic number" which distinguishes bottleneck from non-bottleneck conditions. Earlier UNECE work has, necessarily, made such judgements, e.g. the suggestion that exceeding 60,000 pcu per day for more than 80–120 days p.a. represents a bottleneck situation on a 4-lane motorway [ECE/TRANS/WP.5/2006/2, page 2];

(i) Bottlenecks can be on links themselves or at nodes (border crossings, modal transfer points), but in modelling terms the distinction is irrelevant since nodes with delays can be represented as a combination of friction-free nodes and dummy links. The policy responses may, of course, be quite different;

(j) The emerging development of Europe-wide modelling capability, as for example embedded in the TEN-TOOLS collaboration, has the potential to facilitate Europe-wide infrastructure planning, but, for the immediate future, is unlikely to be able fully to replace analysis which starts from a link-by-link, country-by-country assessment of bottlenecks and missing links.

(k) This understanding of what can and cannot be contributed by theory, coupled with knowledge of how in practice these questions have been addressed in previous work, and then linked to an appreciation of the broader policy process is the foundation for a set of recommendations in the following section for how bottleneck and missing link identification should be undertaken and fed into the work supporting the UNECE's and others' work on transport infrastructure master planning.

4. RECOMMENDATIONS

Robust procedures that are realistic in data requirements should be developed for each of the main modes

The following is recommended as an appropriate way to develop the UNECE work on bottlenecks and missing links in relation to transport infrastructure network master plans. In many respects it builds quite directly on the work set out in TRANS/WP.5/R.60 in that the primary thrust is towards initial bottleneck identification devolved nationally to the link level with deviations between measured/forecast levels of service and accepted norms lying at the core following identification of link capacity and demand.

(a) Given the current state of international transport models and available data sources, UNECE should, for the time being, continue to use a devolved approach to bottleneck and missing link identification.

If this is underpinned by a common methodology then the output is of real value and can be used to inform identification of national transport priorities as well as providing a basis to inform international discussions.

(b) Identification should be based as far as possible on shared and technically explicit guidelines as to what constitutes a bottleneck or how a missing link might be identified.

(c) Adopting a shared set of assumptions for traffic forecasting should be firmly encouraged.

(d) If it is not possible to achieve this degree of commonality of assumption, then the relevant growth assumptions should at least be explicit and addressing a series of growth scenarios could be helpful.

Allowing for national differences in data availability, etc., forecasts and subsequent bottleneck and missing link assessments should use a recognized best practice traffic forecasting model, preferably one that explicitly recognizes international flows.

(e) The focus should be primarily on bottleneck identification, because methodology for recognizing missing links is less developed, few links are totally missing in the more developed parts of the networks, and because missing link identification is better done from an overall network perspective, rather than link-by-link or country-by-country.

(f) Separate approaches to bottleneck identification (and to some extent missing links) are needed for the three individual modes, road, rail and inland waterway. Countries should be encouraged to understand border crossings and modal interchanges as the equivalent to links in the networks and identify them as bottlenecks or missing as appropriate.

(g) The guidelines, should in broad format draw on those articulated in TRANS/WP.5/R.60 and since implemented by the ITC in some of their work, should seek to encourage a moderately "inclusive" approach to bottleneck identification; initially it is better to identify rather too many than too few. The performance indicators/link profile approach brought forward in TRANS/WP.5/R.60 and developed further in the *Northern Axis* report, concentrating on user-experienced quality of service indicators, should be adopted.

(h) The guidelines must not be over-engineered relative to forecasting capacity or data availability. The data demands implicit must be realistic with respect to some of the less well established transport administrations and data sources, since many of the important infrastructure developments are likely to involve such regions and missing data needs to be avoided if at all possible.[6]

(i) The objective should be to construct a "long list" of candidate investments and/or administrative actions. Thus very heavy analytical effort simply to identify members of the candidate list is hard to justify.

Guidelines for individual modes should, as above, have at their core the quality of service concept – bottlenecks and missing links fundamentally undermine the expected quality of service that users might reasonably anticipate. Identifying the locations where such issues arise is an appropriate, "customer focused" response that should be a major (although not the only) element informing how changes to infrastructure and administrative processes are made. Other important questions to bear in mind include environmental concerns and wider socio-political ambitions reflecting EU and other relevant policy directions.

The following recommendations are intended as starting points for discussion among experts and professionals. In particular, this is necessary with regard to the road and rail guidelines, where the parameterization is not complete (in the former case) and the practicality is not clear (in the latter). It is recommended that UNECE should initiate a process of consultation in this regard as a continuation of the present stream of work.

An approach to missing links and bottlenecks in road networks

Missing links

Although there are some very general benchmarks in relation to network density, no general guidelines for pin-pointing missing links have been identified that do not depend upon either expert judgement at a network level or running a (national) network model.

It is recommended that national administrations be encouraged to explore for links that may be missing in the following way:

(a) identify any group of existing links which appear to be carrying heavy traffic by a physically indirect route and assess the overall flow over the group of links using the same set of indicators (below) as are applied in estimating the quality of service performance indicators for an individual road link;

(b) Compare the indicators with those assessed if, hypothetically, an appropriate direct link were to be introduced to the network;

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[6] For example, the accepted tender in response to the recent EC project proposal *Traffic Flow: scenario, traffic forecast and analysis of traffic on the TEN-T, taking into consideration the external dimensions of the Union* is explicit about data issues, including the level of spatial resolution, in some new member States.

(c) Identify the link concerned as “missing” if the difference in the performance indicators is seen as significant, relative to the approximate cost of the missing link.

Bottlenecks

It is recommended that the general approach adopted in WSP (2007) pp.153/4 should be adopted, with some limited modifications. This work follows in broad style the stream of UNECE and related applications which have established that this general approach is feasible.

Specifically, it is recommended that the indicators on weight bearing capacity, vehicle dimensions, hgv travel speed and reliability of travel are adopted. The indicator in relation to safety should be set at 50% above the EU average for similar roads, but environment should not at this form an explicit part of the assessment profile, because of lack of reliable measurement methods and the fact that there will be a degree of correlation typically between environmental degradation and indicators such as speed and reliability. Although this correlation will not always be perfect, it us arguably strong enough at the level of analysis being undertaken here.

Precisely what profiles of performance against these indicators would justify identification as a ‘bottleneck’ would need to be settled by consultation. See Annex 2 for further information about this approach.

An approach to missing links and bottlenecks in rail networks

Missing links

Recognising that the question of missing links is probably less severe in the rail system than with roads, it is recommended nonetheless that a broadly analogous approach to that adopted for road links should be used. Expert judgement must inevitably lie at the heart of this assessment.

Bottlenecks

The work recently published by UIC (UIC, 2008) makes a substantial contribution to our understanding of inadequacies in the rail system in Europe. Set alongside the previous TER work, it should provide a good indication of where the main capacity problems lie. It would be helpful also to compare these two sources’ lists of bottlenecks with one based on the approach put forward in the *Northern Axis* report, pp.159-61. See Annex 2 for further information about this approach.

Nodal, as well as link bottlenecks are potentially important in the rail network and national administrations should be reminded not to overlook them. UIC has plans to carry out further work in this area, looking at the possibility of applying the UIC (2004b) approach to nodes.

Although substantially more sophisticated approaches to assessing rail bottlenecks are available (e.g., UIC, 2004a,c), it seems doubtful whether their general deployment is feasible at this time, because of limitations in available analysis time and also, more importantly, data gaps.

An approach to missing links and bottlenecks in inland waterway networks

In general, the inland waterway system is relatively small and specialized. The amount of analytical work that has been done in relation to missing links is negligible and that on bottlenecks is limited and has mostly been standards-driven. In this sector, a ‘light touch’ analysis at the national level seems appropriate, especially as substantial progress seems to have made under the auspices of the Working Party on Inland Water Transport (see Annex 3).

Missing links

It is recommended that national administrations should review the identification of missing links as established in the *Blue Book* based simply on their expert knowledge of their own network without formal guidelines, save that their thinking should have an explicit focus on expediting international freight movement and that they should be aware of possibilities for development in multi-modal transport.

Bottlenecks

It is recommended that the standards-based guidelines adopted by the UNECE Inland Transport Committee should continue to be employed. National administrations should continue to identify:

<u>Basic Bottlenecks</u> - sections of E waterways whose parameters are not in conformity with the requirements of European Inland Waterways, Class IV;

<u>Strategic Bottlenecks</u> - other sections satisfying the basic requirements of Class IV but which nonetheless ought to be modernized to improve the structure of the network or to increase the economic capacity of inland navigation traffic.

In view of the progress already made in this area (annex 2) relatively little extra work may be needed.

Multi-modal traffic needs separate analysis

Both with regard to missing links and bottlenecks, it is recommended that the prime responsibility for identifying multi-modal possibilities should lie with the national administrations for the three separate modes. Where appropriate, Ministry of Transport or equivalent personnel should be consulted. It is anticipated that, regarding international transport, the best insights about multi-modal possibilities may occur at the stage when national priority recommendations are brought together internationally. This is a further matter on which some further consultation regarding the practicality of this approach would be helpful.

5. REFERENCES

Arnold, J. (2005) *Best Practices in Corridor Management*, Trade Logistics Group, IBRD/World Bank.

Banomyong, R. (2000) *Multimodal Transport Corridors in South-East Asia: a Case Study Approach*, PhD thesis, University of Cardiff Business School.

Beresford, AKC and Dubey, RC (1990) *Handbook on the Management and Operation of Dry Ports*, UNCTAD, Geneva, pp92.

Cambridge Systematics (2005) *An Initial Assessment of Freight Bottlenecks on Highways*, report prepared for the FHA, Cambridge Systematics.

CEDR (2004) *Bottlenecks in Road Networks*, Conference of European Directors of Roads SG-TERN, document 04-02.

ECE-ESCAP (2008) *Joint Study on Developing Euro-Asian Transport Linkages*, United Nations, New York and Geneva.

ESCAP (Economic and Social Commission for Asia and the Pacific) (2003) *Transit Transport Issues in Landlocked and Transit Developing Countries*, United Nations, New York.

European Conference of Ministers of Transport, *National Systems of Transport Infrastructure Planning*, Round Table on Transport Economics, Meeting 128, ECMT, Paris, 2005.

Haggett, P. and Chorley R.J. *Network Analysis in Geography*, Edward Arnold, London, 1969.

Peters, D. (2003) Cohesion, polycentricity, missing links and bottlenecks: conflicting spatial storylines for pan-European transport investments, *European Planning studies*, vol. 11, pp.317-23.

Rathery, A. (2007) Policy actions for developing efficient inland transport links between Asia and Europe, paper to the 1st. Black Sea and 4th. Silk Road Conference, Istanbul.

UNECE Transport Division (2005a) *Trans-European Motorway (TEM) and Trans-European Railway (TER) Projects' Master Plan*, UNECE Transport Division, Geneva.

TEM (2005) *Inventory of the TEM Network Capacity Bottlenecks*, UNECE paper TEM/WP.253.

TRB (2000) *Highway Capacity Manual*, Transportation Research Board, Washington DC.

Tsamboulas, D. (2007) A tool for prioritizing multinational transport infrastructure investments, *Transport Policy*, vol. 14, pp.11-26.

UIC (2004a) *EURAILINFRA Summary Report*, UIC, Utrecht.

UIC (2004b) *Capacity*, UIC Leaflet 406, UIC.

UIC (2004c) *Capacity Management (Capman Phase 3) Summary Report*, UIC.

UIC (2008) European Rail Infrastructure Masterplan (ERIM) 2007 Report, UIC, Paris.

UNECE Inland Transport Committee (1993a) *Infrastructure Bottlenecks and Missing Links in the European Transport Network*, Report TRANS/WP.5/R.44, UNECE Transport Division, Geneva.

UNECE Inland Transport Committee (1993b) *Infrastructure Bottlenecks and Missing Links in the European Transport Network: Report of the Small Informal Group of Experts*, Report TRANS/WP.5/R.44/Add.1, UNECE Transport Division, Geneva.

UNECE Inland Transport Committee (1994) *Methodological Basis for the Definition of Common Criteria regarding Infrastructure Bottlenecks, Missing Links and Quality of Service of Infrastructure Networks*, Report TRANS/WP.5/R.60, UNECE Transport Division, Geneva.

UNECE Inland Transport Committee (2005b) *Inventory of Most Important Bottlenecks and Missing Links in the E Waterway Network*, TRANS/SC.3/159.

UNECE Inland Transport Committee (2006a) *Monitoring of Developments Relevant for the pan-European Transport Corridors and Areas*, Report TRANS/WP.5/2006.2.

UNECE Inland Transport Committee (2006b) *Inventory of Main Standards and Parameters of the E Waterway Network* (Blue Book), ECE/TRANS/SC.3/144/Rev.1.

WSP (2007) *The Northern Transport Axis* (Pilot Study for the analytical support framework to monitor the implementation of the infrastructure and “soft” measures proposed by the High level Group, WSP Finland Ltd., Helsinki.

United States Government Accountability Office (2007) *Surface Transportation: Strategies Are Available for Making Existing Road Infrastructure Perform Better.* Report to the Ranking Member, Committee on Environment and Public Works, U.S. Senate.

Annex 1

Background to the decision to commission the current work

The immediate background

The UNECE Inland Transport Committee Working Party on Transport Trends and Economics at its nineteenth session, held on 14-15 September 2006 considered the progress made on its work on Infrastructure, Bottlenecks and Missing Links.

The July 1993 Report (TRANS/WP.5/R.44)

This report was entitled "Infrastructure bottlenecks and missing links in the European transport networks". It built upon a series of earlier pieces of work, e.g., TRANS/WP.5/R.37). Key features of the report (R.44) and the work which lay behind it include:

(a) A focus on road, railway and inland waterway infrastructure only;

(b) Underpinned by responses to a questionnaire that sought information on current capacity problems; regulatory measures to alleviate bottlenecks; infrastructure measures to relieve bottlenecks; and financing of up-grading and construction of infrastructure;

(c) Difficulty in securing a good response rate to the questionnaire and, where responses were received a tendency for information not always to be complete or in sufficient detail;

(d) Bottlenecks, as identified in the responses, were increasing in number over time and were resulting in longer transport times and higher operating costs, also with some negative impact on the environment;

(e) Bottlenecks derive fundamentally from insufficient transport infrastructure capacity and/or low quality of infrastructure;

(f) Part of the problem in identifying bottlenecks was the lack of adequate benchmarking in terms of either a relationship between traffic density and required infrastructure or an understanding of what quality of infrastructure (service) would be seen as acceptable;

(g) Work on missing links derived from a study, "The Cost of Inadequate Transport Infrastructure in Europe", prepared in 199x for the European Parliament and the European Commission;

(h) This report used a high level of the existing network between major nodes to identify zone pairs where, using separate criteria for roads, rail passenger and rail freight, an inadequate quality of service existed;

(i) This links were identified as "inadequate" rather than "missing";

(j) Although the benchmarks set to define "inadequate" were somewhat arbitrary, they do provide an evidence-based approach to support an assessment of where infrastructure provision may be inadequate, albeit at a high level of spatial aggregation.

Addendum 1 to the July 1993 Report (TRANS/WP.5/R.44/Add.1)

A small informal expert group considered the above report and offered, among others, the following observations:

(a) There are no common criteria across countries for defining bottlenecks, missing links and quality of service;

(b) There may be some value in identifying common criteria;

(c) The importance of getting co-operation from all ECE member countries in supplying and up-dating relevant data;

(d) That work being undertaken by the ECMT was potentially relevant to complement this work, albeit that its approach was somewhat different;

(e) That accessibility to peripheral regions/countries had been given only limited attention.

The July 1994 Report (TRANS/WP.5/R.60)

(a) A basis for this further report was the view that, before proceeding to further work to identify investment priorities on major international links, closer analysis of the methodological basis for identifying bottlenecks, missing links and quality of service problems was necessary;

(b) There was a view that earlier work may have been at too operational a level;

(c) Identification of bottlenecks or missing links is only one (initial) part of the process of evaluating whether investment in transport infrastructure may be appropriate;

(d) The report argued that the lack of criteria commonly adopted across countries to define bottlenecks and missing links leads to great difficulty in establishing the relative importance of specific proposals and that this was necessary if a Europe-wide assessment of infrastructure priorities was to be made;

(e) Nonetheless, identification as a bottleneck did not of itself justify investment which has to be determined against a much wider set of criteria, including both economic and others, reflecting social, environmental, etc. concerns;

(f) It was argued that the specificity of the three modes – road, rail and inland waterway – with regard to the key parameters of capacity, quality of service and traffic flow means that separate consideration of each mode is necessary;

(g) It was recognized that, although very subtle relationships exist between capacity, quality of service and traffic flow, at the European strategic level a set of relatively 'broad brush' straightforward procedures would be needed;

(h) It is important to recognize that transport demand varies temporally and that assessments of quality of service and bottlenecks must both respond to that variation and be consistent in doing so;

(i) Variability in data format is a major barrier to application of common criteria;

(j) Assessment of bottlenecks and missing links should be with respect to *future* levels of traffic, implying that common forecasting assumptions should be made; in turn this requires high-level assumptions about transport policy in terms of the extent to which infrastructure will be expanded to try to accommodate demand;

(k) The report recommends, for each mode, possible standardized criteria and suggests that these may offer appropriate indicators of whether or not a bottleneck is present which are practicable and allow international comparison.

Annex 2

The Northern Axis Bottleneck Methodology for Road and Rail

The *Northern Transport Axis* study argues that bottlenecks may be identified in three different ways: assessment against pre-selected *design standards*; through *capacity analysis* which compares measured or predicted traffic volumes against link or node capacity; or, *outcome-based analysis*, where only system performance with regard to selected objectives is taken into account. Its preference is for the last of these three, since it allows bottleneck identification to be carefully targeted on important and specific indicators of the quality of transport service experienced by users.

Typical performance indicators might relate to travel speeds or times, or border crossing delays, for example. Indicators should be chosen to align with policy targets. Such indicators are scalable and can be applied to individual locations or across larger elements of the infrastructure system or of a logistic chain. They can also be focussed on specific aspects of systems performance, with a focus on international flows being one of particular relevance to the current study.

Clearly, an approach of this kind lays particular stress on ensuring that the policy targets are well chosen and truly appropriate to underlying social and political wishes and that the performance indicators are (i) selected so that individually and collectively they throw light on the extent to which movement towards achieving policy targets is taking place; and (ii) are unambiguous and readily measurable at reasonable cost. Indicators will typically relate to aspects of transport system performance such as Accessibility, Mobility, Economic development, Environment, Safety, Security and System infrastructure quality.

Within this set, the *Northern Transport Axis* Study recommends a focus on:

(a) Mobility

- (i) Travel time/speed
- (ii) Delay at nodes
- (iii) Travel time reliability

(b) Transport safety
(c) Environmental protection.

It does not directly assess travel cost, primarily because of the complexities involved in its assessment. It is worth noting however that, for some modes at least, there will be a link between pricing, volume and delay, so that the question of cost cannot be seen as irrelevant to the overall assessment.

One of the attractions of an outcome-based analysis of this sort is that the performance indicators can be used to create an overall performance profile that will respond to both policy and infrastructure changes using the same set of indicators.

In addition to performance indicators of this kind, it can also be helpful to collate information on regulatory and legacy constraints and institutional restrictions – issues such as incompatible vehicle standards, different rail gauges, variations in procedures at border crossings and so on.

Despite the relatively broad nature of the performance indicators, there will be, nonetheless, on occasions problems of data availability that may compromise the ability to make the assessments directly in the manner suggested above. The *Northern Transport Axis* therefore also recommended some specific sets of performance indicators for road and rail projects respectively:

<u>Road</u>

Bearing capacity	Maximum axle weight 11.5 tons Maximum vehicle weight 44 tons
Vehicle dimensions	Length 18.75m. Height 4.00m. Width 2.55m.
HGV travel speed	Good 75kph or greater Insufficient 50 – 75 kph Congested less than 50 kph
Reliability	Derived from congestion-related recurring delay estimates
Road safety	Expert judgement
Environment	Expert judgement Length of urbanized area along link

<u>Rail</u>

Operational and technical harmonization	Train weight – maximum 3000 tons Length allowable – 750m. GC load gauge Axle load – maximum 25 tons Signalling system ERTMS
Line speed	Insufficient – less than 100 kph Normal - 100 kph or higher
Capacity utilization	For example, the UNECE guidelines of 60 – 80 trains per day (single track) or 100 – 200 trains per day (double)

Annex 3

Bottlenecks in Inland Water Transport

The following is derived from material provided by UNECE setting out the current status at July 2007 of work on the inland waterway network.

Most important bottlenecks in the E-Waterway Network

The UNECE Working Party on Inland Water Transport (SC.3) is paying special attention to the issue of bottlenecks in inland waterways as part of its work on the *European Agreement on Main Inland Waterways of International Importance* (AGN). To support the AGN implementation, the Working Party has issued a so-called "*Blue Book*" (ECE/TRANS/SC.3/144/Rev.1, 2006) on technical characteristics of European inland waterways and ports of international importance, which provides UNECE member states with:

(a) A common definition and classification of inland waterway bottlenecks (see definitions below);

(b) A list of bottlenecks and missing links in the E Waterway Network.

Since October 2002 CS.3 has been maintaining an inventory of the most important bottlenecks and missing links in the E-Waterway Network (Resolution No.49, ECE/TRANS/SC.3/159), which as of July 2007 identified 42 strategic and 31 basic bottlenecks in 18 countries of Western, Eastern and Central Europe, including bottlenecks on the Danube, Sava, Rhine, Moselle, Elbe, Main, Oder, Don, Volga and on other major European inland waterways.

Policy responses

Compared to the road and railway sectors, the infrastructure capacity on inland waterways is more dependent of weather conditions, since a low level of water is often the major cause of restrictions. The other main factor relates to infrastructure and involves insufficient lock capacity. Many policies aimed at removing bottlenecks, therefore, focus on improving/adding locks and barrages and represent long-term projects requiring substantial financing.

States party to the AGN agreed to adopt its provisions as a coordinated plan for the development and construction of a network of inland waterways, and, therefore, undertook to work on removing the bottlenecks and missing links. The Working Party monitors the progress in this work and regularly updates the Blue Book and Resolution No.49 .

Definitions

Bottlenecks and Missing Links in the Network of Main Inland Waterways of International Importance

In the course of its work on the draft AGN Working Party SC.3 endorsed the following definitions of "bottlenecks" and "missing links" in the inland navigation network, elaborated by the ad hoc Group of Experts on Inland Waterway Infrastructure:

Those sections of the European waterway network of international importance that have parameter values being substantially lower than target requirements are called bottlenecks.

There are two kinds of bottleneck:

Basic bottlenecks are the sections of E waterways whose parameters at the present time are not in conformity with the requirements applicable to inland waterways of international importance in accordance with the new classification of European inland waterways (class IV);

Strategic bottlenecks are other sections satisfying the basic requirements of the class IV but which, nevertheless, ought to be modernized in order to improve the structure of the network or to increase the economic capacity of inland navigation traffic.

Missing links are such parts of the future network of inland waterways of international importance that do not exist at present.

The basic condition for the elimination of bottlenecks and completion of missing links is the positive result of economic evaluation” (TRANS/SC.3/133, paragraph 18).
