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RESEARCH ARTICLE

Congestion from a Multimodal Perspective

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Abstract

This paper investigates the multimodal nature of urban congestion and network performance, with the aim of developing practice ready policy tools to alleviate the adverse effects of excess demand, no matter in which mode it realizes. As part of the efforts to get an overall understanding of how congestion is defined in various disciplines, we conduct a literature review of relevant engineering and microeconomics studies. The investigation reveals the main areas where contradiction can be identified between engineering and economics approaches. In a second step, we investigate the results of an expert survey about the principles of congestion analysis from a multimodal perspective. The main contribution of the paper is twofold. First, we draw attention to the pitfalls of oversimplified and narrow viewpoints on congestion. Second, we operationalize these principles in order to enable decision makers to assess the impact of urban transport measures on congestion.

Keywords

congestion, active modes, definition, multimodality, urban mobility

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1 Introduction

Traffic congestion is a growing problem in many cities around the world due to increasing urbanisation and motorisation. For many years, the standard solution for congestion has been widening roads for automobiles. However, today it is clear that simply providing more road space induces more automobile travel (Feng et al., 2017), and the level of congestion may even get worse than before capacity expansion. What's more, "[c]ongestion relief […] does not necessarily make for a sustainable and liveable metropolis. Thus residents of places that are able to build themselves out of traffic congestion might not necessarily like what they get" (Cervero, 2003).

Most of the traditional literature on congestion reduction focuses on motorized transport (DG Environment, 2004; Duranton and Turner, 2009; 2011; Litman, 2017a). Neirotti et al. (2014) state that many cities consider introducing ICT based initiatives to mitigate their congestion problems. Nakamura and Hayashi (2013) review international strategies for promoting low carbon urban transport. They find that many cities consider public transport as a tool to relieve car congestion.

In a study on the impacts and costs of congestion reduction strategies, Litman (2018; 2014) examines which types of measures are most promising in reducing congestion at a reasonable cost. The study identifies the improvement of multimodal transport alternatives that include walking and cycling policies as the most promising group of measures.

The problem statement of this article is rooted in the observation that the traditional understanding of congestion focuses on motorized transport in isolation. Due to this focus of mainstream urban mobility policy, measures to reduce congestion still concentrate on providing more space for cars. If the understanding of congestion were truly multimodal, then the congestion-reduction potential would be considered for all alternative modes, and decision makers would also consider all modes as potential sources and remedies for car congestion. Therefore, this paper explores the current understanding of congestion and in how far this current understanding falls short of a multimodal perspective. On this basis, it develops key principles to be considered to expand the currently mainly monomodal understanding of congestion, and make it multimodal.

To do so, the paper presents the results of a survey addressed to experts in the field of urban transport planning and traffic engineering. The survey collected various kinds of congestion definitions. The purpose of the survey was to confront the experts with current understandings of congestion and thereby to initiate a reflection about potential issues that should be considered if all modes had to be regarded as potential sources and remedies for congestion. Thus, the experts were supposed to be inspired about multimodal ways to reduce urban congestion.

The paper conducts a gap analysis by comparing existing definitions of congestion with multimodal understandings gathered in the expert survey. The results of this analysis form the basis for the development of principles of multimodal congestion. The paper concludes by reflecting on how these multimodal principals could be operationalized to become a part of impact assessment procedures.

2 Current understandings of congestions and multimodal aspects

2.1 Congestion in engineering disciplines

Based on traffic flow theory, congestion was defined in the traffic engineering discipline as early as 1935 by Greenshield, together with the macroscopic fundamental diagram of congestion (Greenshields et al., 1935). This fundamental diagram has remained valid until nowadays (Stamos et al., 2015). The main traffic parameters in traffic engineering and traffic flow theory are speed, flow and density. The fundamental diagram is the combination of three graphs that shows the relationship between these variables. Transport modeling, on the other hand, uses a slightly different method to represent congestion. The volume-delay function in that field to represent saturation levels and delays on a road network.

As the above-mentioned techniques were designed for highways, it considers static traffic conditions along a homogeneous road section. Furthermore, they normally include another simplification when all traffic volumes are transformed into personal car units (PCUs). One PCU is equivalent to an average passenger car, while a bike is represented by one half of a PCU.

The fundamental diagram has been further developed to represent the traffic dynamics of a multimodal transport system, without explicitly accounting for active modes, however (Zheng and Geroliminis, 2013). Some contributions in the literature analyze how non-motorized traffic affects the fundamental diagram. Purohit et al. (2014) measured mixed traffic conditions and derived information about modal interactions in congestion.

In the traffic engineering field congestion is defined as: "The occurrence of a traffic demand that exceeds the capacity of the highway segment during an interval of a specific duration" (Anja, 2011). To operationalize this critical saturation level, the ratio between volume and capacity is defined. Under realistic conditions, the ratio F/C cannot be higher than one, while in transport modeling this is often the case. Juhász et al. (2016) discussed the main differences between the two approaches (MFD vs. VDF).

Nowadays, many road authorities use relevant guidelines such as the American "Highway Capacity Manual" (TRB 2000) or the German "Handbuch für die Bemessung von Straßenverkehrsanlagen" (FGSV 2015) to analyse the state of traffic flow. In these guidelines, traffic flow and congestion are measured by delay and density as performance indicators. The indicators enable the analysis of transport network performance for all modes using objective measures. They apply the principle of moving people rather than vehicles, first introduced by Fruin (1971).

2.2 Congestion in microeconomics

In microeconomic theory, there exists a general definition for congestible services, with no specific focus on the transport sector whatsoever. It states that a service is congestible if, for a given capacity, the benefit that consumers can extract from using the service decreases with the number of simultaneous users. This phenomenon exists in many industries. Simple examples include a crowded theatre where visitors in front of each other in the audience may reduce visibility for fellow users sitting behind, a cell phone network that may slow down or become unavailable during mass events like concerts, or electricity supply that may experience power shortages under irregular peaks in demand. As it may be apparent from the list of examples above, network industries are particularly sensitive to congested usage, because capacity and demand in their case have a geographic dimension. Demand increases and then falls at various locations in space, and therefore it is more likely that in certain locations capacity becomes insufficient, at least temporarily.

A general feature of congestible services is the presence of consumption externalities, as it comes directly from the above definition of a congestible facility. Users induce costs for fellow users in terms of inconvenience, time or indirect monetary expenses. The problem with consumption externalities is simply that the costs borne by fellow consumers are often not taken into account in personal decisions about using or not using the service. This implies that in certain cases the social cost of a trip, for instance, may be higher than its social benefit, but the trip is still undertaken because on the individual level the net benefit (excluding externalities) is positive. Such trips are wasteful on the aggregate level and, with microeconomic terminology, cause a deadweight loss for society. The source of the consumer's ignorance is not necessarily selfishness; the lack of information about the magnitude of externalities also prevents the altruistic internalization of costs imposed on others. Therefore, policies that rely on raising people's conscience and cutting externalities by putting a moral pressure on them may not work in practice, or in fact induce more reduction in consumption than necessary. The knee-jerk reflex of economists about the optimal management of a congestible facility is simply that the sum of all externalities has to appear in the monetary price of service usage, and this will enforce people to consider external costs in their personal decisions to the correct extent.

Focusing now on the transport sector, it is clear that road usage is subject to consumption externalities. The externality appears in several forms, but the largest element in magnitude is the time lost when traffic slows down due to the density of vehicles simultaneously using the infrastructure. Road congestion generates other consumption externalities as well, including the increased risk of accidents, nervousness, frustration, uncertainty in the expected travel time, and potential health effects of local pollution. These are just the externalities that drivers impose on each other, without considering the impact on other agents in society. Again, it is easily possible that the net social benefit remains positive for many useful trips, even when all externalities are taken into account. What requires policy interventions, however, is that certain trips may have positive net personal benefits, but negative net social benefits. These drivers should somehow be taken off the roads. It is remarkable that congestion pricing is still so rarely applied in transport policy, even though the theory behind it exists since almost a century (Pigou, 1920). Capacity expansion or traffic calming, two measures often advocated as a remedy against congestions, cannot provide a targeted solution for wasteful trips only: capacity expansion gives an incentive for more wasteful trips, while traffic calming roots out useful trips with positive net benefits as well.

It may be a natural response that trips performed on congested roads should be diverted to other transport modes. However, consumption externalities (and thus congestion from an economic point of view) exist in most of the alternative modes as well. The second most burdensome source of congestion for society is crowding in public transport. The inconvenience that we feel in close proximity to fellow passengers may be just as much costly as the time we lose on roads. It is more difficult to measure, though. The predominant method of measuring the user cost of crowding is discrete choice modeling. There are many travel situations in which passengers must choose between alternatives (e.g. routes, modes, time of travelling) that differ in the density of crowding and other attributes, including price and travel time. By observing these choice situations, it becomes possible to derive the cost of inconvenience in terms of the equivalent monetary expenditure or travel time.

Wardman and Whelan (2011) as well as Li and Hensher (2011) provide excellent summaries of the literature of stated choice crowding cost estimation experiments. Recent contributions like Kroes et al. (2014) and Hörcher et al. (2017) show that the cost of crowding can be captured in a revealed preference framework as well, especially when demand patterns can be recovered using smart card and vehicle location data. In terms of the magnitude of disutilities, these empirical results reveal that the cost of crowding may be similar to the cost of uncrowded travel time. In other words, the user cost of travelling doubles simply due to congestion in public transport. This may be somewhat less than the time loss in the heaviest road congestion (on roads travel time may increase to more than twice the free-flow travel time), but it is definitely not negligible.

Congestion-related phenomena are present in active modes as well. Due to frictions between pedestrians and cyclists, the walking and cycling experience is definitely not the same when these facilities are congested as under low-demand conditions. Passing slower cyclists becomes difficult when cycle paths are congested, and the risk of accidents increases. Travel times may also increase at junctions or other bottlenecks of the infrastructure. These perhaps are not the most stressing problems of European cities currently, but we certainly cannot state that congestion can only be present in motorized transport modes. What we can state with more certainty is that the magnitude of externalities is lower in alternative modes, compared to road congestion.

2.3 Multimodial aspects of congestion based on expert survey

As highlighted in the preceding sections, the relationship between demand and capacity is a fundamental element to determine congestion levels. Delay is considered as a consequence of little traffic network capacity as compared to the demand of persons and vehicles trying to use a transport facility. However, is congestion described multimodally if all modes are considered, and if the description of congestion applies the principle of moving *peoples* rather than moving *vehicles*?

In what follows, we present results of a survey that discussed urban congestion in the context of walking and cycling. The survey participants were transport professionals working for (urban) road authorities and other experts working in the fields of urban transport planning and traffic engineering. The experts were presented definitions of congestion and were then asked to comment on their respective ability to properly incorporate walking and cycling as potential sources and remedies for congestion. The following three exemplary definitions had to be discussed:

- "Congestion may be defined as a state of traffic flow on a transportation facility characterized by high densities and low speeds, relative to some chosen reference state" (Bovy and Salomon, 2002): This understanding points to capacity/demand restrictions to describe congestion.
- "Congestion is a condition of traffic delay (i.e. when traffic flow is slowed below reasonable speeds)…" (Weisbrod et al., 2001): This understanding points to delay as a description of congestion).
- "Traffic congestion refers to the incremental costs resulting from interference among road users" (Litman, 2017b): This understanding points to the costs incurred as an impact of congestion.

The reasons to let the experts reflect on the impact of walking and cycling on congestion was that the dynamic space allocation of pedestrians and cyclists are lower than car users, and therefore any change in demand from cars to non-motorized or shared transport modes can increase the effective transport network capacity. The experts were also asked for aspects that may have been missed and their relevance. Furthermore, they were given the opportunity to provide an alternative suggestion for a new multimodal definition of urban congestion. In short, they were given space to think about multimodal understandings of congestion. In the following, the experts' answers are compiled to present the key points:

1. Acceptable travel time is different to ideal travel time: The experts pointed out that walking and cycling are active modes and therefore any definition of congestion needs to be expanded to account for this. Delay as a common indicator for congestion is usually defined as the average time loss per traffic participant along a route – where motorized transport is considered. It is calculated as the discrepancy between the actual travel time and the ideal travel time being defined under free-flow conditions.
   However, the mobile person may regard travel times in relative terms. A traffic participant experiences delay when an acceptable threshold is exceeded by the actual travel time. The perception of delay is not linear in the increase in delay. It also includes functional elements such as the trip purpose, the proportion of the delay within the overall journey time, and further constraints such as the need to meet a public transport connection. The purpose to choose walking or cycling as transport mode is not only to move from origin to a destination, but walking and cycling may be a purpose in itself. In other words, a detour or different travel speeds may be acceptable to have a safe and enjoyable trip, if the trip purpose incorporates such objectives.
   As an example, empirical evidence in Sweden shows that conditional upon the attractiveness and safety of the transport network, travel time is differently valued by cyclists. The higher the perception of a safe and comfortable transport infrastructure, the less the travel time saved is perceived as valuable. Accordingly, the 'acceptable' threshold of travel time delay may increase with cycling infrastructure that is perceived as qualitatively better (Börjesson and Eliasson, 2012).
2. Under urban conditions, infrastructure extension for one mode may be at the expense for another mode: Cities are characterized by a high concentration of land usage, sanitation, utilities, housing, and transportation. Many of the experts highlighted that urban congestion occurs because urban space can be overused in a way that additional use imposes significant costs (e.g. in terms of time or energy) on other users of urban space. Many times, the extension of urban road space and other transport facilities imposes significant alternative costs.
   Normally, cities apply indicators such as vehicle density, saturation level, travel time, delay and variation of travel time to assess their urban congestion levels. However, these measurements are used monomodally in the sense that the indicators are applied for each mode separately. If they are applied separately for different modes, they may neglect available infrastructure capacity (for non-motorized transport). A multimodal understanding of congestion has to incorporate the transport system's (potential) capacity reserve.
3. A certain degree of congestion may be desirable: Although congestion is often regarded a major problem in urban areas, it can also be considered as an indication of successful economic development, and it fosters modal shifts away from the car in crowded urban areas (OECD/ECMT, 2007). The experts highlighted that planners worldwide know that urban transport based on cars does not depict a sustainable development path – neither with respect to urban functions nor to the environment. Urban quality can be maintained on a satisfactory level by preserving adequate conditions for walking and cycling. At the same time, additional land use for roads leads to traffic growth and increased distances covered. The strengthening of walking and cycling infrastructure is assumed to be more effective in the long run compared with other strategies like roadway expansion. Although congestion can be reduced quickly by building more and/or wider roads, a rise in traffic will be induced again by the free flow conditions. Therefore, a certain degree of congestion enforces people to consider alternative transport modes. According to the experts, the prioritization of walking and cycling can be in itself a means to reduce congestion. Moreover, congestion should be regarded as the undesired part of transport network performance, whereas it is up to the cities to define, when and under which conditions they define their transport network as congested.

3 Discussion

Does the above reasoning imply that, by convincing certain drivers to use other modes, road congestion could disappear? We would like to highlight three caveats here. First, as soon as certain drivers switch to other modes, and therefore congestion-related costs decrease, new demand could be generated again on the road. The usual caveat of induced demand, which is normally mentioned in the context of road capacity expansion, applies for policies aiming for mode shift as well. The strength of induced demand depends on many factors, and it is not necessary the case that the overall level of congestion remains unchanged, but ignoring this phenomenon in policy evaluation may lead to biased conclusions.

Second, a natural way to prevent induced time could be to reduce road capacity simultaneously with promoting mode shift and making alternative modes more appealing. In this case one has to be sure that the new pedestrians and cyclists who appear on the new infrastructure as a result of the combined policy are actually people who used their cars previously. This is not necessarily the case. The new trips performed with active modes may have different origins, destinations, trip purposes and overall benefits for society than the car trips that have to be ceased due to the reduction in road capacity. Policy makers have to make sure that they do not replace high value trips with low value trips, even if the former imposed more externalities on society than the latter.

Third, as intuition suggests, if externalities are present in the alternative mode where we would like to divert road users, then it is easily possible that we just incentivize another type of overconsumption. This is particularly threatening in case of public transport. By underpricing public transport with the aim of making it more attractive compared to the unpriced road congestion, we can get rid of one group of external costs, and generate in the same time another burden for society in the form of crowding. As a result of this policy, induced demand may appear in public transport as well: more people will decide to use the service, and many of them may not travel by car otherwise.

The expert survey on how to understand and define multimodal congestion pointed to three main aspects which had not been considered in the literature. These are: 1) to define acceptable travel time for pedestrians and cyclists, 2) to use a multimodal measurement instead of mode-specific measurements, 3) to use city-specific congestion thresholds.

The following sections will discuss how these principles can be operationalized to calculate the impact of urban transport and mobility measures on transport network performance and congestion.

To define acceptable travel time: Different travelers assign different values to their time (Hensher and Greene, 2011; Raux et al., 2012; van Wee et al., 2006; Abou-Zeid et al., 2010). A multimodal understanding of congestion should account for the fact that traffic participants perceive travel times in relative terms. For example, due the physical and mental attention that is needed for travelling by car as a driver, the potential use of travel time for other activities is more confined. Moreover, when saving travel time, there may be an intrinsic utility in travelling that could thereby be lost. There are some obvious examples where the disutility of travel is lower than this intrinsic utility: consider strolling trips, e.g. whether by walking for driving, or even some shopping trips, where the intrinsic utility in travelling merges with the utility of destination.

However, empirical findings of what is perceived as acceptable are rare and so are empirical utility functions about value of travel time. Such numbers probably vary for different modal users, trip purposes, urban conditions and other factors. It is standard engineering practice to calculate delay for motor vehicles as the difference between the actual travel time and the ideal travel time under free-flow conditions. For other non-motorized transport modes such standards do not exist. A corresponding value for ideal travel time of cyclists could be the average cycling speed (assumed to be 15 km/h as a common standard) multiplied by the distance over the network from origin to destination. Here, the network may include roadways with or without dedicated cycling facilities. For pedestrians, ideal travel time could be defined as the time it would take to walk as the crow flies between two points at an average walking speed (assumed to be between 1.2 and 1.4 m/second as a common standard). This definition recognizes the nature of pedestrian movement and can be applied to dispersed movements at major junctions and open spaces as well as movement along links. However, these are simplified assumptions. Ideal travel time for active modes should be replaced by empirical values for what traffic participants consider as acceptable travel time.

To expand mode-specific measurements: Standard design guides such as the American "Highway Capacity Manual" (TRB, 2000) or the German "Handbuch für die Bemessung von Straßenanlagen" (FGSV, 2015) define "delay" and "density" as key performance indicators to measure congestion. However, such monomodal indicators need to be aggregated to find a multimodal performance index; a value which represents the system capacity of the transport network.

Aggregated values can complement the description of the traffic situation at a junction, segment or corridor, as they provide an indication of the performance of all modes. The current understanding of multimodal congestion focuses solely on high densities or significant delays for single modes, and therefore neglects available infrastructure capacity for other (oftentimes non-motorized) modes. In contrast, an aggregation of single, mode-specific measurements takes the multimodal transport system's capacity reserve into account.

A pre-requisite for aggregation (and comparison) is a common base. Therefore, mode-specific variables must be transformed into the same units. For indicators such as travel time, travel time variability and delay, calculations should use person-based values for all means of transport by means of mode- and purpose-specific vehicle occupancy ratios. The measurement could use Level of Service (LOS) as a derived indicator. LOS transforms quantitative, infrastructure-oriented operational performance indicators into a single measurement to reflect the quality of service experienced by traffic participants (TRB, 2000).

To use city-specific priority factors and congestion thresholds: Every city establishes own priorities. Many have sustainable urban mobility planning processes that facilitate decision-making. One outcome of such a process may be a decision to prioritize walking, cycling and public transport over car travel. Such a priority should be included into an understanding of congestion. Of course, intuition suggests that society as a whole is better off in case the priorities are set based on a transparent methodology taking various socio-economic factors into account, instead of moral or purely political judgment. As perceived congestion can be different in a small town relative to a densely populated mega-city, the congestion threshold where politicians are alerted should reflect the fundamental variations in local circumstances.

4 Conclusion

No matter which mode we consider, congestion is an inevitable feature of the transport sector. It is rooted in the fact that the same capacity has to serve demand that fluctuates over time periods, network sections and often between the two directions of a link as well. Let us limit our attention to two time periods only: peak and off-peak. It is clear that the optimal capacity in the peak would be wastefully under-utilized in the off-peak. On the other hand, the optimal off-peak capacity would be insufficient under peak demand conditions. What we normally supply is a *second-best* capacity, somewhere between the peak and off-peak optima. This implies that demand in the peak still suffers from certain level of congestion inevitably.

From the perspective of constant capacity and fluctuating demand, congestion is not necessary the sign of mistakes in planning or policy, as it often appears in public opinion. Congestion becomes problematic if it consists of trips with less personal benefits than external costs for society. In this sense, modes with less external costs are definitely superior than others with more negative externalities, given that congestion remains unpriced. From a microeconomic efficiency point of view, however, the ideal set of transport policies would internalize externalities through time and usage dependent infrastructure charges, and let users to select their most preferred modes, thus ensuring individual as well as social wellbeing. Of course, it is an important precondition of the efficiency of pricing policies to supply the optimal (second-best) capacity in all competing modes.

The multimodal nature of congestion in a large urban transport network may be captured with the following definition: "Congestion is a state of traffic involving all modes on a multimodal transport network (e.g. road, cycle facilities, pavements, bus lane) characterized by high densities and over-used infrastructure compared to an acceptable state across all modes against previously-agreed targets and thereby leads to (perceived or actual) delay". Further discussion on the use of this definition is available in Rudolph and Szabo (2016). The methodological question that remains unanswered by this analysis is the treatment of unequal congestion levels on seemingly substitutable modes and their infrastructure. Can we say that, for example, the combination of an unused cycle path and a highly saturated road is less congested than only the road under similar demand conditions? By contrast, if modal shift is a feasible option, experience summarized in shows that multimodal approach in infrastructure development can significantly improve the efficiency of urban land use (FLOW, 2017).

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