INDUCED TRAFFIC GROWTH THROUGH THE LOOKING GLASS: A COMPARISON OF MICROECONOMIC AND SYSTEMS-BASED EXPLANATIONS OF TRAVEL BEHAVIOUR AND GOVERNANCE RESPONSES TO URBAN MOTORWAY DEVELOPMENT

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ABSTRACT

This paper examines two different explanations using different theoretical frameworks to account for the phenomenon known as *induced traffic growth*. The first explanation is framed in terms of micro-economic theory and shows that under some conditions, induced traffic growth can undermine the economic benefits arising from urban motorway development as the additional traffic can erode travel time savings for existing traffic so that congestion returns until a new equilibrium is reached. But this explanation has a limited capacity to explain how and why traffic interacts with the rest of the urban system. The second explanation framed in terms of systems theory renders induced traffic growth as a form of *positive system feedback* — which if allowed to continue would eventually destroy the system. By tracking the path of decisions needed to complete the feedback loop, it is shown that information passes between a soft-system — or decision-making system, usually located within government transport agencies — and a hard-system — the transport network that provides access for people. Critical to this explanation is a misunderstanding on the part of transport decision-makers controlling the soft-system as to what the addition of road space actually does to service levels on the hard system that is controlled by a confluence of material factors.

INTRODUCTION

This paper examines two different explanations using different theoretical frameworks to account for the phenomenon known as *induced traffic growth*. In simple terms, induced traffic growth refers to the additional traffic generated in response to faster travel speeds made possible by the addition of road or motorway capacity. Such traffic increases may result from a variety of travel behaviour responses, such as mode-shifting, trip redistribution and the generation of new trips (SACTRA 1994, p. 21). Under some conditions — especially those involving congested urban networks — this can lead to counter-productive outcomes where congestion and delays for many commuters become worse (Downs 1962; Thomson 1977; Mogridge et al. 1987; Downs 1992; Mogridge 1997).

The first explanation examines the phenomenon through the lens of microeconomics, providing an overview using concepts that are fundamental to conventional approaches to transport assessment. Using a microeconomics framework focuses on a particular part of a system, which, it will be argued, involves a high level of conceptual abstraction and treats changes in travel demand in relative isolation from the rest of the urban system.

The second explanation treats induced traffic growth as a form of positive system feedback — a concept used in systems theory to describe a particular type of process arising out of the structural relationships between the components that work to form a system. Using a systems-based framework requires identification of each system component and articulation of its role and working relationship to the rest of the system. Within this framework, a more literal and holistic picture is created of the outcomes from additional road space, enabling an articulation of the *causal mechanism* responsible for the phenomenon.

The reason for comparing the explanations for induced traffic growth arising from these two different conceptual frameworks is that recent empirical analyses have found that macro data for whole city systems reveal outcomes that are substantially different to those anticipated in microeconomic assessments (for example, Zeibots 2007). Cities with a high proportion of urban motorways, when assessed as a whole, are less efficient in terms of fuel use, operating and infrastructure costs than those with comprehensive public transport networks (Newman and Kenworthy 1988). In these cities, average trip costs are higher despite the reduction in the marginal cost of trips estimated to occur when new urban motorways and road widenings are brought into operation (Newman and Kenworthy 1984). This apparent disjunct between micro assessment methods and macro system outcomes, raises the prospect of potential short-comings in the way that microeconomic concepts are being applied.

In the past, induced traffic growth has been something of a sticking point within transport assessment. Up until the mid 1990s, the phenomenon was contested. Its status changed however after publication of a report by the UK Government's Standing Advisory Committee on Trunk Route Assessment (SACTRA) in 1994 — *Trunk roads and the generation of traffic* — which found that the phenomenon is real and that assessment methods needed to be overhauled to include it (SACTRA 1994). Many of the assumptions about urban transport networks that enabled induced traffic growth to be denied still pervade our thinking, raising the possibility that further exploration in this area may enhance our understanding of urban systems.

Section 1 revisits the explanations for induced traffic growth using a conventional microeconomics framework. This section also examines the notion of marginal utility used to justification assumptions about the relationship between supply and demand factors and their relationship to the wider economy.

Section 2 examine the phenomenon using systems theory as a way of tracking changes to an urban system that occur after the addition of road space. In this explanation, assumptions based on notions about marginal utility are replaced by a different set of concepts to account for what controls the system. This explanation highlights the spatial and geometric relationship between transport and land-use elements that give rise to induced traffic growth.

1 MICROECONOMIC EXPLANATIONS FOR INDUCED TRAFFIC GROWTH

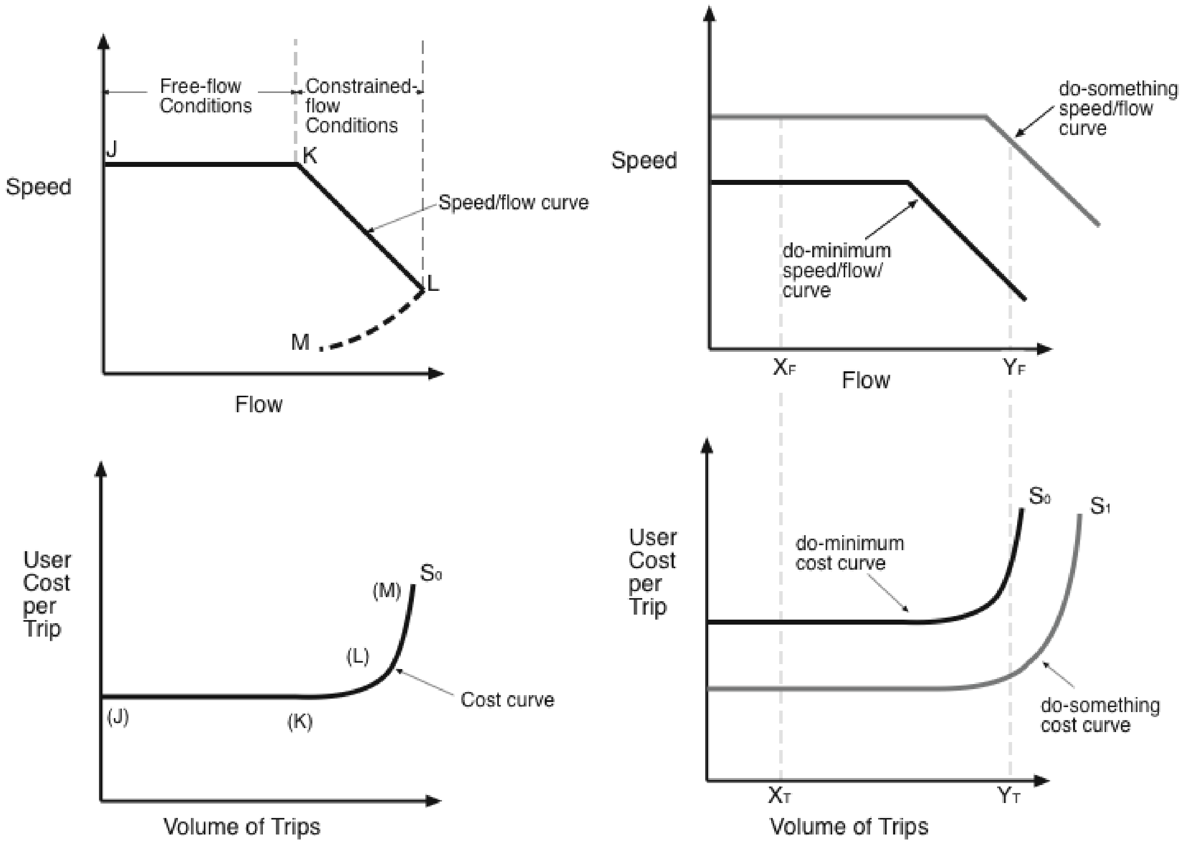
Part of the reason why SACTRA's findings on induced traffic growth were accepted can be attributed to the committee's use of microeconomics to explain it. In microeconomic terms, induced traffic growth is simply an acknowledgment that the demand for travel with respect to time is elastic (Goodwin & Noland 2003). Or in other words, if travelling from a particular set of origins and destinations is made faster then demand for that service will increase. Historically, the transport community has accepted that demand is elastic with respect to other factors that affect the generalised cost of travel — like fuel and vehicle operating costs — so accepting that changes to travel time might also affect demand is not unreasonable.

The following section revisits the logic of microeconomics used by SACTRA to account for induced traffic growth. This is followed by a discussion of the concept of economic utility and how this informs our understanding of induced traffic growth and the implications it has for macroeconomies.

1.1 Microeconomic evaluation of speed–flow–cost relationships

When evaluating the economic credentials of road and motorway projects, the process begins by identifying benefits that can be offset against the cost of construction. This is undertaken within a CBA framework, wherein the estimated benefits are divided by the costs and the corresponding value ranked against other projects (for example, NSW Treasury 1997). But to do this, a way of estimating benefits relative to costs has to be found. How induced traffic can affect this relationship can be demonstrated within the terms of a microeconomic framework (SACTRA 1994, pp. 123–128).

Figure 1 The Speed–Flow–Cost relationship and effect of user costs on road improvements



Source: SACTRA. 1994, Trunk roads and the generation of traffic. HMSO, London, p. 116 and 117.

For roads and motorways, the basic characteristics of the infrastructure — or supply curve — are set alongside behavioural responses of the people using it — the demand curve. To derive the supply curve, the relationship is defined between the speed at which people are travelling and the flow, or number of vehicles able to pass a given point. The diagrams to the left in Figure 1 show this relationship.

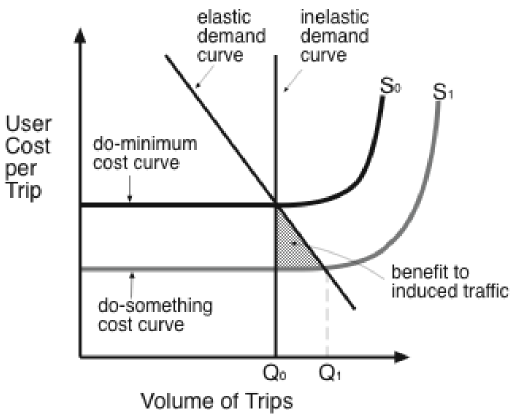
When only a few vehicles are using a road facility, the speed at which they travel is set by a legal speed limit or design speed. The number of vehicles able to travel at this speed can vary, which is why section JK of the speed/flow curve remains flat. But once vehicles reach a critical number, as indicated at point K, the speed begins to fall because the necessary headways between vehicles, or stopping distances, begin to encroach on one another. When this happens, drivers travel at slower speeds for safety reasons. As vehicle numbers increase, headways become smaller, speeds slow, queues form and delays accumulate throughout section LM as traffic flow deteriorates (SACTRA 1994, p. 116).

The speed/flow curve shown at the top left of Figure 1 is equated with a cost curve shown below. Costs for a trip remain the same between JK, irrespective of how many vehicles are on the road. These costs include the operating cost of vehicles and people's travel time. For most road appraisals, the value of travel-time savings is a critical factor comprising most of the monetised benefits (Goodwin 1981; Rayner 2003). As conditions become congested, costs begin to rise, as shown at KL. Where roads begin to reach saturation, costs rise more steeply, because of increased journey times, as indicated at LM. If road space is added, travel times are reduced and the speed–flow relationship changes, as do user costs.

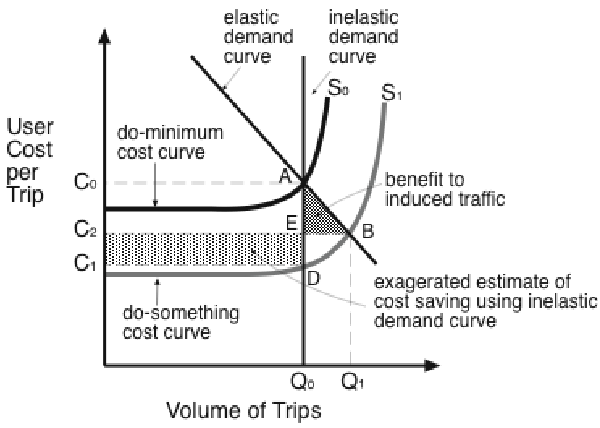
When new motorway capacity is added to a congested road network — shown in grey as the do-something scenario — the speed–flow relationship for traffic is changed, as is the cost curve. This is shown on the right of Figure 1, where it can be seen that when capacity is increased, the volumes for which the facility is able to provide free flow conditions is greater and the point at which flow-rates deteriorate is higher (SACTRA 1994, p. 117).

There are broadly two ways in which additional road space can affect the speed–flow relationship and hence costs. The first refers to cases where a by-pass might be built, for example, enabling people to travel at 110 instead of 70 km/h. In this way the travel time component of the User Cost is reduced as shown in Case X in Figure 2. The second occurs when additional capacity enables vehicles to increase headways between them so they can travel at higher speeds, reducing travel times.

Figure 2 Addition of road space in uncongested and congested conditions



(Case X: increasing free-flow speed)



(Case Y: increasing capacity and free-flow range)

Source: Source: SACTRA. 1994, Trunk roads and the generation of traffic. HMSO, London, p. 118 and 119.

The supply and demand curve on the right in Figure 2 considers changes in User Costs as a result of projects that increase the free-flow speed of traffic, such as a by-pass. Because the trip is quicker, people may make that trip more often. The elastic demand curve shows this change and the section indicated by the dark-grey hatching shows the benefits to induced traffic. Because this increase in demand does not adversely impact on the flow of vehicles, any evaluation that did not include the possibility of induced traffic growth — one based on an inelastic demand curve — would return an underestimation of the benefits. But if the addition of road capacity is introduced under congested conditions, a different result is achieved (SACTRA 1994, p. 118).

When an inelastic demand curve is used as shown on the right in Figure 2, costs are reduced from C0 to C1. But when an elastic demand curve is used, User Costs are only reduced to C2. The key difference between Case X and Y is the point at which the demand curve intersects the supply curve. The more elastic the curve, the greater the degree to which estimated benefits are eroded. In Case Y, the benefits are exaggerated if an inelastic demand curve is used. In these cases the critical question becomes: are the cost differences between C1 and C2 such that estimated benefits are not large enough to off-set construction costs? (SACTRA 1994, pp. 119–120).

While such a framework provides a means of evaluating changes to road networks, it does not provide an explanation as to why in structural terms individuals might choose to change their travel behaviour in such a way that they travel further or more often when travel speeds increase. Or in other words, a microeconomic framework does not contextualise travel. For this explanation, microeconomic theory relies on the concept of utility, as outlined in marginal utility theory.

1.2 Marginal utility theory and economic happiness

This section discusses two issues relating to marginal utility theory and then returns to the question of apparent disparities between the findings of microeconomic assessment methods and macroecononomic outcomes. The first issue is what is utility in a transport context and how does it differ from productivity and efficiency? The second relates to the nature of utility transfers from the transport sector to other parts of the economy.

Samuelson defines utility in the following way:

> Utility denotes satisfaction. More precisely, it refers to the subjective pleasure or usefulness that a person expects to derive from a good or service (Samuelson, Nordhaus et al. 1992).

Samuelson describes utility as an *expository concept* — unable to be described in and of itself, but rather an idea that needs to be understood within the context of a range of other ideas.

Within the context of the dynamic relationship between the supply and demand for a particular good or service, utility — as a goal of consumers — provides the rationale for the downward slope of the demand curve. As more units of a good are consumed, the marginal utility, or additional satisfaction, becomes less with the consumption of each additional unit (Samuelson, Nordhaus et al. 1992). Likewise, the shape of the supply curve changes with the production of additional units depending on the conditions that apply to the supply of that good or service (Samuelson, Nordhaus et al. 1992).

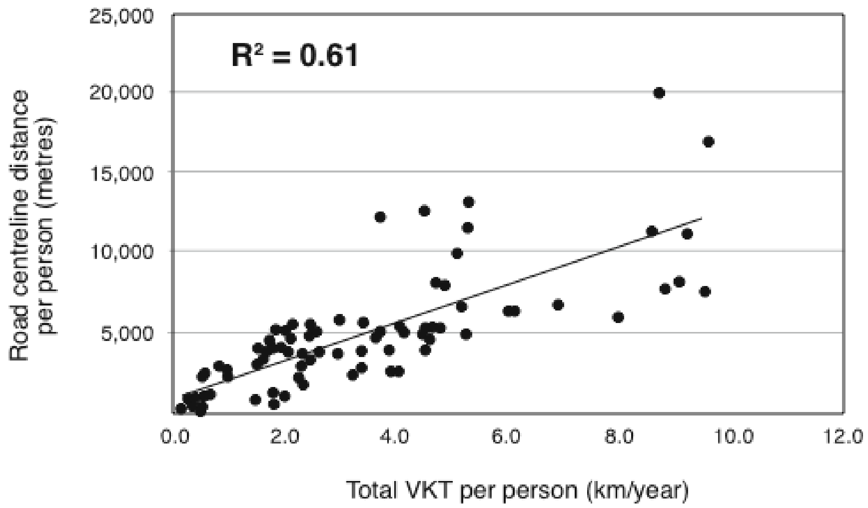
Importantly, where the supply and demand curves intersect utility is thought to be maximised. The maximisation of utility, and how it sits within the corresponding framework of supply and demand profiles, transforms the concept of utility, so that it becomes more than a general notion about individual satisfaction, but one involving a form of optimisation. Ultimately, it is the prospect of optimisation that gives the concept and attendant framework its credibility and authority (Samuelson, Nordhaus et al. 1992).

So by optimising utility, is the system made more efficient and more productive?

Figure 3 shows VKT per capita levels against road length, which is used as an indicator of road capacity. As can be seen, those cities with greater amounts of road capacity generally have higher levels of VKT per capita. This supports the contention that by adding road space to a network, induced traffic growth occurs. In this particular regression, an R^2 value of 0.61

is achieved. It is important to take into account that if the amount of driving people do is related to the amount of road space available then the correlation would likely be higher if data for road lane length were available rather than centreline distance.

Figure 3 VKT vs road length per capita for 78 international cities (1995)



Note: Road capacity is measured as centreline road distance and not centreline *lane* distance, due to data availability. The latter would be a more accurate measure of operating capacity.

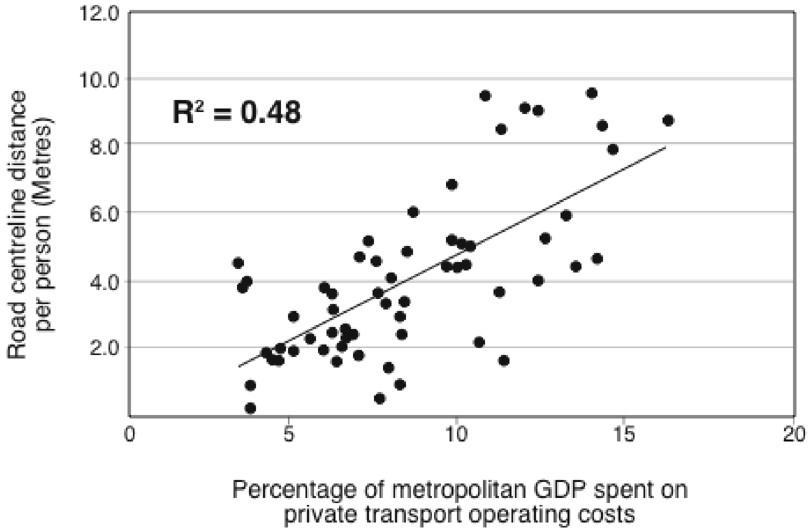
Data source: UITP 1995, *Millennium Cities Database*. International Association of Public Transport Providers (UITP), Brussels.

In relation to Figure 3, if microeconomic assessments along the lines discussed in the previous section were conducted for the various roads built within this spread of cities, it would have been found that marginal utility would have increased with each road capacity addition. If this was the case then those cities with more road space should have a higher degree of utility within the system than those with less road space. But was does this mean in practice? Does it mean that those cities with more road space and higher VKT levels per capita are spending less on travel in order to produce?

Figure 4 shows the percentage of GDP spent on transport operating costs for the same suite of cities shown in Figure 3. As can be seen, the R^2 value has dropped to 0.48, and perhaps it would be higher if data for centreline road lane distance was available, but the relationship suggests that those cities with more road space are generally directing a higher percentage of their total economic production towards transport.

But what does this mean in terms of utility? It is acknowledged that utility, efficiency and productivity refer to different things.

Figure 4 Metropolitan GDP spent on operating private transport vs road space (1995)



Note: Road capacity is measured as centreline road distance and not centreline *lane* distance, due to data availability. The latter would be a more accurate measure of operating capacity.

Source: UITP. 2000, *Millennium cities database*. UITP, Brussels.

Transport is classified as a derived demand (Roess, Prassas & McShane 2004). In simple terms this means that consumer demand for travel is derived from the utility that is gained from the access it provides to goods, services and places. Technically, the term derived demand comes from macroeconomics. Within the structural context of a macroeconomy, demand is classified as taking place within either one of two different types of markets — product or factor markets. Product markets comprise the goods and services that households consume and exports that are sold on international markets. These might also be considered production outputs. Factor markets comprise inputs to production processes that take place within a macroeconomy and typically include land, labour and capital (reference). The demand for production factors is derived from the demand for goods and services in product markets (Johnson). Infrastructures fall into the category of factor markets as they support production but are not goods or services that a macroeconomy could potentially earn an income from. On this basis, it would seem that those cities that are directing a lower percentage of their GDP towards transport — an input to production — are likely to be more efficient and more productive than those who are directing more.

Microeconomic assessments for roads assume that the utility gains incurred by road users will be transferred to the rest of the economy. In light of the implications raised by the results above an obvious question arises as to whether or not all the utility transfers — including significant disutilities — are captured in the analysis, and if not, to what degree might the absence of these factors be skewing results?

The problem with microeconomic assessment frameworks is that they do not take into account how the transport system relates to other elements in the urban system.

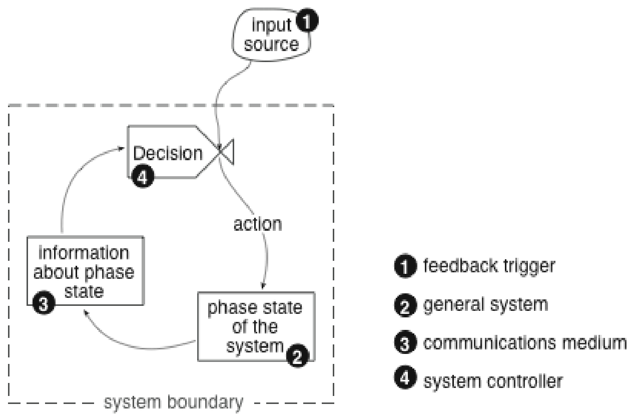
2 SYSTEMS-BASED EXPLANATION OF INDUCED TRAFFIC GROWTH

This section examines induced traffic growth using concepts from systems thinking or General Systems Theory (GST).

2.1 The structure of system feedback loops

Feedback loops have been described as the basic building blocks of systems (Forrester 1968). Within a system boundary there are many *paths,* or sequences of actions, that form feedback loops — processes that produce outcomes that are then fed back into the same sequence to form a loop (Sandquist 1985). In their most basic form, system feedback loops have four basic features — a feedback trigger, a phase state, a communications medium and a system controller (Forrester 1968). The relationship between these features is illustrated in Figure 5.

Figure 5 Basic components of a system feedback process



Adapted from: Forrester, J. W. 1968, *Principles of systems.* 2nd preliminary edition. MIT Press, Cambridge, Massachusetts, p. 2.4.

To start a feedback process, an input of some kind is needed to trigger a change in the system. The illustration in Figure 5 shows the trigger coming from a source outside the system. Once set in motion, the input generates an action that changes the *phase state* or *level* at which a system parameter is operating at a particular time (Forrester 1968). Information about the change in phase state is then communicated to a component within the system that makes a decision about what to do in response to the change. This last component is called the system controller.

In the case of natural systems, system controllers keep the system stable. In the case of designed, or artificial systems, controllers are critical to ensure that the system is able to achieve its design goal.

The significance of system control to feedback loops can best be appreciated through a simple example like a water heating system. In such a system, the thermostat operates as the system controller, regulating energy inputs to the system in accordance with a design goal. When the thermostat senses that the water temperature — or phase state — is dropping below the design goal, it sends a signal to the heating element to increase the amount of energy entering the system, thereby increasing its temperature. Once the thermostat senses that the water temperature is moving above the design goal, it sends a signal to the heating element to reduce the amount of energy entering the system. In systems nomenclature, both increasing and decreasing the amount of energy entering the system in this example constitute forms of *negative system feedback,* as each serve to stabilise the phase state.

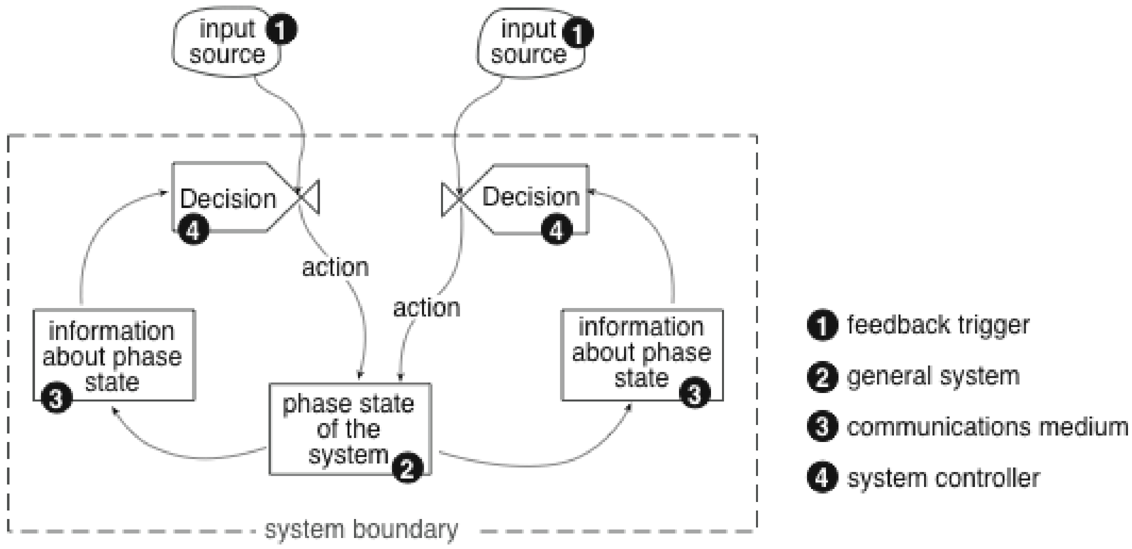
Negative system feedback generally works in the opposite direction from the stimulus or feedback trigger. In the case of the water heating system, the loss of energy through heat dissipation, or hot water usage, reduces the water temperature. The system controller senses this, triggering a switch that adds energy to the system to counter the losses. Similarly, as the water temperature rises and reaches the design goal, the thermostat triggers a reduction in water temperature by cutting the amount of energy entering the system.

By contrast, *positive system feedback* works in the same direction as the stimulus or feedback trigger and generally destabilises systems. This can be illustrated with the water heater by reversing the action of the thermostat to increase the amount of energy entering the system when it is above the design goal and decreasing the energy input when below. In each of these cases the water would either boil off, or permanently cool, depending on the initial condition, with no stable state in between.

While all components are necessary to the end function of a system, from an analysis perspective, the system controller plays a central role. This is because if the controller can be identified and understood, the underlying logic for the rest of the system structure can be identified more easily.

In nature, multiple arrays of system feedback loops often work together to form the general fabric of a system. In such cases, an outcome from one feedback loop may function as an input to another, generating a hierarchy. Multiple system controllers may be at work in such hierarchies, as shown in Figure 6, or a single system controller may lie at the centre of several feedback loops.

Figure 6 Multiple system feedback processes



In teleological systems that have been specifically designed — like a water heater — the system controller is easy to identify. In highly complex systems like cities that comprise both natural and artificial subsystems, identifying a system controller often requires some investigative work or chance discovery. Where multiple system feedback processes are at play, identifying control conditions becomes increasingly difficult and it is easy to confuse component parts from different types of subsystem with each other.

The next section describes the controller that sits at the centre of the system feedback process that gives rise to induced traffic growth.

2.2 Travel time constancy for urban populations

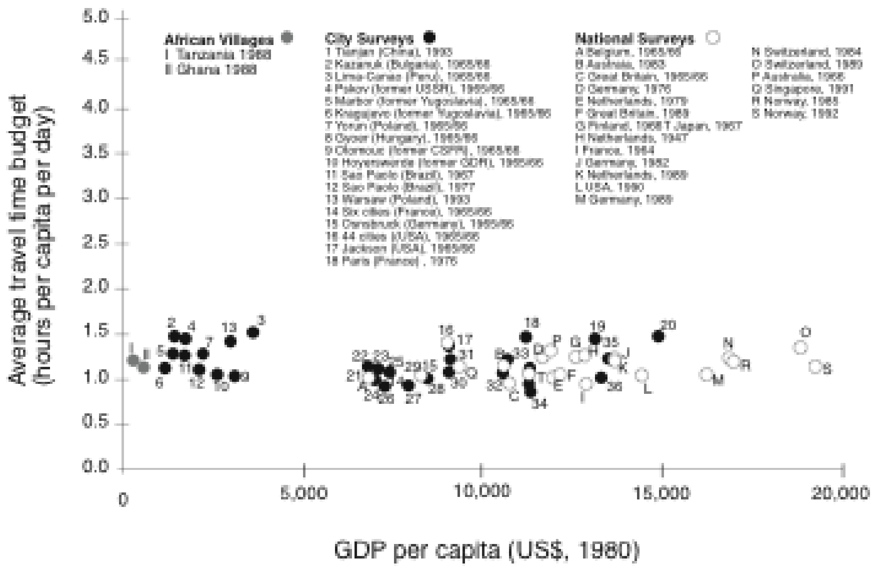
One of the more enduring points of interest in studies of urban travel behaviour is debate over the existence of what has been called the travel time budget constant. Put simply, a travel time budget refers to the amount of time people spend in transit. What is most interesting about travel time budgets is that for a diverse cross-section of cities, the statistical distributions of these budgets have similar means and distribution shapes.

Within the broader rubric of urban transport theory and analysis, the travel time budget constant has on occasions been used as an intellectual rallying point for the formulation of unorthodox transportation planning models (see, for example, Kitamura, Fujii & Pas 1997; Zahavi 1979) as well as general theories about cities and urban travel behaviour (Laube, Kenworthy & Zeibots 1998, p. 100). This is because universal constants have a habit of pointing to lynchpins within systems. By trying to account for constants, the organising principles generic to the operations of all systems within that class can often be identified. From a systems perspective, constants also suggest *control*, or a level to which the various system components organise themselves around.

The confluence of material and human physiological factors that give rise to travel time constancy will be shown to play the role of a system controller. And travel time budget constancy will be shown to be the phase state that the system attempts to return to after changes have been made to the structure and consequent speed of the urban transport system.

Schafer (1998) collated data from over 17 international studies of average daily travel time budgets, revealing that a wide selection of populations on average appear to budget around 70 to 75 minutes for their travel requirements. The data includes both national and city aggregations and encompasses a wide array of different cultures and degrees of industrialisation (Schafer 1998, p. 459). These data are shown in Figure 7.

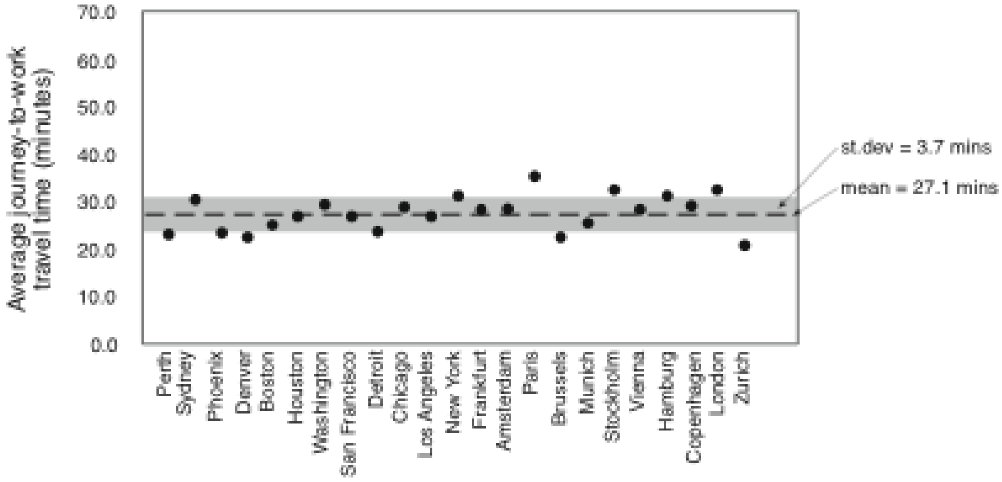
Figure 7 Average daily travel time budgets for a selection of international populations



Source: Schafer, V. 1998, 'The global demand for motorised mobility' in *Transportation Research: Part A*, Vol. 32, No. 6, p. 459.

Researchers have also observed that average travel time budgets for the journey-to-work reveal a high degree of similarity between different cities which is usually cited as being around half an hour (Laube 1997, p. 18; Manning 1984, p. 42; Robinson, Converse & Szalai 1972, p. 123). shows average travel times for the journey-to-work for a selection of EU, US and Australian cities. The average for these cities is just on 27 minutes and there is a difference of only a few minutes between the averages.

Figure 8 Average journey-to-work travel time budgets for 23 cities (1990)



Adapted from: Laube, F. B. 1997, *Optimising urban passenger transport*. Doctoral dissertation, ISTP, Murdoch University, Perth, p. 19.

While the observations are interesting, the problem that researchers have encountered is knowing what to do with the concept of travel time budget constancy. Researchers have not been able to successfully use this feature of aggregate travel behaviour in a model or assessment method for projects. This is because the phenomenon has to be seen as a feature of whole systems.

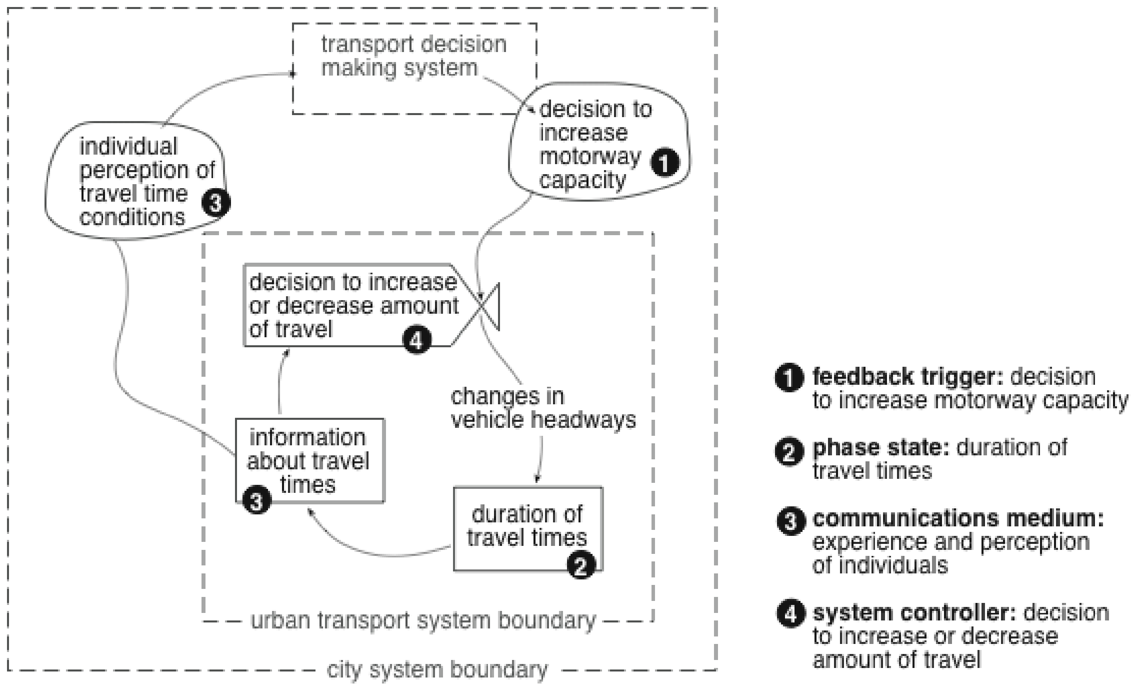
2.3 Induced traffic growth as a form of positive system feedback

Induced traffic growth is a form of positive system feedback. While this observation is often made by transport researchers when discussing the phenomenon (see, for example, Blunden 1971; Luk and Chung 1997), few have articulated the structure and consequences of the process using the standard nomenclature of GST. And few, if any, have articulated specifically how this process sits within a wider systems framework of feedback processes that combine to form complex urban systems. This shortcoming is likely due to problems with articulating a system controller and the difficulties incurred when seeking its empirical verification.

The sequence of events that make up the feedback loop that gives rise to induced traffic growth begins when capacity is added to a congested urban road network. As a consequence, traffic density is reduced so that the headways between vehicles increase, and with this the speeds at which vehicles can travel also increase. The increase in speed reduces travel times for standard journeys. In this way, the addition of motorway capacity changes the phase state, or amount of time that people need to spend in order to complete the trips that make up their daily routines. As people perceive the changes in travel time, they make decisions as to how they will use the time saved as a result of the quicker travel speeds. In line with the confluence of factors that control behaviour in the transport system, some people may choose to spend it on additional travel, either to new destinations or on additional trips, so that traffic volumes grow.

As the volume of traffic on the system increases, headways between vehicles are reduced, slowing travel speeds and increasing journey times. This change in the system phase state is experienced by individuals in such a way that the number of people choosing to travel further slows, reducing the rate of growth in vehicle numbers within the terms of the urban transport system. This response constitutes a form of negative system feedback. The sequence is shown in Figure 9.

Figure 9 Induced traffic growth feedback process nested within complex city system



There are two consequences that arise from the change in phase state that is communicated to individuals through their direct experience of conditions in the transport system. The first concerns changes to travel behaviour within the transport system. The second concerns the way individuals perceive these changes and communicate them back to the transport decision-making system.

Once the sequence shown in Figure 9 has been set in motion, the *chokepoints* in the road network shift to new positions. In many cases, the effects of congestion confront a different set of individuals from those who may have benefited from the original decision. This second set may be unhappy about the change in traffic conditions because their travel times are now longer. Some subsequent changes in travel behaviour will feed back into the urban transport system, but perceptions in the form of opinions will be fed into the political processes of the transport decision-making system. Feedback to the transport decision-making system may include ideas about what needs to be done in order to ameliorate the apparent decline in Level of Service on the road network. Individuals in the community may advocate increasing road capacity or changes to intersection treatments to those areas that directly affect them, for example. But whatever the calibre of the response, it is important to acknowledge that for many people such a problem is not experienced or perceived, and so they do not register complaints with governments, but nor do they register their satisfaction. Consequently, feedback to governments concerning Levels of Service on the road network is predominantly about perceived problems, so that responses may be slanted.

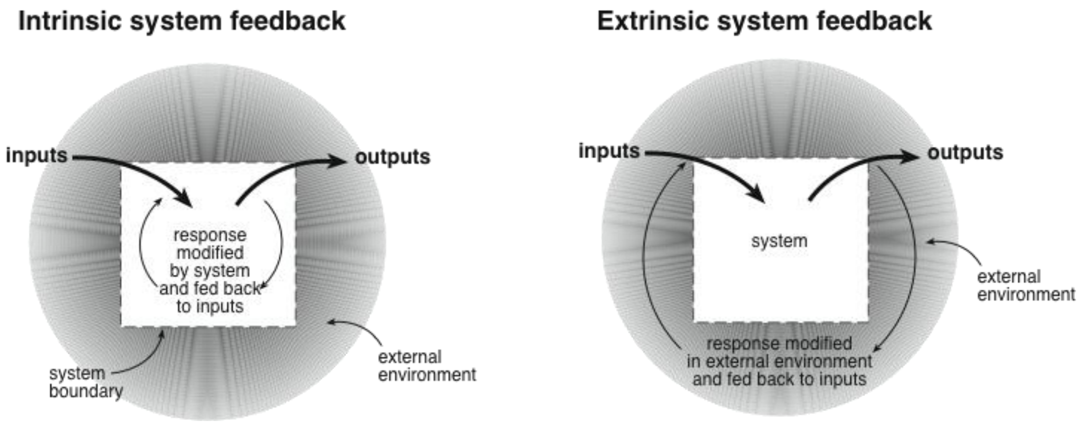
In practice, the views of the community are more complex than what has been presented here. The views of professional transport planners and traffic engineers, as well as commercial industry sector interests interplay with the perceptions and opinions of individuals who contribute to form *public opinion*. So that while a diversity of views is recognised in this general analysis, for the purposes of understanding induced traffic growth as a positive system feedback loop, the views of people will be kept simple.

A positive system feedback loop is completed within the urban system if a further increase in road and motorway capacity is implemented because of outcomes from the transport decision-making system. The feedback is positive because the response moves in the same direction as the stimulus.

In its entirety, the feedback loop crosses the boundaries between two different subsystems nested within the urban system — the transport decision-making system and the urban transport system. The sequence engages with two ontologically disparate forms of system control — a soft political system with a teleological controller and the behaviour of a hard infrastructure system with a non-teleological controller. This means that elements — in this case perceptions — from two logically different categories are interacting with each other, consequently, confusion may arise and actions may be pursued that bring about outcomes that are different from those that were intended.

In addition to positive and negative system feedback, Sandquist notes that system feedback loops have one of two different configurations. They can be *intrinsic* and have an internal feedback structure, or *extrinsic,* and have an external feedback structure (Sandquist 1985). The distinction is dependent on the location of the elements that modify the original response that is fed back into the system that initiated the sequence of events. As can be seen in Figure 10, intrinsic feedback locates the system controller inside the system boundaries, whereas extrinsic feedback locates the system controller outside the system boundary in the system environment. The distinction is significant because intrinsic feedback loops enable self-regulation, while extrinsic loops do not. Consequently, extrinsic feedback loops are more prone to instability.

Figure 10 Intrinsic and extrinsic system feedback processes



Source: Sandquist, G. M. 1985, *Introduction to system science.* Prentice Hall Inc., New Jersey, pp. 34–35.

Induced traffic growth is a form of extrinsic feedback. This is because the path, or sequence of decisions that form the feedback loop, crosses the boundaries of two different subsystems. While the feedback loop in its entirety is located within the boundaries of the urban system, the control mechanism — or confluence of factors that modifies travel behaviour in response to changes in travel times — is located outside the transport decision-making system that initiates the process and determines what response will be made, given the modification that takes place within the transport system.

The difference between intrinsic and extrinsic feedback is significant from the perspective of sustainability, because self-regulated systems are more able to respond to changes in a way that enables their survival. In complex systems like cities, there are various subsystems that undergo both intrinsic and extrinsic feedback processes. The sustainability of the urban system as a whole can become precarious when outcomes from subsystems whose feedback processes are extrinsic destabilise other subsystems. Such disjunctions can be more readily appreciated when induced traffic growth — an outcome from an extrinsic feedback process — is conceived as taking place between subsystems that are nested within a wider urban system.

The decision to increase urban motorway capacity is not generated by the urban transport system, but by the transport decision-making system. The latter is a normative subsystem of the urban system. Significantly, the feedback process that influences responses from the transport decision-making system is extrinsic and so potentially less stable.

The next section discusses other system parameters that measure the phase state of the urban system and its transport subsystem. For while the amount of time that an urban population on average spends on travel will return to its previous level after the addition of motorway capacity, significant and lasting changes occur in other parameters that affect the material structure of urban systems.

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