The induced travel: overview and perspectives

Cristina PRONELLO
Michel ANDRÉ

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Report INRETS-LTE N° 0417
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Authors:

Cristina PRONELLO — *Associate Professor of Transport Planning*

Michel ANDRÉ — *Senior Researcher*
Vehicles use and air pollution

Research laboratories :

POLITECNICO DI TORINO – DITIC, Dipartimento di Idraulica, Trasporti e Infrastrutture Civili
C.so Duca degli Abruzzi, n° 24 – 10129 TORINO – Italia

INRETS - LTE, Laboratoire Transports et Environnement
25 avenue François Mitterrand, case 24, 69675 BRON cedex - France

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La question du trafic induit n'est pas nouvelle, les premières études datant de la première moitié du 20ème siècle. Ce rapport tente une synthèse de ce sujet, en analysant au travers de nombreuses études, l'évolution du concept et des modèles élaborés pour rendre compte du phénomène.
On s'intéresse d'abord à la définition du trafic induit, rendue nécessaire par des différences de points de vue sous-tendus par des divergences d'intérêts, et qui conduisent à des compréhensions différentes du concept.
Une revue des travaux menés en Europe et aux USA permet une compréhension des mécanismes de causalité entre l'offre et la demande et tente de répondre à la question : “Est-ce le comportement de l'utilisateur du transport qui induit la décision politique de créer de l'infrastructure” ou est-ce l'inverse ?
Finalement, on considère l'acceptabilité du concept et la réponse des autorités.
Il ressort assez clairement de ces travaux que la réponse comportementale est prédominante. Négliger le trafic induit conduit à une sous-estimation des impacts du transport en particulier sur l'environnement.</td></tr>
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The animated debate on induced traffic is going on since long time, as the first studies on this matter go back to the first half of the XXth century.
This report intends to give an overview of this argument, analysing the historical evolution of the approaches used in the studies on the induced travel and of the models carried out to take into account this phenomenon.
The starting point will be the definition of the concept, necessary because either the lack of understanding or the misunderstanding between the different point of views can partly be generated by different meanings given to the concept; the other part of disagreement can lay on different interests involved in road construction.
Then, the overview of the studies carried out in Europe and USA will allow for the understanding of the mechanism of causality between the supply and demand and will try to answer to the questions: “does the transport user’s behaviour generate the policy makers’ decisions” or “does the policy makers’ decisions generate the transport users’ behaviour” ?.
Lastly, some considerations about the acceptance of the analysed concept and the answer of Administrations and relative eventual interventions are given.
It emerges quite clear from this work that the behavioural responses are the real focus and that an adequate policy on the land use that drives the transport systems is the unique way to have a real sustainable development either of land use or of infrastructures. To manage the transport demand through land use could control the transport demand, deviating it towards sustainable solutions.
In addition, neglecting the induced travel effects leads to underestimate the impacts due to transport systems. That generally leads to a non-sustainable policy, deteriorating rather than improving the quality of life in urban and extra-urban areas.</td></tr>
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Introduction

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This report intends to give an overview of this argument, analysing the historical evolution of the approaches used in the studies on the induced travel and of the models carried out to take into account this phenomenon.

The starting point will be the definition of the concept, because the lack of understanding or the misunderstanding between the different points of view can partly be generated by different meanings given to the concept; an other part of disagreement can lay on different interests involved in road construction.

The first part of this report analyses the historical evolution of the studies on induced travel and the definition of the concept.

A second part gives an overview of the studies carried out in Europe and USA.

In a third part, we consider the ability of the current transport models to take into account the phenomenon of induced travel in transport planning, and propose a critical overview of the models developed to quantify the induced travel;

Lastly, some considerations about the acceptance of the analysed concept and the answer of Administrations and relative eventual interventions.

The results of this analysis should allow to think about the consequence of land and transport planning and to understand better the causal linkage between transport supply and demand, but also between the land-use planning and transport supply and demand, as also between the environmental conditions and land use and transport.

The key for a more sustainable development is probably inside the linkage and interaction among different variables characterising the land use, the transport systems, the environment. But it has not be forgotten that the real causal linkage is always between human action and reaction.

An interesting question could be:

> “does the transport user’s behaviour generate the policy makers’ decisions” ?

or

> “does the policy makers’ decisions generate the transport users’ behaviour” ?

The focal point is anyway on the people behaviour and on the possibility to influence it. It is a huge point, very delicate and not politically correct.

1. Historical perspective

The concept of "induced travel" is quite old as the first studies on traffic-generating effects of road improvements go back to the first half of the XXth century.

In Europe, a historical perspective has been carried out by Goodwin (1996) who cites the first study by Bressey and Luitens (1938) who observed a significant increase in traffic on a new English road, the Great West Road. Twenty years later, in 1958, Glanville and Smeed showed that the traffic growth on roads that were already congested was much slower than traffic growth on roads which were less congested. This observation was confirmed by more recent studies, by Institution of Highways and Transportation (SACTRA, 1994), and by Mogridge et al. (1987) who extended the approach followed by Glanville and Smeed. Pells (1989) cited 78 published and unpublished studies with a wide range of results in term of percentage of induced traffic where more evident was the trip retiming. Hawthorne and Paulley (1991) analysed the effects of changing levels of congestion founding reference to choice of route, departure time, mode shifts, trip frequency, changes in travel and willingness to own cars. These conclusions were not accepted by Howard Humpreys and Partners (1993); they stated the reassignment as the only evident response of users to road improvements. In Holland, Bovy et al. (1992) examined the consequences on travel and traffic patterns of the opening of the Zeeburger Tunnel, final part of M10 Amsterdam Beltway.

In USA, an historical review of induced traffic was carried out by Transportation Research Board (1995). The first who studied the effects of new road was Jorgensen (1947). He analysed the traffic counts before and after the opening of the new facilities founding a traffic increase higher than normal rate of growth. In the following years, Lynch (1955), Frye (1964a, 1964b), Holder and stover (1972), Ruiter et al. (1979, 1980) examined the effects of the construction of expressways and highways. In the most recent years the studies of Hansen et al. (1993) examined before-and-after traffic volumes for18 California highway projects involving capacity additions to existing highways.

Before to deeply examine the mentioned studies to emphasise their finding and results, it is important to clarify what is the induced travel, by the way of the numerous definitions given during several years because this can help to compare the hypotheses and, hence, the results of the different studies.

2. Induced traffic: definitions and causes

In this chapter definitions of induced travel given by numerous researchers will be presented, trying to solve the existing ambiguity and to reach a univoque definition.

Then, the causes of induced travel will be investigated to deepen the effect of causality between supply and demand of transport, studied by a long number of researchers.

2.1. Definitions of induced travel from different authors

Before reviewing the significant definitions given by a large number of researchers, it is useful to try to individuate a strict meaning for induced travel as, for example, that given from dictionary.

The meaning given for "to induce" is:

- to cause or to produce the formation of something;
- to move by persuasion or influence ...; to call forth or bring about by influence or stimulation.

This definition is quite interesting because it helps to individuate a literal meaning of the word and to compare that with the different interpretations given by the researchers.

These definitions are given in historical order, also to see if some kind of evolution has been occurred.

Brand, D., Benham, J., (1982) state that the travel on a new or improved transit facility is composed of four components:

1. the travel not existing today and due to growth of population and job;
2. the travel diverted from (or to) the automobile mode due to change in operating costs;
3. the travel diverted to the improved transit facility from facilities of the same mode;
4. the induced travel.

"Induced transit travel" is the travel that is induced in the corridor and specifically on the transit alternative being evaluated as a result of the new or improved transit facility; induced transit travel includes travel that results from increased rates of choice of destinations served by the improved facility and increased transit trip frequency (including automobile trips diverted to the transit improvement).

The **SACTRA** committee **(The Standing Advisory Committee on Trunk Road Assessment, 1994),** made an important distinction between "generated" and "induced" basing it on the general proposition of public concern that "roads generate traffic". It points out that a particular care has to be put about the term "generate" because two reasons:

- it considers axiomatic that travel is rarely an end in itself and very few journeys are made simply for the pleasure of the journey itself. What really generates travel are the patterns and locations of residences, workplaces, sources of materials and supplies, shops, hospitals, leisure facilities, etc. This means that an increase of accessibility between places enhances social and individual activity while the increase of accessibility in itself favours changes in land-use locations, development of new places, and evolution of land-use patterns;

- the word “generation” relates quite universally to the technical meaning of “average number of trips that are made, per hour or per day, by a specific category of travellers in a specific geographical area”. So, it speaks about number of trips and not about volume of traffic.

So, to avoid any confusion, the committee proposed and adopted, “the word induced”.

The definition of induced travel given by SACTRA can be synthesised by a table (Figure 2.1) where all the behavioural responses occurring after a new road is opened are depicted.

The starting point is to distinguish the different matrices: the fixed matrix of person-trips, the semi-variable trip matrix, and the variable trip matrix.

A further distinction, then, has to be made between trip matrix and vehicle matrix. Really, the trips switched from other modes are considered as existing trips in a person-trip matrix, but they would be induced trips in a vehicle-trip matrix.

In the case of fixed matrix of person-trips per day the behavioural responses due to the opening of a new road can be:

- diversion from old to new road (change in route);
- change in timing (travel in peak period);
- diversion from one mode to another (e.g. from bus to car);
- decrease in vehicle occupancy (use own car instead to be passenger on another car);

and no new trip is induced, the people having already chosen to undertake the trip. The only exception is the “trip frequency” response (Figure 2.2) where more trips are made between any origin and destination because the new road (e.g. going to home for lunch).

About the fixed trip matrix, the four responses mentioned above involve existing trips, so there are no induced trips, but some changes could result in induced traffic (e.g. journeys made previously by train and after by car, adding traffic to road network).

Also if the mentioned behavioural responses are plausible, but also commonplace and observable, the conventional economic evaluation procedures do not take much account of them, as showed in figure 2.2 by the shaded area covered by the COBA 9 (Cost Benefit Analysis) procedure (DoT 1993); really the traffic assignment is the concept used in the economic and environmental assessment of schemes.

Anyway a component of induced traffic can result also from the traffic assignment in a fixed matrix, arising from extra distance travelled to reach destination, using the new road. So, some journeys could be shorter and quicker, but for most trips a trade-off between distance and time will be needed. People perception in term of willingness to pay for time saving despite the increase of vehicle operating costs is fundamental in this trade-off.

About the semi-variable trip matrix, where new origins and destinations occur for existing trips there is almost bound to be some induced traffic as the highway network improves. In the long run the variable trip matrix prevails because there are less constraints on origins and destinations and the framework becomes more complex: it is fundamental to distinguish the traffic related to existing development (before the completion of the new road scheme) from that related to new development (occurred after the new road scheme).

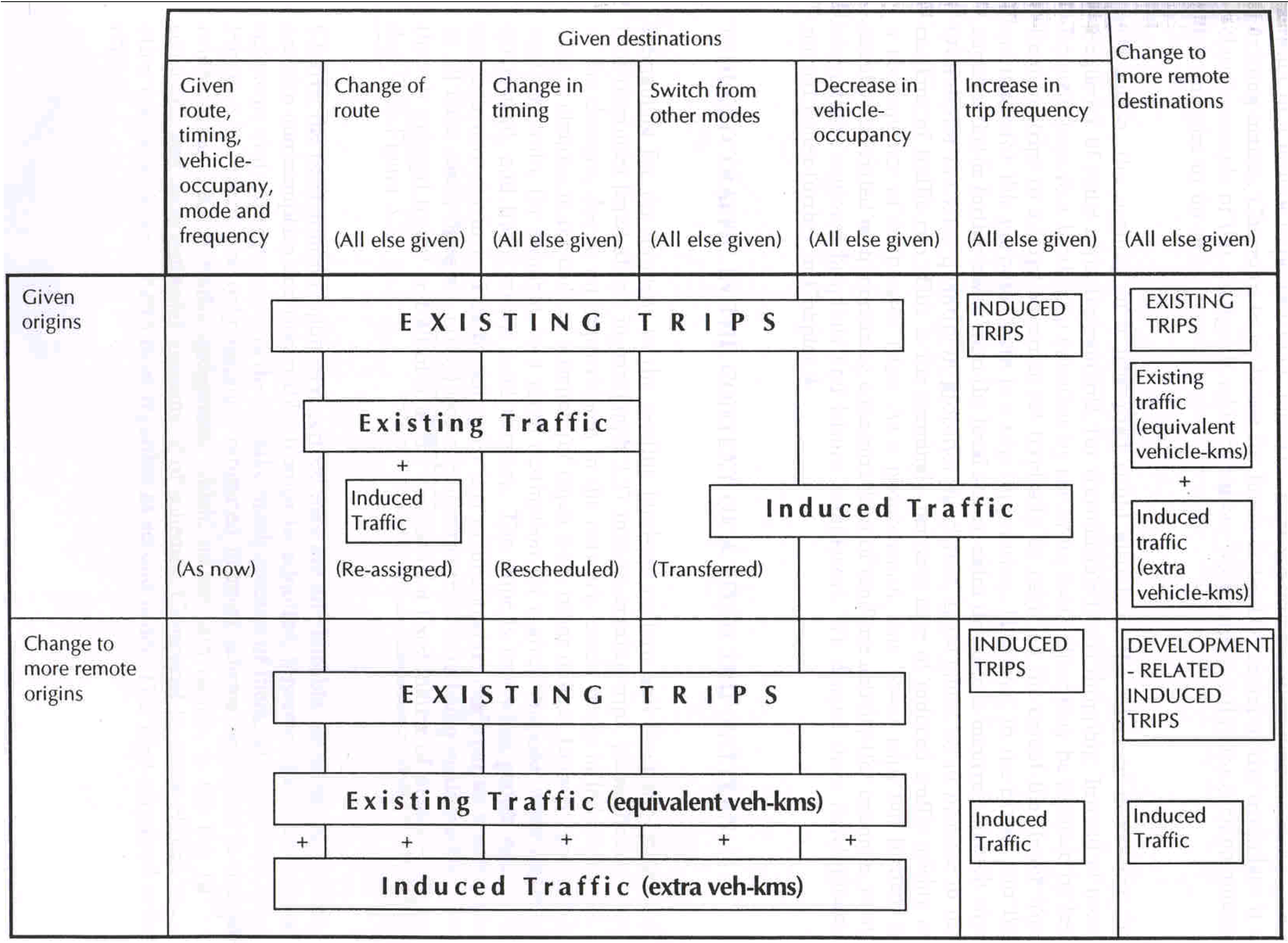
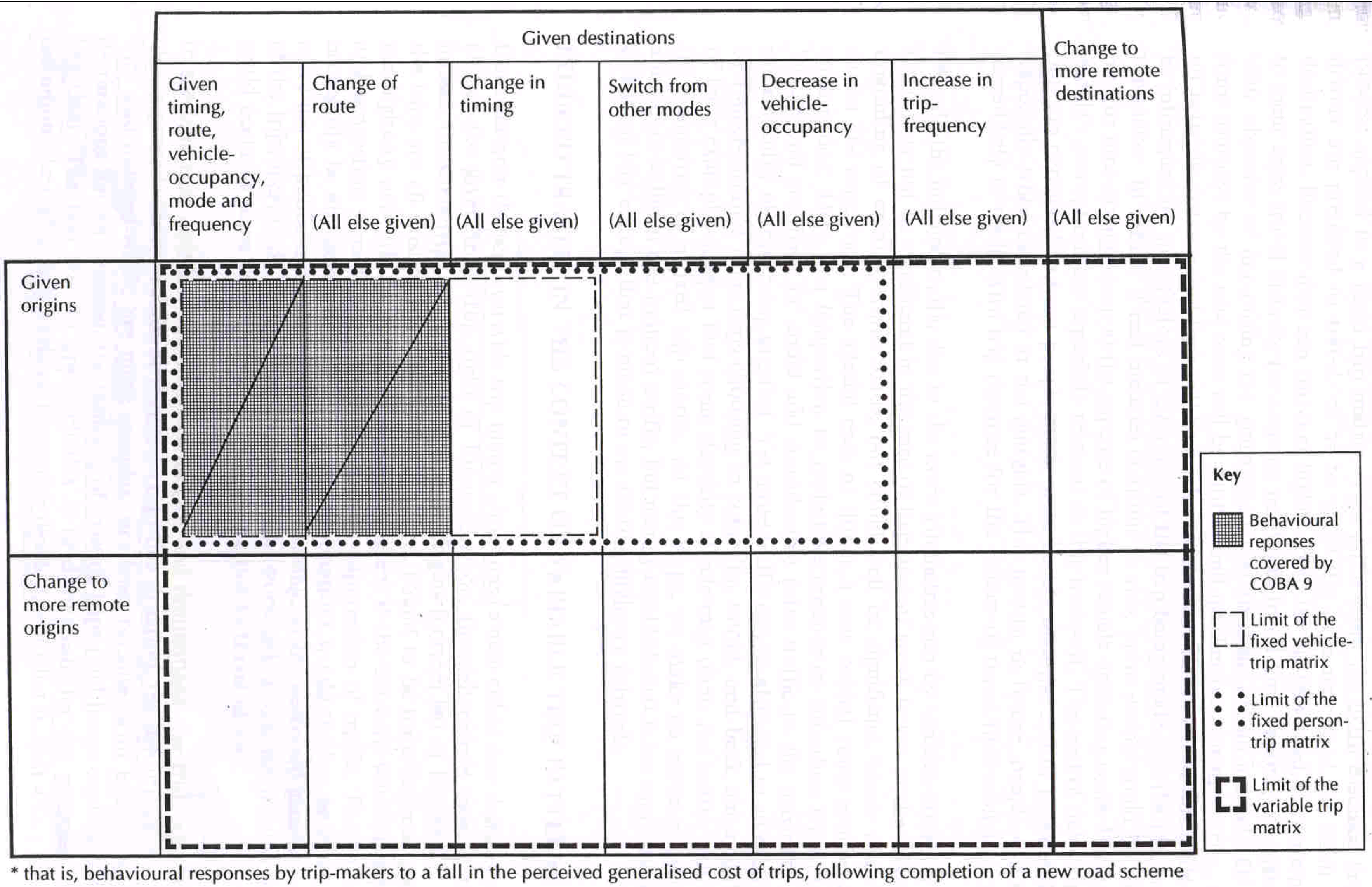


Figure 2.1: Definitions of existing and induced traffic and trips (Source: SACTRA, 1994)



Source: SACTRA, 1994

Figure 2.2: Coverage of responses evaluated by COBA 9*

When both origins and destinations change, the induced traffic would be the extra vehicle-kms due to greater trip distances, and it can be estimated by monitoring the changes in trip distances over time for different journey purposes.

In case of new development occurring after the implementation of a road scheme, it is difficult to distinguish the development induced by the locations due to the new road scheme from the development that would have occurred anyway regardless the increase of accessibility. Really, only the traffic generated by the first component is induced traffic, because the other traffic increase is due to economic growth, exogenous to the road scheme.

Hills, P.J., (1996) starts from the SACTRA's definition of induced traffic, observing that a sharper definition is needed and that the change of accessibility is the central point because it changes the travel times and creates new origins and destinations.

So, he asserts that, while all the traffic is generated by people's decision to travel, induced or suppressed traffic is confined to those vehicle-movements associated with any given change in the accessibility of the network. The behavioural responses of vehicle-users are decisive to determine such vehicle-movements.

For **Heanue, K., (1998)**, the highway planners defined induced travel as the increase in highway trip making resulting from a highway improvement. All other changes such as shifts in destination, mode, and route were accounted for separately.

Then, popular press and academics define induced travel as encompassing any combination of increases in trips and trip lengths resulting from a system change.

The different perspective of highway builders and the other is evident.

He therefore concludes that "induced travel" is any increase in daily travel (measured as passenger or vehicle miles of travel) resulting from a change in the transportation system.

Lee, D.B., (1999) does an interesting distinction between "induced traffic" (or travel) and "induced demand" basing it on the time concept. The demand is generally assumed fixed in the short run, so the changes in volumes are due to the movements along the demand curve, whereas the short run demand curve can shift in the long run. So, "induced traffic" is a movement along the short run demand curve, while "induced demand" is a movement along the long run demand curve, or an endogenous shift in the short run demand curve.

Lee uses the term "induced" referring to any endogenous change (positive or negative, that is increase or reduction of traffic), and he says that the possible causes of induced traffic are:

- diverted traffic due to change of route;
- rescheduled traffic at a different time (spreading or contracting the peak period);
- diverted traffic from other modes (including change in occupancy);
- change of destinations;
- additional travel of people already using the facility (change of frequency).

DeCorla-Souza, P., Cohen, H., (1999) propose first a list of possible interpretations of induced traffic, emphasising the difference between person travel and vehicle travel, about the unit of measure of trip (trips or miles) and the time and geographic frame of reference of a trip (facility, corridor, subarea, regionwide area). They affirm then that "induced travel" is an increase in daily vehicle miles of travel, with reference to a specific geographic context, resulting from expansion of highway capacity.

The author developed also a taxonomy of sources of induced travel that are:

- increase in person trip production due to development;
- increase in person trip attraction due to development;
- increase in number of daily motorized person trip production's and attraction's per development unit;
- increase in average motorized person trip distance;
- increase in share of person travel by private motorized vehicles;
- shift in vehicle travel to improved facilities from unimproved facilities within a corridor, or to an improved corridor due to the diversion of traffic from other corridors.

The first three sources are generally not estimated from the models and represent the most evident error in the forecast activity and, consequently, in the evaluation of different policies.

In **Transtech Management, Inc. & Hagler Bailly (2000),** the authors focus the attention on the change in travel behaviour due to time savings created by the new or improved facility, and so on its economic aspect. This change in behaviour generates two effects:

- induced travel, formed by new trips and longer trips;
- redistributed travel, formed by mode shifts, diverted travel (route change) and time of day shifts.

This definition is based on the most common way to consider induced travel: new and longer trips, but not diverted travel and time of day shifts. The mode shifts do not induce new travel, but sometimes are considered to be part of induced travel (see Litman, 2001) because they generate additional vehicle miles of travel (VMT).

The authors' definiton is so based on a consensus reflecting work by Cohen, Heanue, De Corla-Souza and Cohen, Noland and Cowart and others: "an increase in total daily travel that results from a change in transportation system capacity within a defined geographic area".

According to **Cervero, R., (2001)**, the increase of capacity prompts behavioural shifts in the short run that express latent demand and triple convergence of Downs (1992): switch of mode, route, time to travel. Over the long term, instead, structural changes can be expected.

The author says that induced traffic is generative in nature and some is redistributive.

The generative travel represents new travel that did not previously exist in any form. Included here are formerly suppressed trips, longer trips as motorists opt to travel farther because of free flowing traffic, and modal shifts.

Redistributive travel are route and schedule changes, in the sense that they do not increase total miles traveled.

The study: **Environmental Protection agency (EPA) 231-R-01-002 (2001),** starts with the affirmation that "induced traffic is a term for traffic growth produced by the addition of highway capacity". Induced travel is considered as increase in trip making (changes in trip frequency and switches to alternative destinations) and mode switches, while switching routes and changing travel times do not constitute new vehicle travel.

Litman, T. (2001) starts from the definition of "generated traffic", considered as the additional vehicle travel that results from a road improvement.

Litman defines the generated traffic as the sum of diverted plus induced, where in diverted traffic he puts trips shifted from other routes, destinations and time while in induced traffic he puts shifts from other modes, longer trips and new vehicle trips.

So, induced travel refers to the increases in total vehicle travel (VMT), excluding traffic diverted from other routes or times.

Noland, R.B., (2001) gives a first definition of induced travel thinking about the disagreement on such a definition, observing that some would argue that only direct behavioural changes that generate new trips should be called induced travel, while others may claim that shifts between modes do not generate new trips and therefore cannot be called induced travel (despite the increase in VMT).

So, he defines induced VMT as any infrastructure change that results in either short run or long run increases in VMT. Short run effects include changes in travel departure times, route switches, mode switches, longer trips, and some increase in trip generation. Of these, mode switches and new trips clearly contribute to induced vehicle travel. Longer run effects are related to how land use patterns adjust to the newly available capacity and the resulting spatial allocation of activities, and can be included in the definition of induced travel since they are the result of economic changes induced by capacity additions.

Noland, R.B., Lem, L.L., (2002), as already Lee (1999), base their definition on the economic theory of supply and demand.

The source of induced travel is the generalized cost of travel that is reduced by the supply increase by reducing the time cost of travel.

Induced travel naturally assumes some elasticity of demand associated with travel, but traffic engineers have traditionally assumed that travel demand has totally inelastic demand implying that total travel will be constant irrespective of changes in the price (or time cost) of travel.

The authors observe that if the travel demand is considered inelastic and the travel growth is attributed to exogenous factors, a disagreement over the existence of induced traffic has to be expected.

In addition, also the definition of induced traffic is debated. They define the induced travel as an increase in VMT (vehicle miles travelled) attributable to any transportation infrastructure project that increases capacity.

The effects expected from capacity expansion are:

- immediate behavioural effects such as rescheduling of time departure, route diversion, mode diversion, longer trips, increase of total trips;
- longer run effects such as increase in household auto ownership levels, spatial reallocation of activities, changes in land development patterns within a region.

Finally the authors individuate a consistency of induced travel with Downs (1992) theory of "triple convergence" about the three immediate effects occurring in response to a capacity addition: route diversion, rescheduling of time travel, mode diversion. These effects can lead to Downs-Thomson paradox whereby road capacity increases can actually make overall congestion on the road worse (Mogridge et al., 1987).

Another interesting theory based on people behaviour and connected to induced travel concerns the Travel Time Budget (TTB). This theory assumes that the total budget allocated to travel tends to remain constant over the time (see Zahavi and Ryan, 1980 and Zahavi and Talvitie, 1980) because the travel time savings from increased travel speeds tend to be off-set by increased travel distance, rather than actual travel time savings. So, individual TTBs tend to remain constant.

2.2. Induced traffic definitions: some remarks

Some first remarks concern the differences envisaged in the definitions of induced travel given by the mentioned authors, and which kind of trips are included in induced travel.

Litman (2001), for example, does not consider the mode shift as a diversion, but this is probably ambiguous when the author asserts that "in the short term, most generated traffic consists of trips diverted from other routes, times and modes, called Triple Convergence (Downs, 1992). Over the long term an increasing portion consists of induced travel." So, it is not so clear if the mode shift is diverted in the short time and induced in the long time (as said) or is always induced (as depicted in table 2.1 and highlighted in yellow).

To solve the ambiguity, it could be said that the mode shift is induced traffic because it generates more VMT and this would correspond to Noland and Lem (2002) definition. Really, they affirm that induced travel is an increase in VMT, simplifying the ambiguity in Litman who "distinguishes between induced traffic and generated traffic", where the latter includes diverted traffic (from other routes), while induced traffic does not include any diverted traffic".

This ambiguity, really, had already been solved by SACTRA (1994) and Hills (1996) when they did the distinction between the person-trip matrix and vehicle-trip matrix: the difference are the trips switched from other modes. These are existing trips in a person-trip matrix, but would be induced trips in a vehicle-trip matrix. The increase in trip frequency changes the number of trips and, so, the person-trips matrix. These are induced trips, as also the longer trips: the increase in VMT is induced traffic.

So, it seems largely accepted that induced travel can be well defined by the increase in vehicles miles travelled (VMT) due to a supply modification.

Type of Generated Traffic	Category	Time Frame	Travel Impacts	Cost Impacts
Shorter Route Improved road allows drivers to use more direct route.	Diverted trip	Short term	Small reduction	Reduction
Longer Route Improved road attracts traffic from more direct routes.	Diverted trip	Short term	Small increase	Slight increase
Time Change Reduced peak period congestion reduces the need to defer trips to off-peak periods.	Diverted trip.	Short term	None	Slight increase
Mode Shift; Existing Travel Choices Improved traffic flow makes driving relatively more attractive than other modes.	Induced vehicle trip	Short term	Increased driving	Moderate to large increase
Mode Shift; Changes in Travel Choice Less demand leads to reduced rail and bus service, less suitable conditions for walking and cycling, and more automobile ownership.	Induced vehicle trip	Long term	Increased driving, reduced alternatives	Large increase, reduced equity
Destination Change; Existing Land Use Reduced travel costs allow drivers to choose farther destinations. No change in land use patterns.	Longer trip	Short term	Increase	Moderate to large increase
Destination Change; Land Use Changes Improved access allows land use changes, especially urban fringe development.	Longer trip	Long term	Increased driving and auto dependency	Moderate to large increase, equity costs
New Trip; No Land Use Changes Improved travel time allows driving to substitute for non-travel activities.	Induced trip	Short term	Increase	Large increase
Automobile Dependency Synergetic effects of increased automobile oriented land use and transportation system.	Induced trip	Long term	Increased driving, fewer alternatives	Large increase, reduced equity

Source: Litman, 2001

Table 2.1: Types of generated traffic

2.3. Induced traffic: which cause ?

Having clarified the definition of induced travel, the next step is better analyze its causes, paying attention overall to the people behaviour.

Hills (1996) says that “all the traffic that one can observe using a network will have been generated as a result of the travel-decisions made by the population at large. Induced or suppressed traffic (on the other hand) is confined to those vehicle-movements associated with any given change in accessibility of the network. In this sense, roads themselves cannot generate traffic (unless you regard joy-riding as a legitimate journey-purpose) but the improvement of a road to the existing network can induce extra traffic, by influencing those travel-decisions in many and various ways.”

The first proposition states the human beings as the main cause of traffic generation with their decisions to travel and could be so synthesized:

1. *Human beings → decision to travel → travel*

The second proposition suggests that traffic can be generated by a characteristic of the road as the “accessibility”, where its variation could influence people decision to travel:

2. Human beings → decision to travel → travel
Change of accessibility ↗

The third sentence affirms that the road itself cannot generate traffic, because this would mean that an intrinsec capacity of generation could be inside the infrastructure, and this can be only the joy-riding, envisaged as a purpose. In this way, it does not seem to be clear if the joy-riding is the cause generating the travel because:

- it is the purpose of the travel and so it becomes the cause

3a. Joy-riding → human beings → decision to travel → travel → joy-riding

- or it is a characteristic of the travel in itself (not of the infrastructure) and it influences the decision to travel:

3b. Human beings → decision to travel → travel
joy-riding ↗

- or it is a pure human attitude, influencing also the decision to travel (the same of 3b.).

So, which is the real cause in traffic generation ? a human-related variable or an infrastructure-related variable ?

Hills (1996) suggests that the characteristics of the infrastructure can influence the decision to travel and so they are the indirect cause of the travel. Thinking about the classical economical approach of elasticity of demand, Lee (1999) says that “induced traffic is a movement along the short run demand curve”. He refers to endogenous changes as reducing congestion (or improving accessibility), reducing tolls, etc., other things being equal, causing an increase in traffic volumes; this happens because these changes vary the travel cost, and, hence the utility of the travel.

An interesting question arising from the previous considerations concerns the concept of “utility”. Which parameters are and should be contained in the utility of the travel, and hence, actually, in the generalised cost function ? This is a focal point to understand the people reaction and, so, their behaviour in term of mobility.

Then, Kevin Heanue (1998) says that: “transportation system capacity itself, a priori, does not influence travel behaviour. Travel times, costs and other measures of perceived travel difficulty do influence travel decisions”. He puts the stress on “human beings and their decisions”, but he says also that the characteristics of the transportation system represent a set of attributes influencing travel decisions. So, indirectly, the transportation system capacity can influence travel behaviour, in the same way as accessibility or joy-riding. This means that the right way could be put the human beings before everything and decide what could influence them in term of their decisions. But, if the “transportation system connectivity, usage, and performance can influence the location, nature and timing of activity growth” (Heanue, 1998), how much transportation system can change human life ? It is not a trivial question, as it seems always harder understand which is the cause and which the effect, and probably it is not a cause-effect matter, but the process could be circular where no more cause or effect exist.

But, then, Heanue affirms that, according to a survey of *Money magazine,* the main criteria for choosing the ideal place to live were: crime, environment and health services while transportation criterion ranked a very low level; he concludes that the high level of access mobility generally available in the U.S. lessens its impact on specific location decisions. However this answer is probably linked to the population aimed by this survey (with higher than average income, education, etc.), which could be less sensible to the cost of the mobility.

Cervero (2001), discussing about the cause of traffic increase, affirms that the lane miles addition is not the cause of induced traffic, but the benefits that the lane miles confer are the cause of traffic increase. Again, as seen before, the cause is not the infrastructure, but what it represents: economical benefits seen basically as time saving.

It seems to play with the words: the cause is the "object" or the "pleasure" that the object provides ? Anyway, without the "object" also the "pleasure" cannot exist. So, they could be merged without any risk.

3. Induced traffic and induced demand: the economic theory

The matter of induced travel contrasts with the traditional approach followed by transport planning in term of transport demand.

Historically, demand forecasts have been based on exogenous variables (land use, population, employment, and income) and this means that neither transport infrastructures nor money price influenced them; the transport models, so, cannot control any aspect beyond these exogenous variables (Lee et al., 1999).

The existence of a latent demand, supported by the sentence symbol "build it and they will come", shift the attention on the endogenous aspect of demand, that imply a potential control of demand by policy choices: if there is the supply, the demand will be born, and if the supply is suppressed, also the demand will die.

Anyway the concept of balancing demand and supply is well known by the economists, as also the mechanism relating price and quantity demanded, that has become generally accepted. From this perspective, all endogenous changes in volume are movements along the demand curve. If "price" is generalized to include travel time, operating costs, and accidents, then changes in capacity and alignment alter the "price" and thereby cause movements along the demand curve (Lee et al., 1999).

In general, the travel demand is the result of a combination of both exogenous factors that determine the location of the demand curve, and endogenous factors that determine the price-volume point along the demand curve. Such a result is well expressed by an indicator named "elasticity" that is the responsiveness of quantity demanded to changes in price. The elasticity can show the effects of an increase in capacity that, lowering the travel time (at least in a first time), results in additional travel and can be different in the short or long run. Generally the short run elasticity is lower (less elastic) than long run elasticity, also if there is a continuum state between short run and long run demand.

This is illustrated in figure 3.1, where two short run demand curves (D_1 and D_2) are depicted and related to their common long run demand curve (D_{LR}). At the "long run" the price p_1 corresponds to volume v_1 and the short run demand curve D_1 applies; changes in the price cause changes in the volume along this curve in the short run and if the price decrease to p_2 the volume will increase to $v_{1,S}$. If this price stays at this level p_2 for the long run, the curve D_1 will shift outward to D_2 and the relative volume will be v_2. If the price changes again to p_1, the volume will drop to $v_{2,S}$ in the short run, but could also back to v_1 in the long run.

The effects on demand of the fuel price are well-known examples. When the fuel price declined in USA, the effects were the increase in size and weight of vehicles, while a fuel increase would restrain the gasoline consumption, but the secondary consequence was, in a longer time, the effort to evolve the car fleet to more fuel-efficient one.

The distinction between the short and long run elasticity leads to the similar distinction between "induced travel" and "induced demand". The "induced travel" is due to the fixed demand in the short run, so that the changes in volumes are the results of movements along the short run demand curve; the "induced demand" is due to the shift in the long time of the short run demand curve and it is a movement along the long run demand curve, or an endogenous shift in the short run demand curve (Lee et al, 1999).

These movements can be well represented by the short- and long run elasticities, respectively e_{SR} and e_{LR}, where the elasticity is considered as the ratio of the percent change in quantity demanded to the percent change in the price of the good.

Referring to figure 3.1, the elasticity between the points (p_1, v_1) and (p_2, v_2) is the long run elasticity demand e_{LR}:

$$e_{LR} = \frac{\%\Delta v}{\%\Delta p} = \frac{\Delta v}{\Delta p} \times \frac{p_1}{v_1} = \left(\frac{v_2 - v_1}{p_2 - p_1}\right) \times \frac{p_1}{v_1} \qquad (3.1)$$

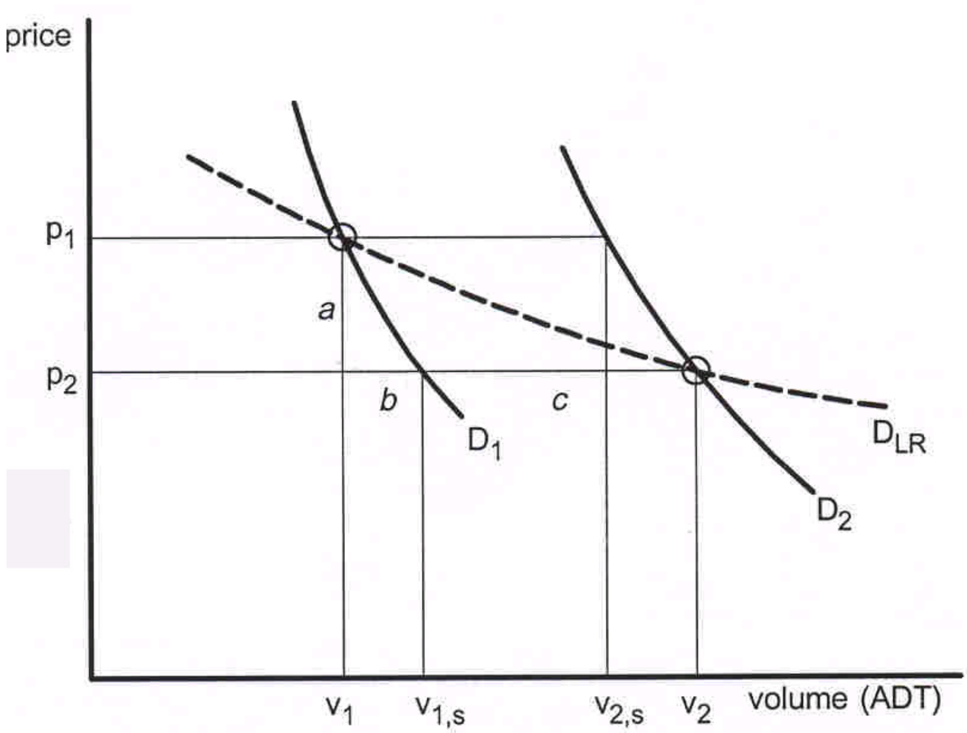
and using the symbols in figure 3.1, some simplifications can be made:

$$\begin{aligned} a &= p_2 - p_1 \\ b &= v_{1,S} - v_1 \\ c &= v_2 - v_{1,S} \end{aligned} \qquad (3.2)$$

and so:

$$e_{LR} = \frac{b+c}{a} \times \frac{p_1}{v_1} = \left(\frac{b}{a} \times \frac{p_1}{v_1}\right) + \left(\frac{c}{a} \times \frac{p_1}{v_1}\right) \qquad (3.3)$$

where the first term in parentheses is the short run elasticity (e_{SR}) and the second term is the shift in the demand curve over the long run, represented as an elasticity.



Source: Lee et al., 1999

Figure 3.1: Long run demand with short run demand curves

So, the long run elasticity is the sum of the e_{SR} and a purely long run component, named the long run share e_{LRS}:

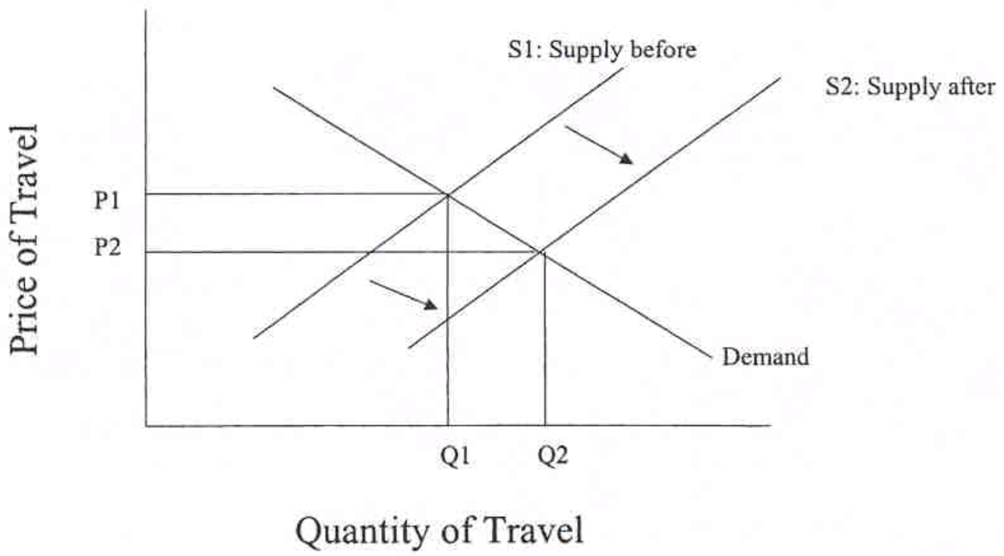
$$e_{LRS} = \left(\frac{c}{a} \times \frac{p_1}{v_1}\right) = \left(\frac{v_2 - v_{1,S}}{p_2 - p_1}\right) \times \frac{p_1}{v_1} \tag{3.4}$$

so that:

$$e_{LR} = e_{SR} + e_{LRS} \tag{3.5}$$

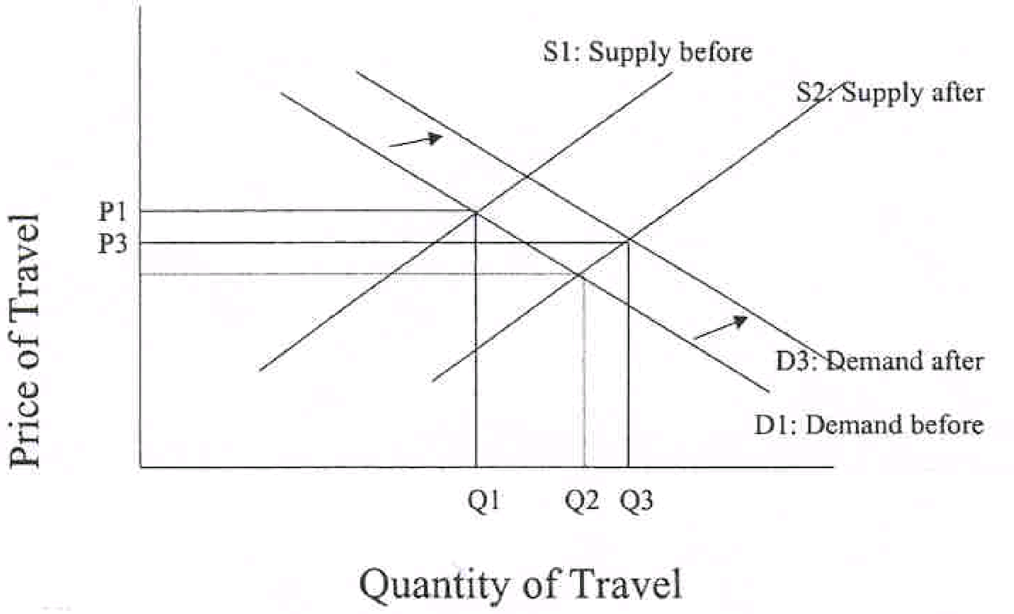
The e_{LRS} is an elasticity, measured as the difference between the short run elasticity and the long run elasticity estimated for the appropriate time period (see Taplin, 1982 for theory).

Until now the supply has not been explicitly mentioned, but implicitly inside the concept of price on the demand curve. The economic theory provides the concept that the congestion is self-regulating, implying an automatic balancing of supply and demand. The supply curve is based on the cost of travel that is determined by different factors as the cost of gasoline, of parking, of tolls, and of time. The common understanding is that an increase of the road capacity results in a reduction in the time of travel (Noland, 2001). Travel supply and demand and the induced travel effect are illustrated in figure 3.2 where the line S_1 is the supply before a capacity expansion that lowers the cost of travel, and the line S_2 is the supply after the change in capacity. S_2 is shifted downward to show the decrease of price of travel from p_1 to p_2, causing a movement along the demand curve (remaining constant) and the increase of quantity of travel from q_1 to q_2 (representing the induced travel effect). But, in measuring the induced travel effect there are other confounding factors that also drive growth in travel as population growth and demographic effects, etc.. Figure 3.3 shows these effects determining the shift ouwtard of demand curve from D_1 to D_3, but also the simultaneous shift of demand and supply curves. This determines a higher increase of quantity of travel to Q_3, in respect to figure 3.2. To isolate these two concurrent effects is quite difficult and is also the cause of the great debate about the magnitude of the induced travel effect, as distinct from the growth effect. So, in figure 3.3 the induced travel effect is measured along the horizontal axis as the difference between Q_2 and Q_1, while the effect from exogenous growth is the difference between Q_3 and Q_2 (Noland, 2001).



Source: Noland, 2001

Figure 3.2: Induced travel



Source: Noland, 2001

Figure 3.3: Induced travel during a period of underlying growth in demand

4. Studies in Europe and USA

A high number of studies have been carried out overall the world, as seen in the historical perspective of induced travel (section 1.). Here they will be depicted in more detailed way, to understand the evolution of the thought and the debate on this topic of research.

In 1995 the Transportation Research Board reviewed historical literature, as mentioned in the historical perspective (section 1.) and showed that the most part of the methods used in the analysed studies involved measuring traffic counts before and after the construction of a new facility (e.g. Jorgensen, 1947; Lynch, 1955). Adjustments were then made to control for "normal" growth in the corridor and the resulting difference was attributed to the new highway capacity. The limits of these studies was that, statistically, it was not possible to explicitly attribute differences in traffic to the new capacity. Really, these studies did not use statistical models to control for other effects that cause VMT growth.

More recently, Noland and Lem (2002) presented a review of empirical studies on induced travel.

Let see now in more detail the main studies analysed and mentioned in the recent literature.

The first study, cited by Goodwin (1996), is made in UK and attributed to ***Bressey and Luytens (1938)*** that reported that the Great West Road: " ... as soon as it opened, carried 4,5 times more vehicles than the old route was carrying; no diminution, however, occurred in the flow of traffic on the old route, and from that day to this, the number of vehicles on both routes has steadily increased ... These figures serve to exemplify the remarkable manner in which new roads create new traffic".

The first study in USA is attributed to ***Jorgensen (1947)*** that studied the effects of the construction of the Merritt and Wilbur Cross parkways on traffic in the corridor between New York City and New Haven, Connecticut. He concluded that the parkways generated 20 to 25 % more traffic in the corridor than expected from the normal rate of growth and based his results on the analysis of traffic counts on several years before the opening of the new facilities and after that.

Really he found a strong correlation between the traffic counts and the gasoline sales in Connecticut, and he used this observation to estimate the normal growth in traffic after the opening of the parkways.

Some years later, ***Lynch (1955)*** estimated the traffic effects of opening the turnpike on the Maine Turnpike/U.S. Route 1 corridor, founding a traffic on the corridor 30 % greater than expected from normal growth five years after the opening of the turnpike. The results were based on the data of the growth of traffic on major roads in Maine outside the corridor.

An important study is due to ***Glanville and Smeed (1958)***; they showed that traffic growth on roads that were already congested was much slower than traffic growth on roads which were less congested (Goodwin, 1996). This results was confirmed later by Mogridge et al. (1987) and SACTRA (1994) that extended this approach.

After about six years, ***Frye (1964a, 1964b)*** based his study on the comparison betwen the traffic counts and origin-destination survey data collected before and after the opening of two expressways, the Dan Ryan and the Eisenhower expressways in Chicago. The results emphasized an increase of traffic, through a 5 miles screen line centred on the Dan Ryan expressway, of about 11% after the opening of the Dan Ryan expressway, and an increase of 21% for the Eisenhower expressway versus a 14 % increase in three control areas. He concluded that great part of the increase on Dan Ryan was due to route diversion, while the huge growth on Eisenhower was the result of four factors: natural growth, adverse traffic (more VMT on local and arterial streets to get to or from expressway on- or off-ramps), diverted traffic (from other routes outside the study area to the new expressway or to local streets and arterials), and induced traffic (additional trips in the study area because the improved level of service on the new facilities and old competing facilities). This study began to highlight the difficulty to distinguish the four factors, and assigned scarce weight to induced traffic.

The data of eight urban highway projects in Texas were analyzed by ***Holder and Stover (1972),*** who compared corridor traffic growth before project opening with either regional trends or corridor growth before project completion. They identified six components: diverted traffic from other roads; converted traffic from other modes; growth traffic from increase in population; developed traffic from changes in land use; cultural traffic from changes in the propensity to travel resulting from socioeconomic changes; induced traffic from new trips made because of added convenience. The conclusions of the authors were that:

- apparent induced traffic can represent a significant portion of the traffic on a new facility;
- most induced traffic occurs during off-peak hours;
- the eventual substantial amount of induced traffic on a new facility can be due to the significant reduction of the off-peak travel time or by the congestion on the existing facilities.

A wide analysis was carried out by ***Pells (1989),*** on 78 published and unpublished studies, theoretical discussions, modelling exercises and traffic counts. The studies were analysed considering the measurements of traffic in the corridors before and after the construction of the facilities and the comparison of the percentage growth in traffic with the percentage growth in control corridors. The difference measured represents the combined effects of different factors: wide area reassignment (also rerouting of trips from corridors external to the study area); redistribution of trips to different destinations; attraction of trips from other modes; retiming of trips; generation of trips (new trips or made more frequently). The results covered a wide range, and the estimated induced traffic ranged from 0% to 76% of observed increases in traffic flow.

An extensive before-and-after study ***(Bovy et al., 1992)*** was carried out by the Rijkswaterstaat Transportation and Traffic Research Division on the consequences of the opening of the final part of M10 Amsterdam Beltway, the Zeeburger Tunnel, in September 1990. The traffic counts, the interviews to households and the roadside survey origin-destination showed that the opening of the Zeeburger Tunnel caused a 4.5 percent increase of traffic across the North Sea Canal, formed by 1.5% from route diversion, 1% from diversion from transit, 2% from changes in destinations or travel frequency. Also if the increase in traffic was not consistent, a significant increase in peak-period was found (+16%) due to changes in travel time.

Then, some researchers used transport planning models to estimate the effects on VMT of improvement projects and others estimated the elasticity of VMT with respect to capacity.

Ruiter et al. (1979, 1980) did not use the conventional travel forecasting models because the trip generation rates were sensitive to travel times, also if the changes in VMT associated with changes in land use patterns were not incorporated in the model outputs.

The authors analysed two highways in California; the first project was concerned with the construction of 5 miles of a new 8-lane freeway causing a 0.855 percent increase in capacity in the study area. Such an increase caused a 0.379 percent increase in VMT in the same area, so that the estimated elasticity of VMT with respect to capacity is of 0.4. The other project involved widening a 12-miles section of freeway from 4 to 6 or 8 lanes, giving a 0.647 percent increase in capacity in the study area. This enlargement caused a slight decrease in VMT because the new trips were offset by reduced length of existing trips.

The difference in the results regarding the two projects is interesting and is due to the different time saving produced. The first project was a new freeway that caused a consistent time saving either in peak or in off-peak periods; the second one was only a widening of an existing freeway, producing significant time saving only during the peak period, so that caused a shift of trips from the off-peak to peak period.

Ruiter et al. (1979) analysed also several studies regarding entire metropolitan areas and summarized them in the form of elasticities (table 4.1); these elasticities are generally small, showing small changes in areawide VMT in respect to supply change. The only exception regards the highway speed, with estimated elasticities of 0.58 and 1.76.

Transportation supply measure	Elasticities	Sources
Average highway speed	+ 0.58; + 1.76	A.M. Voorhees & Assoc. (1971); Zahavi (1972)
Total lane miles of highway	+ 0.13; + 0.15	Kassoff and Gendell (1972); Koppelman (1972)
Lane miles of Interstate	+ 0.0056	Mellman (1976)
Lane miles of freeways	+ 0.05	A.M. Voorhees & Assoc. (1971)
Miles of rail transit service	- 0.033	Mellman (1976)
Vehicle miles of transit service	- 0.09	EIC Corporation (1976)
Seat miles of transit service	- 0.0098	A.M. Voorhees & Assoc. (1971)
Fraction of driving surface on freeways	+ 0.16	Koppelman (1970)

Source: Ruiter et al., 1979

Table 4.1 – Estimated elasticities of VMT with respect to transportation supply measures

Another study regarding the California projects involved capacity additions to 18 existing highways and was carried out by ***Hansen et al. (1993)***.

The researchers examined before-and-after traffic volumes for the 18 highways and used pooled time series and cross-sectional data to estimate the elasticities of traffic volumes with respect to capacity. The limit was that the study concerned only individual segments, that showed elasticities of 0.3 to 0.4 during the first 10 years after capacity increase, and of 0.4 to 0.7 after 20 years.

Anyway, this study considered only traffic levels on improved segments and this disregards that any additional traffic on the improved segments must also use other links on the roadway network, and a large proportion of the additional traffic may have diverted from other routes. This means that "the complement-substitute relationships between different links in a road network imply that if a change to one link has a substantial traffic impact on that link, other links are likely to be significantly affected as well" (Hansen et al., 1993).

In addition to the mentioned study, the same authors ***(Hansen et al., 1993)*** carried out an areawide analysis in which they used data on VMT, lane miles, population, density, personal income, and gasoline prices for 32 urban counties in California from 1973 to 1990. These data were in form of pooled time series and cross-sectional data and were used to estimate VMT models. The results were reported as elasticities of VMT with respect to lane miles, found to be 0.5 to 0.6. One of the main problem of the study was the lack of data on several years regarding the VMT on roads other than state highways; so, the total data were available for a shorter span of years, while the state highways data were available for all the period. Anyway some limited analyses using total VMT data were carried out and showed that the increase in traffic observed on state highways primarily represented new traffic and not diverted traffic.

An interesting finding of the authors was the discussion on the problem of causality between capacity increase and VMT; this argument will be debated afterwards by other researchers, as we will se later. They observed that the causality is bidirectional and either road supply is the cause and traffic the effect, or traffic levels affect road supply. This finding did not affect their results, they said, because there are too many exogenous factors in state and regional planning processes that significantly loosen the coupling road supply-road traffic.

The elasticities were found on the basis of regression equations containing variables as population, gasoline price, two-worker commuting, car ownership. The variable most affecting the VMT growth was population growth, with an elasticity of 0.7 to 0.8, contributing more than increase in lane miles. The other influent factors were the decline of gasoline prices, the increase in two-worker commuting, and the increases in per capita car ownership.

The most recent effort in empirical work in induced travel was initiated by the Standing Advisory Committee on Trunk Road Assessment ***(SACTRA, 1994)***, in UK, that reviewed the evidence for the existence of induced traffic on the basis of a review of cases studies of major European highway projects, and of the studies of before-and-after traffic flows on road improvement projects.

The result was that the traffic increases on new/expanded road segments more than exceeded traffic reductions on unimproved segments, so that a growth in traffic beyond route shift has occurred. In addition a greater than expected traffic growth on many corridors was probably not solely attributable to other impacts such as increase of income. The limit is that is not trivial to distinguish the components influencing the traffic growth and this was not solved by the SACTRA's study.

The use of transport models allowing demand to vary confirmed the evidence for induced travel; the estimates of induced traffic from major highway capacity additions in congested urban areas were small if viewed at the network level, while the effects were more significant in the corridors directly affected by the road project. SACTRA noted that induced traffic was large when the network operates close to capacity, where elasticity of demand with respect to travel cost is high, and where the implementation of a project causes large changes in travel costs. Then, the major source of induced travel was identified in the new travel resulting from development induced by highway capacity additions, but noting that is very difficult to separate the development due to accessibility provided by the new/improved facility from development anyway occurred because of other economic conditions. Some factors of inaccuracy in the estimates occur, due to timing of measurements (sometimes taken only one year after the scheme completion), to lack of a broader measurement of total traffic on alternative roads.

So, also if evidence of induced travel comes out from the UK study, firm conclusions cannot be drawn yet due to weakness of current forecasting procedures (Noland and Lem, 2002).

In SACTRA, a number of studies are reported that were undertaken mainly in UK, and in which calibrated transport models have been used in a systematic way to give some insight into the relative importance of the various components of induced traffic. These studies analyse the effects of road schemes using: a theoretical single link model; conventional four-stage transport models of Cardiff and Belfast; elasticity models in Cardiff, Belfast, West London and Norwich; land-use interaction models in Leeds, Bilbao, Dortmund; and a model of land-use effects in Norwich.

In the concluding remarks (chapter 10 of the SACTRA report) some interesting aspects come out:

- apart from William's theoretical single link model, all the other models dealt with congested urban areas and there was not any relationship with actual trunk and primary route interurban network;
- also if some conflicting messages about the scale of the individual forms of induced traffic occur, it seems that the magnitude of the estimates of induced travel produced by the models is not large overall;
- the effects are more significant in the corridors directly affected by the road proposals;
- the changes in benefits are quite modest; in the case of modal transfer this is due to the quite low implied elasticities; in the case of trip redistribution, the implied elasticities were greater, but there would be offsetting effects as trips are redistributed from more congested areas to less congested parts of the network. Where researchers used elasticity methods, in congested urban areas, substantial reductions in benefit occurr using elasticities sufficiently large to capture all the induced traffic effects. This can be explained because the elasticities implied by transport models calibrated against cross-sectional data are lower than real-life elasticities. The values of elasticities employed in the elasticity modelling work are generally comparable with those derived from surveys of real-life elasticities. So, it is to be expected that the elasticity-based analyses will show larger reductions in economic benefits than analyses undertaken using conventional modal choice and trip distribution models;
- small changes of traffic in congested urban areas will result in large changes in economic benefit. If the percentage reduction in economic benefits due to induced travel is considered substantial, it has to be recognised that the percentage reduction in Net Present Value will be much greater. The absolute reduction in the Present Value of Benefits is the same as the absolute reduction of the Net Present Value, but as the latter is always smaller than the former, the percentage reduction of the latter is always larger than the former;
- **Williams et al.** (1991) came to the conclusion that, insofar as current procedures for the appraisal of highway schemes in urban areas do not allow for the full range of trip response, they can be said to be flawed. The errors introduced by the weakness in the appraisal procedures are greater where:
    - the congestion is greater;
    - user behaviour is more responsive to changes in travel costs;
    - the traffic growth over time is assumed to be solely a function of exogenous factors and independent of travel costs;
    - a significant portion of the response is new traffic, whether due to trip generation or mode transfer or induced land-use changes.

Cairns et al. (1998) carried out a study on the effects of highway capacity reductions on traffic to find the ways of supporting alternative modes of travel while reducing total vehicle traffic levels. They examined over 40 specific case studies where road space was either temporarily or permanently removed. The results showed that traffic chaos did not occur, but some short-term transitional impacts could be; anyway, traffic volumes were found to be reduced when road capacity was removed.

More recently, empirical work has began to separate the effects of different exogenous variables using econometric techniques. The first researchers that followed this approach were Hansen et al. (1993) and Hansen and Huang (1997) as we will see hereafter.

5. Models proposed to evaluate traffic induced by new infrastructures

The first approach followed in the study of induced travel was to consider only the traffic counts before-and-after the construction/enlargement of the new facilities. This approach is restrictive, and the major problem is to well choose the area of influence of the infrastructures; really, the limits of several studies were to restrict the boundary to the analysed roads.

As any type of transportation project can have an induced travel effect, not only the highways, but always arterial and transit systems (Transtech Management, Inc. & Hagler Bailly, 2000), the way to understand which of added VMT are really new is not simple, because not all the travel growth that take places on new facilities is necessarily new when considered on a regional level. So, there is not a well defined geographical boundary for induced traffic. This aspect has to be joined to the numerous exogenous variables contributing to traffic increase, that makes so difficult to separate and distinguish the effects on induced traffic of the several variables, as showed by the mentioned researches.

The other way followed to analyse the induced travel was the use of transport models, but evidence was found on the inefficiency of the models to well take into account the induced traffic; really, amongst the problems regarding the travel demand models there is one aspect that needs deepness: the induced demand produced by an increase of capacity or by a TCM/ITS (Traffic Control Measures/Intelligent Transport Systems) deployment that causes a congestion relief.

As seen before, the report SACTRA (1994) in the United Kingdom changed much of the debate on induced demand and was an acknowledgement by the U.K. government that many road projects generate extra traffic.

In the USA the debate on induced travel remains controversial and much of the effort has focused on the modelling procedures used in regional travel demand forecasting (Coombe, 1996; Mackie, 1996). These models are recognised as generally not being able to account for various induced travel effects. Minor upgrades such as re-calibrating trip distribution models based on changes in travel speeds and inclusion of mode choice and route choice procedures can account for some of the increase in vehicle miles of travels (VMT).

However, these modifications would not measure changes in trip generation (U.S. DOT, 1996) or any impact of long run land use changes.

A study carried out in Hong Kong (Lam and Tam, 1997) showed how there are always discrepancies between the traffic forecasts and the actual flows on the roads if the standard four stages model (CTS-2) adopted by the Hong Kong Government is used. They remark that the CTS-2 model cannot capture the growth of the vehicle ownership accurately and that it would be important to incorporate the dynamic trends into the car-ownership forecasting process, which can be accomplished through the use of longitudinal data. Then, the proportion of vehicles given by the model is very different from the actual value because the model is still confined to single user class assignment and should be extended to multiple user classes. So, they affirm, the conventional transport demand models cannot guarantee consistency in the choices of travel; the combined models simplify the sequential process of traditional transport planning, and the research on them has proceeded in two directions: single user class combined trip distribution and assignment model and multiple user classes.

Another study has emphasized the problems in modelling the travel effects of new HOV (high occupancy vehicles) lanes (Johnston and Ceerla, 1996). The authors put the attention on the need to forecast emissions accurately and to evaluate a wide range of TCMs (traffic control measures) and their cost-effectiveness in reducing emissions; this requires better methods than have been used in the past by transportation planning and air quality agencies.

The HOV lanes represent a delicate problem in transport planning; a guidance document by the California Air Resources Board (ARB, 1991) has included the HOV lanes in US regional transport plans because it finds that new HOV lanes will reduce emissions per mile, but does not address emissions per trip or total daily regional emissions. The authors note that ARB ignores the increased VMT that will result from increased capacity, recognized in an earlier report by the same agency (ARB, 1989). The major problem in the ARB report is that it is inaccurate and biased to look at only certain freeway segments and not at overall travel behaviour in a region when evaluating systems of new HOV lanes.

Older studies observe from that new roadway capacity and new transit capacity can be quickly offset by induced auto trips, as the transit lines and road links are in equilibrium in crowded urban corridors, the authors affirm that the difference is that new transit capacity induces fewer auto trips in the long run than does a new HOV lane, because there are fewer auto lanes.

So, on this basis, Johnston and Ceerla (1996) demonstrate that latent demand does not "fill up" new freeway lanes in the short-run, or even in the medium-term, but that travel does increase substantially. For that it is better to study the effects of major HOV lane additions on regional travel than to focus on the involved freeway segments (as recommended by USDOT, 1991), especially if the aim is the evaluation of regional VMT and emissions. When such a study has to be carried out, the regional travel demand models are used and their reliability has to be verified.

The authors have analyzed the current models and made some observations:

- congested impedances (travel time in many models) in assignment need to be iterated back to all model steps that use zone-to-zone impedances as an input variable;
- the use of fixed trip tables (not iterating assigned zone-to-zone travel times back through trip distribution) is appropriate only when network loads are far enough below capacity;
- in addition to operating models with feedback to trip distribution and land development, it is needed to use longer time horizons than 20 years when necessary to represent final levels of congestion on roadways that cannot be expanded;
- the development of land allocation models is fundamental to show the effects of changes in accessibility on land development.

Only if the improvements listed above are made, the evaluations of travel, emissions, and cost-effectiveness will be more accurate. Really the simulations carried out by the authors using the Sacramento Regional Transit Systems Planning Study four-step Sacramento region travel demand model have emphasized the structural weakness of the models already seen. So, they planned to repeat the study with a new regional model, improved following the mentioned suggestions.

Recent works about the link between the increase of the capacity and induced travels demonstrated that increased capacity clearly increases vehicle miles of travel beyond any short run congestion relief that may be obtained. While other factors, such as population growth, also drive increases in VMT, capacity additions account for about one quarter of this growth (Noland, 2001). This contribution to VMT growth has significant impacts on various environmental goals.

For example, increasing U.S. highway capacity at historical rates may result in up to 43 million metric tons of carbon emissions compared to a complete freeze on adding additional lane miles[1].

The magnitude of changes in demand as a result of changes in price (this means that capacity is changed) is summarised by the elasticity of demand. In the short run, the demand for travel is relatively inelastic, since travellers cannot readily alter their existing housing and employment locations. Consequently, changes in the perceived user cost of travel have a relatively small impact on travel demand. In the long run, however, households have the capability to select different housing and employment locations and to alter their behaviour in other ways that may increase the demand for travel.

Recent work (Hansen, 1998) shows that the elasticity of VMT with respect to capacity at the county level is 0.62, while the elasticity at the metropolitan level is 0.94. The increased VMT from a capacity expansion is estimated to be realised within two years at the county level and within four years at the metropolitan area level.

Another study (Noland, 2001) shows that urban roads have a greater relationship to VMT growth than smaller rural roads and that the collector roads often have a larger elasticity value than interstates and arterials. He found elasticities between 0.3 and 0.6 in the short run, and between 0.7 and 1.0 in the long run. Elasticities are larger for models with more specific road types.

Some research is needed to improve travel demand models that, actually, cannot adequately model these impacts at either regional or project specific level.

A way followed to solve this deficiency has been to develop ad hoc econometric models to evaluate the effects of induced travel. To better understand this approach, in the next paragraph the econometric theory will be explained and then the models will be presented.

5.1. Econometric approach: the theory

The econometric models are stochastic and explain a variable of interest (dependant variable) as a parametric relationship with socio-economic variables (explanatory variables) which are time series. Times series can be either yearly, monthly or quarterly. The goal of these models is the understanding of the main determinants of the dependant variable studied on the considered time period (Pronello and André, 2000).

An overview on the econometric models used in transport forecasting reports a classification in term of the dependant variable studied and it singles out three types of models where the dependant variable is either an indicator of mobility, a variable related to car fleet or a fuel consumption (Gilson and Favrel, 1997).

The first group of model deals with the indicators of mobility and the dependant variable is a measure of the volume of transport.

This one can be expressed as number of passenger-kilometres, vehicle miles travelled, miles travelled per car (or light trucks or lorries), etc., and the models work on a national scale.

The main explanatory variables are income and relative price of transport, but some models contain also other socio-economic variables (number of licensed drivers, population of driving age, etc.).

The limit of this type of models is that the variables considered do not take into account the mobility determinants as a whole and are highly aggregated.

[1] These estimates are based on forecasts in U.S. DOE/EIA (1998)

The second group of models considers the car fleet analysis as indicator and the dependant variable can be the motorization rate (mean number of cars per adult). The methodology followed in this case is somewhat different than the other groups as a demographic approach is used; it permits to evaluate car fleets, car ownership, and car market changes.

This approach uses data grouped in cells or cohorts followed over time in cross-section data sets (Madre, 1990; Madre, 1995; Gallez, 1994). This longitudinal analysis introduces a dynamic dimension comparing individual behaviour at a precise point in time and expanding the changes in behaviour over time.

The need to locate the analysis of motorization in a precise temporal setting is also discussed by Berri (1997) who highlights the dynamic heterogeneity of individual behaviour and the need for a longitudinal analysis within the framework of the modelling of transport demand and the forecasting of car fleet.

In the demographic approach, "generation" and "life cycle" effects are identified and used for projecting car ownership and use. However, the influence of economics factors is not explicitly modelled.

Another approach, suggested by Jansson (1989, 1990), uses cohort data and regression analysis to model the determinants of car ownership entry and exit. Although economic variables, such as costs, are modelled explicitly, the models are not dynamically specified so that short- and long-run effects are not distinguished. In Jansson's study, the cohorts are based on population data on car registration, rather than on repeated cross-section surveys.

A first attempt to apply a pseudo-panel approach, to estimate a dynamic model of car ownership on the basis of repeated cross-section survey data, is carried out by Dargay and Vythoulkas (1999). The determinants of car ownership they investigate include income, the costs of car ownership and of its use, public transport fares and the socio-demographic characteristics of the households (number of adults and children per household, percentage of household in metropolitan and urban areas and number of cohort by age bands).

The third group of models uses as indicator the fuel consumption and this dependant variable is aggregated and can be expressed in gasoline, diesel or LPG consumption per capita, per household or per vehicle (Epsey 1996).

All the mentioned models consider income and price/cost as main explanatory variables, introduced as exogenous inputs. Only a few other socio-economic variables are taken into account in these models but they are not really significant (e.g. driving licence in the case of passenger-kilometre analysis). Data (explanatory and dependent variables) are, in general, easily available and predictable, but only on a broad aggregated (national) scale (Gilson et al., 1997).

In table 5.1 a synthesis of input and output data of econometric models is given.

The econometric approach has been used by numerous authors to analyze the induced travel phenomenon, and a long number of regression models have been carried out in the recent years.

The general approached followed in modelling the induced travel is the log-linear model relating the VMT with lane mile data and some other exogenous variable (e.g. population, income, fuel price); in addition, when using lane miles as a proxy for travel cost it is necessary to lag the variable to allow individual behaviour to respond to changes in highway capacity. Another technique is to use a model that captures both long run and short run lag effects where long run lags should represent cumulative impacts that occur over time.

The first analysis on the model is to estimate the statistical significance and magnitude of the elasticity of VMT with respect to lane miles. An elasticity provides a measure of how a change in

TRANSPORT MODELS		
Type	**Input data**	**Output data**
Econometric	fuel cost per mile	vehicle miles
	n° licensed drivers	
	income	n° cars per adult
	cost of car ownership and use	
	public transport fares	
	socio-demographic characteristics of population	

Table 5.1 : The input and output data of econometrics models

one variable (lane miles) results in a change in another response variable (VMT) and it is the coefficient of the log of that variable, thus a logarithmic specification is used in the regression analysis. So the elasticity (here named λ) is the estimated coefficient in the regression analysis and can be described as:

$$\lambda = \frac{\partial \log(VMT)}{\partial \log(LM)} = \frac{LM}{VMT} \cdot \frac{\partial (VMT)}{\partial (LM)} \tag{5.1}$$

Logarithmic transformations also minimize any heteroskedasticity in the cross-sectional data from combining states with large differences in size or population, and allow for an easier interpretation of the elasticity coefficients.

The model is defined as a "fixed effects" or dummy variable model (Judge et al., 1985), and it includes a dummy variable for each state (region or any homogeneous part of territory) and is estimated as an ordinary least squares (OLS) model. The use of a dummy variable for each state allows unmeasured factors affecting the dependent variable that are associated with each state to be controlled for. This type of model assumes that all states respond to lane miles increase (and changes in other exogenous variables) with the same behaviour. There is an alternative formulation, the random effects model, that would allow each state to have either a different intercept coefficient or individual slope coefficients, but it has been rejected by selected usage of the Hausman test (Judge et al., 1985).

A problem encountered in this kind of model is that the use of both population and lane miles as independent variables can cause multi-collinearity, and to correct it, lane miles per capita are used generally in the models (as showed later).

Hereafter these models will be presented and studied.

5.2. The econometric models to study the induced travel effects

A long number of empirical studies have been carried out in the years, as shown above, but the turning was represented by the econometric techniques adopted to analyze the phenomenon of induced travel.

5.2.1. Unlagged and lagged fixed effects models

The first studies focused to estimate capacity elasticities of traffic have been carried out by Hansen et al. (1993) and then continued by Hansen and Huang (1997) that estimated econometric models using time series data on VMT and lane miles for state highways in California, by county and metropolitan area.

In the ***first study*** mentioned above (Hansen et al., 1993) the elasticity was estimated at the road segment level and the panel consists of 18 California highway segments, all of freeway or expressway grade, whose capacity was increased sometime in the late 1960s or 1970s. For each segment, annual average traffic count data were obtained for 1, 4, 7, 10, ... years prior to and after completion of the capacity expansion.

The data were used to estimate a model of the form (Hansen, 1998):

$$\log(Q_{it}) = \alpha_i + \beta \cdot \log(C_{it}) + \gamma \cdot \log(SQ_t) + \lambda \cdot \frac{NC_{it}}{t^{\sigma}} + \varepsilon_{it} \qquad (5.2)$$

where:

- Q_{it} = traffic volume of segment *i* in year *t* (t is measured from before the beginning or after the completion of the capacity expansion);
- C_{it} = capacity (number of lanes) of segment *i* at time *t*;
- SQ_t = vehicle-miles travelled on the California state highway system in year *t*;
- NC_{it} = ratio of capacity added to total capacity for $t>0$, and zero for $t<0$;
- α_i, β, γ, λ, σ = coefficients to be estimated;
- ε_{it} = stochastic error term, drawn from a normal distribution with mean zero.

In this model, the hypothesis that traffic is unrelated to capacity implies that $\beta = 0$ and $\lambda = 0$; so, the traffic on segment *i* in year *t* would be determined by the segment specific factor, α_i, and a time-specific factor related to overall traffic level on California state highways, $\gamma \cdot \log(SQ_t)$.

Coefficient (variable)	Coefficient estimate, by assumed σ value		
	$\sigma = 0.05$	$\sigma = 0.20$ [1]	$\sigma = 0.75$
β (road capacity)	1.30	0.86	0.46
	(3.70)[2]	(4.70)	(4.53)
γ (fraction of new road capacity)	-1.59	-1.03	-0.44
	(-3.07)	(-3.68)	(-3.04)
λ = state highway VMT)	1.06	0.96	0.96
	(19.23)	(15.29)	(14.54)
Adjusted R^2	0.9568	0.9580	0.9568

Notes:
1. Preferred model, based on adjusted R^2.
2. t statistics in brackets.

Source: Hansen, 1998

Table 5.1 : Estimation of the coefficients of the road segment based traffic model

The hypothesis that traffic responds instantaneously to change in capacity implies that $\beta>0$ and $\lambda=0$. Finally, if $\lambda<0$, the response of traffic to new capacity is gradual.

This model was estimated on the panel data set mentioned above using least squares to estimate all the coefficients except σ. This one assumed different values and the model with the σ value that yielded the best fit was chosen. In table 5.1 the estimated coefficients are given.

The results of the analysis show that the elasticities are in the range of 0.2-0.3 four years after the expansion, and in the range 0.3-0.4 after 10 years. Anyway they are well below 1.0 that implies the capacity expansion yields a sizable reduction in the ratio of traffic to capacity.

In the ***second study*** (Hansen and Huang, 1997) the panel consisted of urban areas; the basic data were state highway vehicle-miles travelled (VMT), state highway lane-miles, population, and per capita income for every urban county in the state of California, for the years 1973-1990. In one analysis, this panel was used directly; in a second analysis, the county-level data were aggregated to the metropolitan level. The model so obtained was (Hansen, 1998):

$$\log\left(VMT_{it}\right) = \alpha_i + \beta_t + \gamma \cdot POP_{it} + \psi \cdot PCI_{it} + \sum_{l=0}^{L} \omega^l LM_{it-l} + \varepsilon_{it} \tag{5.3}$$

where:

VMT_{it}	= vehicle-miles travelled in area i and year t;
POP_{it}	= population in area i and year t;
PCI_{it}	= income per capita in area i and year t;
LM_{it-l}	= state highway lane-miles in area i and year $t-l$;
α_i, β_t, γ, ψ, ω^l	= coefficients to be estimated;
ε_{it}	= random variable drawn from a normal distribution with mean zero.

This model contains fixed effects for both areas and years, the α_i and β_t respectively. These fixed effects would explain the variations in VMT in the years; γ and ψ capture the traffic growth due to population and income. Lastly, if covariation exists between road supply and VMT, this is captured by ω^l. If the VMT response to a change in road supply were immediate, then only the ω^0 term would be positive. If coefficients on the lagged lane-miles variables are also positive, this implies that VMT response occurs over a period of time, with the complete adjustment occurring after L years.

The models (county panel and metropolitan panel) were estimated starting with L=0 and then incrementing L by 1 until they found the best performance of the models. Then they determined the appropriate number of free parameters to allow for the ω^l.

In table 5.2 the estimated coefficients for the models at county and metropolitan levels are reported.

Coefficient (variable)	County panel model, P-W[1] estimate	Metropolitan panel model, P-W estimate
γ (population)	0.46	0.69
	(9.03)[2]	(3.92)
ψ (per capita income)	0.05	0.21
	(0.88)	(1.87)
ω^l = (lane-miles)[3]	0.21	0.19
	(5.33)	(4.20)
R^2	0.994	0.997
L*	2	4
Long-run capacity elasticity of traffic[4]	0.62	0.94
Number of observations	480	196

Notes:

1. Prais-Winsten estimates. This is a least squares technique that corrects for serial correlation in the data, see Hansen and Huang, 1998.
2. t statistics in parentheses.
3. Coefficient applies to current lane-miles and lane-miles 1,2,...,L* years before.
4. The percentage increase in VMT resulting from a 1 percent increase in lane-miles, after a sufficient period of time for the full effect to be realized. Equal to ω^l coefficient times L*+ 1, with any differences in table due to rounding.

Source: Hansen, 1998

Table 5.2 : Estimation results, area traffic models by geographic unit of analysis

Definitely, Hansen and Huang (1997) estimated several models based on two panels of area-level data, using observations covering the period 1973 to 1990; all the equations are variations of the distributed lag fixed effects model and can be so synthetized:

$$\log\left(VMT_{it}\right) = \alpha_i + \beta_t + \sum_k \lambda^k \log\left(X_{it}^k\right) + \sum_{l=0}^{L} \omega^l \log\left(SHLM_{it-l}\right) + \varepsilon_{it} \tag{5.4}$$

where:

VMT_{it}	= vehicle-miles travelled in region i and year t;
α_i	= fixed effect for region i, estimated in the analysis;
β_t	= fixed effect for year t, estimated in the analysis;
X^k_{it}	= value of explanatory variable k for region i and time t-l;
$SHLM_{it-l}$	= state highway lane-miles for region i and time t-l;
λ^k, ω^l	= coefficients to be estimated;
ε_{it}	= outcome of a random variable for region i at year t, assumed to be normally distributed with mean zero.

This lag structure reflects the expectation that the impact of adding lane-miles on VMT occurs gradually, as travelers, households, and other decision makers adjust their behaviour in response to the added capacity. In addition, the model is log-linear, so the coefficients can be read directly as elasticities. There is a single elasticity for each X variable, implying an instantaneous response; but, since the model includes lagged SHLM terms, it yields time-specific lane-mile elasticities. The basic set of explanatory variables consists of SHLM, population (POP), and personal income per capita (PIN).

The model (5.4) is estimated by relating differences in VMT growth to differences in SHLM growth, while also controlling for other factors and stochastic effects. By controlling for fixed effects, the model (5.4) also substantially reduces the potential distortion from simultaneity bias. Such bias will occur if traffic affects road supply, or more generally, when the error term in a regression equation is correlated with an independent variable. In the long run, the causality between VMT and SHLM does in fact run in both directions. Running the regression of SHLM against several factors considered to be key determinants of VMT, the results revealed that POP and PIN have a statistically insignificant effects on SHLM when fixed effects are included, while the population strongly affect SHLM when the fixed effects are excluded. Since variables affecting VMT also strongly affect SHLM in the model without fixed effects, there may be simultaneity in the VMT model without fixed effects. Conversely, given the insensitivity of SHLM to POP and PIN in the fixed effects model, it is unlikely to be correlated with the error term in the VMT model with fixed effects.

The results obtained by Hansen and Huang (1997) are that VMT for integral regions can be modelled more accurately than that for individual counties. The estimates of the lane-miles elasticity of VMT are in the ranges 0.3 to 0.7 for the county-level panel and cross-section models, and 0.5 to 0.9 for the equivalent metropolitan-level models.

So, cross-section elasticities are considerably greater than panel elasticities, and metropolitan elasticities are somewhat higher than county elasticities. This perhaps occurs because the cross-section models capture long-run effects, whereas the panel models reflect short-term responses, as stated by Abrahams (1983). Instead, the higher lane-miles elasticities in metropolitan models suggest that adding lane-miles in a given county increases VMT throughout a wider region.

Other results show that population is a major determinant of VMT and its elasticity is in the 0.4-0.6 range; the income elasticity ranges from 0.1 to 0.34 and gasoline price is found to have a modest effect on VMT, with an elasticity from –0.8 to –0.10.

Definitely, the unlagged models suggest a stronger immediate effect of a lane-mile change: 1% lane-mile increase leads to 0.4-0.5% VMT increase, more than double the amount of lag panel model. Lag estimates imply that the ultimate effect of a lane-miles addition (occurring after two years at the county level and after four years at the metropolitan level) is greater than that resulting by the unlagged panel models, and is comparable to that estimated in the unlagged cross-section models. This confirms that the high lane-mile elasticity in the unlagged cross-section model is reflecting a long-run effect instead of an upward bias due to simultaneity.

A similar approach was followed by Noland (2001) who used cross-sectional time series (panel data) of the 50 US states between the years 1984 and 1996.

The author utilized the following general modelling approach:

$$\log\left(VMT_{itr}\right) = c + \alpha_i + \sum_k \beta^k \log\left(X_{it}^k\right) + \lambda \log\left(LM_{itrl}\right) + \varepsilon_{it} \tag{5.5}$$

where:

VMT_{itr} = vehicle-miles travelled in state *i*, for year *t*, by road type *r*;

c = constant term;

α_i = fixed effect for state *i*, to be estimated;

β^k = coefficients to be estimated (for demographic and other parameters);

λ = coefficient to be estimated for LM parameter;

X^k_{it} = value of demographic and other variables for state i, and time t;

LM_{itrl} = proxy for cost of travel time (lane miles) by state i, for year t, for road type r, lagged by l years;

ε_{it} = random error term.

The model is estimated with different road types, excluding the local roads: interstates, arterials, and collector roads by urban and rural road categories.

On the general basis given in equation (5.5) he used different forms of model:

- the initial model estimated sums the road types and VMT to determine whether total VMT can be explained by increases in total non-local lane miles. The results show that lane-miles are a statistically significant determinant of VMT, except in the model with a 2 year lag. The elasticities are about 0.25. Population (coefficient about 1), per capita income (coefficient from 0.85 to slightly over 1), and gasoline cost (coefficient from 0.2 to 0.3) all have the expected direction and are all highly significant. The disaggregation of the data into individual road types gives larger elasticities on those specific road types and shows where induced demand effects may be greatest;
- another approach to improve model estimation was to use contemporaneous correlation between error terms (simultaneous equation estimation). This assumes that a given amount of VMT on a specific road type will affect the amount of VMT on another road type. A system of equations, one for each road type, can be estimated using Zellner's seemingly unrelated regression.
  The results show that the coefficient values for the lane-mile parameters are generally larger and show increased statistical significance. The elasticity values are smaller in the 2 year lag model. This model seems to suggest the largest immediate and short-term (up to 2 years) effect from adding interstate and collector lane-miles. On the other hand, while arterial lane-miles seem to generate less VMT, the effect persists over a longer time period (at least up to 5 years).
  Also the other coefficients show some interesting effects. The fuel cost coefficient is generally significant with a negative sign. It is largest for the interstate VMT models, somewhat lower for the arterial VMT models, and much lower for the collector VMT models.
  The same elasticity difference occurs with respect to per capita income; it generally has an elasticity greater than 1 with respect to interstate VMT.
  A further disaggregation of the data can be achieved by breaking out urban and rural VMT and lane-miles for each road class; the results show a strong induced travel effect with some differentiation between different road types;
- a technique to estimate a long-term elasticity is a distributed lag model using a lagged-dependent variable; it assumes that the adjustment process from the other independent variables, population, personal income, and gasoline prices, is the same as for lane mileage. It also assumes an exponential pattern to the lag. The distributed lag model is:

$$\log\left(VMT_{itr}\right) = \gamma \log\left(VMT_{i(t-1)r}\right) + c + \alpha_i + \sum_k \beta^k \log\left(X^k_{it}\right) + \lambda \log\left(LM_{itr}\right) + \varepsilon_{it} \qquad (5.6)$$

  where all the variables have been defined previously. The only difference is the lagged VMT term with a coefficient γ.

Short run elasticities of lane miles with respect to VMT correspond to the coefficient on the lane-mile variable, λ. Long run elasticities can be calculated as:

$$\eta = \frac{\lambda}{1-\gamma} \tag{5.7}$$

Distributed lag models were estimated with both aggregate VMT and lane-mile data and with simultaneous equations disaggregated by road type. The elasticities for the two estimated equations are generally similar (Table 5.3). Long run elasticities are substantially larger (0.7-1.0) than the short run elasticities (0.2-0.5). Short run elasticities are larger for urban road categories than for rural roads, perhaps due to more congestion in urban areas. Long run elasticities are about the same for both urban and rural roads; this suggests that capacity increases are triggering fundamental land use changes that increase VMT in both urban and rural areas. Population is also a significant factor with larger coefficients in the urban equations. Per capita income is significant across equations with smaller coefficients on collector roads. Gasoline price coefficients are generally small. The author observed that one criticism of distributed lag models is that they are highly unstable in providing good predictions. The summarized results are depicted in table 5.3;

Dependent variable is log of VMT by road type Lane miles are by road type per capita	Urban interstates	Urban arterials	Urban collectors	Rural interstates	Rural arterials	Rural collectors
LN (VMT, lagged one year)	0.464 (17.981)	0.370 (12.915)	0.528 (20.251)	0.669 (30.774)	0.485 (16.658)	0.649 (21.658)
LN (urban interstate lane miles, per capita)	0.439 (17.136)					
LN (urban arterial lane miles, per capita)		0.498 (18.002)				
LN (urban collector lane miles, per capita)			0.513 (15.097)			
LN (rural interstate lane miles, per capita)				0.234 (6.473)		
LN (rural arterial lane miles, per capita)					0.369 (10.621)	
LN (rural collector lane miles, per capita)						0.407 (6.726)
LN (population)	0.625 (9.561)	0.652 (10.279)	0.690 (6.645)	0.250 (4.057)	0.509 (8.159)	0.307 (2.950)
LN (per capita income)	0.748 (12.227)	0.489 (9.788)	0.328 (3.545)	0.531 (9.858)	0.630 (11.450)	0.313 (4.387)
LN (cost per BTU of fuel)	−0.085 (−4.191)	−0.047 (−2.308)	−0.019 (−0.478)	−0.064 (−3.590)	−0.035 (−1.746)	− 0.033 (−1.106)
Constant	−9.149 (−9.479)	−5.908 (−7.864)	−6.219 (−4.907)	−4.702 (−6.574)	−7.349 (−10.093)	−3.350 (−2.786)
N	583	583	583	583	583	583
Long run elasticities						
Lane miles per capita	0.819	0.790	1.087	0.707	0.717	1.160
Population	1.166	1.035	1.462	0.755	0.988	0.875
Personal income	1.396	0.776	0.695	1.604	1.223	0.892
Gasoline price	−0.159	−0.075	−0.040	−0.193	−0.068	−0.094

[a] *T*-stats are in parentheses.

Source: Noland and Lem, 2002

Table 5.3 : Seemingly unrelated regression by road type and urban/rural area: distributed lag model[a]

- a technique for eliminating the multicollinearity between the independent variables is estimation of a growth or difference model. The specification estimates the percent growth in

VMT as a function of percent growth in lane-miles and the other independent variables. In such a way the problem of correlation is quite eliminated. The model can be specified as the difference between logs of variables:

$$\log(VMT_{itr}) - \log(VMT_{i(t-1)r}) = c + \alpha_i + \sum_k \beta^k \left(\log(X_{it}^k) - \log(X_{i(t-1)}^k)\right) + \lambda\left(\log(LM_{itr}) - \log(LM_{i(t-1)r})\right) + \varepsilon_{it} \quad (5.8)$$

This corresponds to percent growth in the dependent and independent variables.

The results of the analyses carried out by Noland (2001) demonstrate that induced travel is an evidence, and increase capacity clearly increases vehicle miles of travel beyond any short run congestion relief that may be obtained. Statistical significant relationships between lane-miles and VMT were found, and, while population growth also drive increase in VMT, capacity additions account for about one quarter of this growth.

The different statistical approaches estimated gave a range of values for elasticity estimates. Generally, more disaggregated data by road type led to relatively greater elasticity values for VMT.

Another general effect is that urban roads have a greater relationship to VMT growth than smaller rural roads, probably due to the greater congestion. Collector roads often had a larger elasticity value than interstate and arterials.

The selection of estimation procedure can produce very different results. The use of fixed effects significantly reduced the level of significance compared to modelling without fixed effects. The ability to use simultaneous equations and fixed effects seems to provide robust results that take advantage of the statistical properties of the data.

Noland analysed also a nationwide metropolitan level data (Noland and Cowart, 2000) and obtained similar results; long run elasticity values of 0.8 to 1.0 were obtained using a distributed lag model estimated for VMT and lane miles specific to interstates and arterial road capacity. But also this work does not resolve the issue of causality, merely showing a correlation between lane mile expansion and VMT growth (Noland and Lem, 2002); so the same authors tried to use several instrumental variables to use for lane miles per capita in the regression with a two-stage least squares estimation procedure. The three models contained the instrumental variables "urbanized land" (defined "area" in model A and B, where the population density was removed), and the ratio "population/area" (in the model C), as depicted in table 5.4. The results suggest a causal linkage between increasing lane miles and increased VMT.

Another study was carried out by Fulton et al. (2000) that used cross-sectional time series county-level data from North Carolina, Virginia, and Maryland to estimate "fixed-effects" cross-sectional time-series models that relate travel levels, measured as daily vehicle miles of travel, to roadway capacity in lane-miles. This study strongly supports for the causal nature of the relationship between new highway capacity and increases in VMT.

The authors have used the "fixed-effects" specification approach in all estimated models; such an approach acknowledges the researcher's lack of information about the unique characteristics of each unit in the data, and it can reduce the bias associated with correlations across units that would normally be captured in the error term. A logarithmic specification of the fixed-effects model can be written as:

$$\log(VMT_{it}) = c + \alpha_i + \beta_t + \sum_k \lambda^k \log(X_{it}^k) + \varepsilon_{it} \quad (5.9)$$

where:

VMT_{it}	= daily vehicle-miles of travel for county i in year t;
c	= constant term;
α_i	= fixed effect for county i, estimated in the analysis;
β_t	= fixed effect for year t, estimated in the analysis;
λ^k	= coefficient of the *kth* explanatory variable;
X^k_{it}	= value of explanatory variable k for county i in year t, one component of which is lane-miles (*LM*);
ε_{it}	= outcome of a random variable for county i in year t, assumed to be normally distributed with mean zero.

	(A)	(B)	(C)
LN (VMT per capita)	Insrument = LN (area)	Insrument = LN (area)	Instrument = LN (population/area)
LN (lane miles per capita)	0.760	0.289	1.944
	(18.092)	(2.873)	(6.035)
LN (per capita income)	0.315	0.557	−0.135
	(6.198)	(8.051)	(−0.798)
LN (fuel cost)	−0.005	−0.023	0.135
	(−0.179)	(−0.713)	(2.186)
LN (population density)	−0.160		
	(−7.077)		
Constant	0.476	−3.193	3.595
	(0.887)	(−4.701)	(2.224)
N	1050	1050	1050
Adjusted R^2	0.975	0.967	0.902

[a] *T*-stats are in parentheses.

Source: Noland and Lem, 2002

Tab. 5.4 : Instrumental variables (two-stage least squares) regression[a]

The model is specified with the natural log of the variables to avoid heteroskedasticity and to allow the estimated coefficients λ^k to be read as elasticities.

To solve the issue of simultaneity bias, not explicitly addressed in the above model formulation, a difference (or growth) model has been analyzed; it correlates annual growth in lane-miles with annual growth in VMT, and it has the feature of eliminating much of the collinearity between independent variables. The model is as follows:

$$\log(VMT_{it}) - \log(VMT_{i(t-1)}) = c + \alpha_i + \beta_t + \sum_k \lambda^k \left(\log(X^k_{it}) - \log(X^k_{i(t-l)})\right) + \varepsilon_{it} \quad (5.10)$$

with variables defined above.

To examine the precedence of the variable, that is if lane-miles growth precedes VMT growth or the opposite, the Granger causality test has been used.

Then, a two-stage least squares estimate using lagged growth in lane-miles as an instrument for current growth in lane-miles is given as:

$$\log(LM_{it}) - \log(LM_{i(t-l)}) = c + \alpha_i + \beta_t + \sum_k \lambda^k \left(\log(LM^k_{it}) - \log(LM_{i(t-l)})\right) + \varepsilon_{it} \quad (5.11)$$

This models has provided a strong correlation between the growth in lane-miles in the current year and the lagged growth in lane-miles over multiple years. The instruments are not correlated with current growth in VMT.

The results of the regressions (5.11) are shown in table 5.5, where the coefficients on lane-miles vary from 0.15 to 0.61 in the different counties.

Dependent variable	LOG(VMT) difference									
	All states		Maryland		North Carolina		Virginia		Washington, DC/ Baltimore area	
Years of data	1985–95		1970–96		1986–97		1971–96		1971–96	
Log (lane-miles difference)	0.434	0.433	0.517	0.527	0.609	0.612	0.149	0.145	0.153	0.154
	(5.84)	(5.83)	(3.40)	(3.47)	(6.95)	(6.77)	(3.56)	(3.45)	(1.66)	(1.66)
Log (population difference)	0.067	0.075	0.114	0.243	0.281	0.372	0.117	0.143	0.347	0.379
	(0.485)	(0.535)	(0.423)	(0.877)	(0.989)	(1.17)	(2.21)	(2.67)	(1.88)	(1.92)
Log (income per capita difference)	—	0.023	—	0.257	—	0.095	—	0.103	—	0.062
	—	(0.334)	—	(2.03)	—	(1.02)	—	(2.73)	—	(0.454)
Constant	0.006	0.005	0.058	0.057	−0.020	−0.027	0.034	0.031	0.068	0.064
	(0.275)	(0.238)	(3.01)	(2.95)	(−0.874)	(−1.11)	(2.72)	(2.43)	(3.97)	(3.26)
N	2200	2200	621	621	1200	1100	2496	2496	416	416
"R-Squared"	0.053	0.055	0.175	0.181	0.129	0.131	0.184	0.186	0.328	0.328

T-stats are in parentheses.
County and time specific constants are omitted for brevity.

Source: Fulton et al., 2000

Tab. 5.5 : First difference model results

The results of the Granger test using a difference model suggest that lane-mile growth precedes growth in VMT, but this is not evidence of causality because the increase in VMT can also be explained by planning that correctly anticipates future growth in VMT by building new capacity in advance.

Anyway, the results obtained indicate a significant relationship between the level of highway capacity, as measured by lane-miles, and the travel, measured by daily VMT. After accounting for other important determinants of travel and for potential simultaneity bias, the estimated elasticity between VMT and lane-miles is estimated at 0.2 to 0.6.

5.2.2. Two-way system of equations for demand and supply models

The problem of the causality between lane-miles and VMT has been treated also by Cervero and Hansen (2001) that used an econometric modelling framework to probe roadway supply-demand relationships in California using county level data on a time period from 1976 to 1997.

The model was estimated using a two-way system of equations for demand (D_{it}) and supply (S_{it}):

$$\boldsymbol{D_{it} = f(S, P, A, I, L, F)_{it}} \tag{5.12}$$

$$\boldsymbol{S_{it} = f(SD, A, L, G, F)_{it}} \tag{5.13}$$

where:

D = travel demand vector (e.g., vehicle miles travelled);
S = roadway supply vector (e.g., lane miles of major road facilities);
P = price vector (e.g., fuel price per gallon);
A = population attribute vector (e.g., population size, demographics);
I = income-effects vector (e.g., per capita income levels);
L = localized-effects vector (e.g., land-use densities; meteorological characteristics);
G = governance and policy factors vector (e.g., state political party affiliations; air quality levels);
F = fixed-effects vector (e.g., county-specific dummy variables to account for unique and idiosyncratic characteristics, such as the effects of an earthquake on travel demand and road building in any particular county at any time point;
i = county cross-section observation;
t = year time point.

The model proposed provides travel demand and road supply jointly related and it is predicted as a function of pre-determined (exogenous and lagged-endogenous) variables using reduced-form instrumental-variable estimation to avoid simultaneous equation biases. Then, a two-stage least squares (2SLS) estimation was used. Various lagged structures were attempted and lags up to five years were investigated.

The core variables used by the authors are summarized in tables 5.6 and 5.7. Travel demand was represented by VMT on state-owned facilities (mainly freeways and arterials); supply was depicted by lane-miles of the same facilities used in measuring travel demand. Table 5.6 presents the primary predictor variables; these variables are related to vehicle operating cost, population size and composition, income levels, and fuel economy.

Dimension	Variable	Sources
Demand	VMT, state facilities	Caltrans files, Department of Finance
Supply	Lane Mile, state facilities	Caltrans files, Department of Finance
Price	Operating Cost/Mile	AAA, *Your Driving Costs*, 1997.
	Retail Gas Price, local, cents/gallon	U.S. Department of Energy, Energy Information Administration
	Gas Tax, state, cents/gallon	U.S. Department of Commerce, *The Book of States*, various years
Population	County Population	CA Dept. of Finance, files
	Population by race	CA Dept. of Finance, files
	Density, Persons per acre	CA Dept. of Finance, files
	Density, Workers per acre	CA Dept. of Finance, files
Income	Personal Income, median ($000)	U.S. Department of Commerce, Bureau of Economic Analysis
Fuel Economy	Pass. Car, average miles per gallon	U.S. Department of Transportation, FHWA, *Highway Statistics,* various years

Key: Caltrans: California Department of Transportation; AAA: Automobile Association of America, California

Source: Cercero and Hansen, 2001

Table 5.6 : Key predictor variables and sources

In table 5.7 the variables candidates for predicting and instrumenting road supply are listed:

- the set of topographic and meteorological variables to gauge their effect on road development;
- air quality variables to verify if they shape road investment programs for legal and policy reasons;
- a series of variables on executive and legislative party affiliations and committee assignments to measure the influences of politics on road development.

Dimension	Variable	Sources
Geography/Weather	Precipitation, inches	CA Dept. of Finance, *California Almanac*
	Heating Degree Days	CA Dept. of Finance, *California Almanac*
	Cooling Degree Days	CA Dept. of Finance, *California Almanac*
	Low daily temp., avg.	CA Dept. of Finance, *California Almanac*
	High daily temp., avg.	CA Dept. of Finance, *California Almanac*
	Lowest Elevation, feet	CA Dept. of Finance, *California Almanac*
	Highest Elevation, feet	CA Dept. of Finance, *California Almanac*
Air Quality	No. Days > NAAQS	California Air Resources Board, data files
	Max. Hr., CO, ppm	California Air Resources Board, data files
	Max. 8 Hr., CO, ppm	California Air Resources Board, data files
	Max. Hr. Ozone, ppm	California Air Resources Board, data files
Politics	Governor's Party (0-1)	*U.S. Department of Commerce, The Book of States,*
	Gov. in 2nd Term (0-1)	*U.S. Department of Commerce, The Book of States,*
	House Majority, party affiliation (0-1)	*U.S. Department of Commerce, The Book of States,* various years
	Senate Majority, party affiliation (0-1)	*U.S. Department of Commerce, The Book of States,* various years
	Local Assembly Rep. On Transp. Committee (0-1)	California Assembly, *CA Roster,* various years
	Local Assembly Rep., Chair Transp. Com. (0-1)	California Assembly, *CA Roster,* various years
	Local Senate Rep. On Transp. Committee (0-1)	California Assembly, *CA Roster,* various years
	Local Senate Rep., Chair Transp. Com. (0-1)	California Assembly, *CA Roster,* various years

Source: Cercero and Hansen, 2001

Tab. 5.7 : Candidate predictor and instrument variables for predicting road supply

In tables 5.8 and 5.9 the coefficient of the demand and supply models are depicted, omitting the county fixed effects. For major details see Cervero and Hansen (2001).

In table 5.8 we can see that population growth most strongly accounted for VMT increases. VMT was market-sensitive rising with income and falling when gasoline prices increased. Areas with relatively dense employment averaged less VMT, perhaps due to commute alternatives, higher parking fees, etc., that worked to suppress VMT.

	Coefficient	Std. Error	Prob.
Natural Log of:			
VMT	0.559	0.029	0.000
Population	0.698	0.031	0.000
Employment Density	-0.105	0.013	0.000
Income, $ Per Capita	0.293	0.011	0.000
Gas Price, local, cts.	-0.211	0.021	0.000
Constant	-0.088	0.181	0.626

Source: elaboration from Cervero and Hansen, 2001

Table 5.8 : Predictive model of natural logarithm of annual countywide vehicle miles travelled (VMT), 34 California Counties, 1976 to 1997; 2SLS-IV estimation

Table 5.9 shows that road supply responds to population effects, localized effects (density and temperature differentials), policy-related influences (governor party affiliation and air quality levels). Generally, road investments increased with the variables, except the employment density. The authors found some not expected results as:

- the sensitivity in state road investments with respect to racial composition;
- the positive coefficient on the air pollution variable (max level of CO emissions per hour). So, it seems that worsening of air quality in prior years appears to be a catalyst to road expansion, all else being equal;
- the influence of party affiliation the prior year on contemporary state road investments across counties.

The model shown in table 5.9 explained over 99 percent of the variation in lane-miles additions, mostly due to secular population growth and unique county influences, but VMT was not an inconsequential factor in explaining road development in California.

	Coefficient	Std. Error	Prob.
Natural Log of:			
Lane miles	0.328	0.018	0.000
Population	0.456	0.019	0.000
Employment Density	-0.321	0.005	0.000
White Pop., prop.	0.590	0.069	0.000
Gov. Party, 1 = Dem., lag	0.064	0.001	0.000
CO Max 1 Hour, ppm, lag	0.061	0.006	0.000
Temperature Diff., low-hi	0.520	0.027	0.000
Constant	-4.177	0.102	0.000

Source: elaboration from Cervero and Hansen, 2001

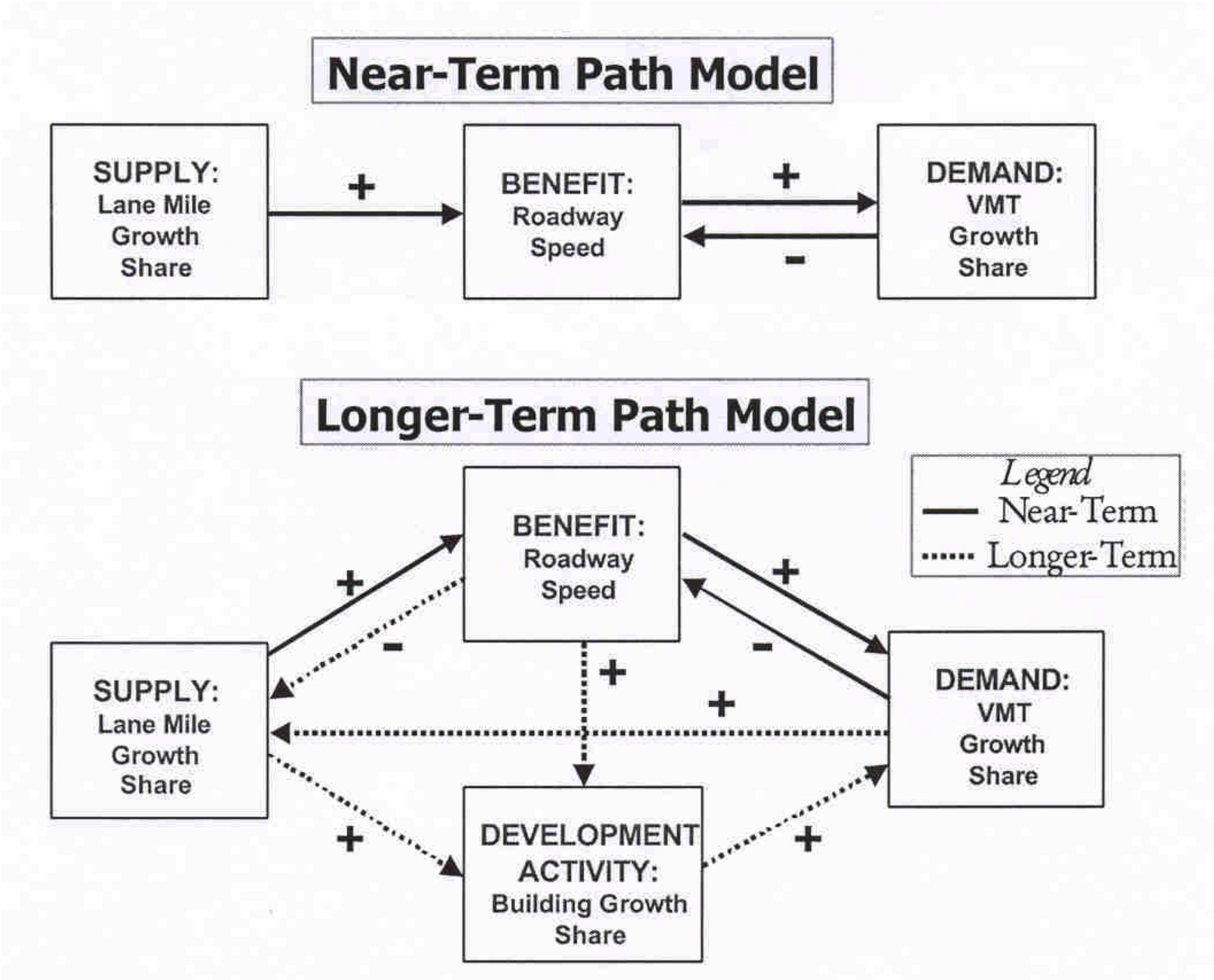
Table 5.9 : Predictive model: natural log of annual countywide lane miles of freeways-highway capacity, 34 California Counties, 1976 to 1997; 2SLS-IV estimation

The measures of short-term elasticities are in line with those of earlier studies, but the results highlighted that when accounting for simultaneity of influences, longer term induced demand effects are actually diminished. Current VMT are not independent of past road investments, and past road investments are not independent of current VMT, suggesting the presence of simultaneity despite the lagged structure. Two sets of estimates, ordinary least squares (OLS) and two-stage least squares (2SLS) were used, and the tendency for the joint influences of road supply and demand to erode with time was clear.

A strong short-term travel induced demand effect was uncovered, but the results also revealed that lane-miles additions were significantly explained by VMT; anyway, "induced demand" effects were found to be stronger than "induced investment" effects, although not overwhelming so. California experiences suggest that road investments induce travel demand and traffic growth induces road investments.

This study was continued by Cervero (2001) employing a path model to causally sort out the links between freeway investments and traffic increases, using data for 24 California freeway projects across 15 years.

In figure 5.1 a path model for tracing the effects of road improvements on travel demand as well as urban development is shown. The model framework provides near-instantaneous impacts (solid lines) occurring within a year's time, and longer-term adjustments (dashed lines), signifying the need for a lagged model structure.



Source: Cervero, 2001

Figure 5.1: Hypothesized path model

Where there is a unidirectional relationship, ordinary least squares (OLS) provides efficient and unbiased estimates, while where two variables have a co-dependent relationship and nearly instantaneously influence each other, OLS will produce biased parameter estimates, as in the case of speed and demand that are endogenously related.

The link between road supply and speed is missing from most past studies; the author uses the average recorded operating speed over one-year period to gauge reductions in generalized costs.

In figure 5.1 the effects of road supply and travel demand on urban development is shown, and the time lapse is often on the order of two to three years.

The induced demand concept is contained in the link between travel speed and demand and urban development and demand. The model in figure 5.1 postulates that the combination of current operating speeds on a roadway (in the short term) and previous-year changes in urban development (in the long term) influence current-period demand levels, increasing VMT.

Figure 5.1 also accounts for induced investments effects, so that travel demand and speed can influence road supply; this feedback loop has been ignored in the past studies. The result is that roads stimulates demand, but also respond to demand.

To test the above hypotheses, a system of log-linear equations was specified and estimated, and the coefficient estimates represent the elasticities. Fot the longer-run analysis, the estimated equations are:

Speed Model: $B_{it} = f(S_{i,t}, D_{i,t}, C_{i,t}, T_t, P_i)$ (5.14)

Development Model: $L_{it} = f(B_{i,t-n}, S_{i,t-n}, C_{i,t}, T_t, P_i)$ (5.15)

Demand Model: $D_{it} = f(B_{i,t}, L_{i,t-n}, C_{i,t}, T_t, P_i)$ (5.16)

Supply Model: $S_{it} = f(D_{i,t-n}, B_{i,t-n}, C_{i,t}, T_t, P_i)$ (5.17)

where:

B = benefit vector (e.g., mean operating speed);
S = supply vector (e.g., lane miles);
D = demand vector (e.g., vehicle miles travelled);
L = land-use vector (e.g., building square footage);
C = control vector (e.g., median personal income in area);
T = time-series fixed effect (0-1 “dummy variable”);
P = project fixed effect (0-1 “dummy variable”);
i = project cross-sectional observation;
t = time-series observation;
n = length of time lag.

The equations above highlights as benefits and demand are jointly related, thus endogenous variables (speed and VMT) are predicted as functions of pre-determined variables (exogenous and lagged-endogenous).

These models were run using data regarding 24 freeway expansion projects occurred in small to medium-size municipalities in suburban settings, over 1980 to 1994 period. These data were chosen on the grounds that four-mile buffers encompassed at least 40 percent of the land area of municipalities that were either traversed or that directly bordered the improved facility.

The results of the analysis confirmed the short-term path model shown in fig. 5.1. Added capacity increases speed, which in turn raises the countywide share of traffic, which then erodes some of the speed benefits, thereby moderating the growth in traffic until more or less an equilibrium condition is reached. The near-term “induced travel” elasticity, estimated by the Californian data, was about 0.24, also if the induced demand is likely smaller because some of this travel increase is due to route diversion. This value of elasticity is smaller in respect to some of other past estimates, and the same result has been found on the longer term.

The long-run model suggests that it takes around 5 to 6 years before the full-brunt of traffic increases spurred by land-use shifts to be felt. So, the addition of lane miles influences the development activity after 2 to 3 years that influences the VMT after other 3 years. In addition, VMT growth seems to feed back to influence freeway investments several years later. The entire lagged structure covers, finally, a 7 to 8 year period.

This very recent study is on line with the past studies and it has uncovered the evidence of induced demand, induced growth, and induced investment. While the induced growth effects found in this analysis are consistent with that of previous studies, the difference lays on the less magnitude of induced demand effects found.

5.2.3. Integrated models using disaggregate data

A different approach was followed by other authors, as Rodier et al. (2001) that used disaggregate data from Sacramento, California region, to examine induced travel effects. They used an integrated land use/transportation model, MEPLAN, to analyse the impact of various scenarios in the Sacramento region. They found that without feedback of the trip distribution step, a null elasticity is calculated, assuming totally inelastic the travel demand. This means that the elasticity greatly varies (from 0.8 to 0.4 for a forecast out to 2015 and from 1.1 to 0.6 for a forecast out to 2040) if changes in land use and trip distribution, in land development, of population, and of employment location are endogenously determined by the model or not.

So, using a disaggregate regional integrated land use and travel demand model assuming full endogeneity gives elasticities similar to the aggregate studies seen above, and such a model can capture about 50% of the induced travel effect relative to current practice capturing no effect. Finally, they showed a clear causal link between behaviour and induced travel, and that about the 50% of the long-term induced travel effects is not captured by the use of travel demand models. The total effects can be reached only if models captured travel and land use changes interactively.

Also other authors used disaggregate data to study the induced travel.

Strathman et al. (2000) combined the 1995 Nationwide Personal Transportation Survey (NPTS) data for 12,009 households with the Texas Transportation Institute (TTI) data and found that per capita roadway capacity has a significant effect upon mode choice, residential density, workplace density, and VMT. People within the metropolitan area tended to be more likely to drive alone to work, live and work at lower densities, and generate higher VMT if the roadway capacity is increased. Precisely, the effect of 10% increase in per capita roadway capacity is estimated to be a 2.9% increase in VMT, when all other variables are controlled for, consistent with values found from other authors (Noland, 2001; Noland and Cowart, 2000; Fulton et al. 2000). In addition to these results, Strathman et al. (2000) found also that reduced residential density results in higher VMT while reduced employment density results in lower VMT.

Barr (2000) use the disaggregate data from 1995 NPTS and used only a cross-sectional database, so that they described correlation and not causation. They focused their attention on time spent travelling by each household, and found travel time elasticities ranging between –0.3 and –0.4. They showed also that elasticities are higher in urbanized areas (–0.36) compared to non-urbanized areas (–0.32). Perhaps this is due to higher congestion and greater access to alternative modes of the urbanized areas, also if this difference is probably not so significant as confirmed by the insignificance of the difference of the elasticities among the metropolitan areas. Instead, interesting elasticity differences are shown for different family life cycles, probably due to higher income elasticities.

Noland and Cowart (2000) confirmed the results of Barr (2000) and showed that there is no difference in the contribution of capacity additions to new VMT between metropolitan areas of different size and different congestion indexes. This could indicate that land use and development effects play a larger role than existing congestion in inducing new VMT. The authors conclude that areas with proportionally greater growth in lane miles can attribute more of their VMT growth to induced travel.

The concept of influence of congestion on elasticity was studied also by Chu (2000) that developed the model shown by eq. 5.17 to estimate elasticity changes for different levels of underlying congestion, using a cross-sectional database of metropolitan areas derived from the NPTS:

$$\log\left(\frac{q}{C}\right) = \beta_0 + \beta_1 \log\left(X^k\right) + \beta_2 \log(C) + \beta_3 \left(\log(C)\right)^2 + \varepsilon \qquad (5.18)$$

where q is vehicle travel (VMT), C is a measure of capacity (lane miles), X^k refers to other variables included in the estimation, and ε is an error term.

The author has found significant coefficients on both the β_2 and β_3 terms, and he concludes that capacity does influence total traffic albeit with a diminishing effect as specified in his theoretical model. So, the Chu's model provides the most convincing evidence of some correlated effects between induced travel and congestion.

5.3. Some considerations about the models and the results of the studies

An interesting summary of elasticity estimates is shown in table 6.1, as presented by Noland and Lem (2002), where the lane miles elasticities are in the range 0.3-0.6 with larger elasticities for long run effects.

Citation	Travel time elasticity	Lane mile elasticity	Type of model	Data used
Goodwin (1996), SACTRA (1994)	−0.5–1.0			Derived from gasoline price elasticities
Hansen and Huang (1997)		0.3–0.7	Time-series cross-sectional fixed effects	California County-level data
		0.5–0.9		California Metropolitan-level data
Noland (2001)		0.3–0.6 (Short-run) 0.7–1.0 (Long-run)	Time-series cross-sectional fixed effects	State-level data
		0.5–0.8	Difference model with fixed effects	
Noland and Cowart (2000)		0.8–1.0 (Long-run)	Time-series cross-sectional fixed effects	Nationwide metropolitan-level data
		0.3	Two-stage least squares with weak instrument	
Fulton et al. (2000)		0.3–0.5	Two-stage least squares with good instrument	County level data from Maryland, Virginia, North Carolina, and DC
Cervero and Hansen (2001)		0.559	Two-stage least squares with good instrument	County level data from California
Rodier et al. (2001)		0.8–1.1	Disaggregate modelling study	Sacramento regional data and modelling system
Strathman et al. (2000)		0.29	Cross-sectional model	NPTS data, individual-level, nationwide
Barr (2000)	−0.3–0.4		Cross-sectional model	NPTS data, individual-level, nationwide

Source: Noland and Lem, 2002

Table 6.1 : Summary of elasticity estimates

Undoubtedly, the results obtained from different authors suggest that forecasting VMT growth needs to include some measure of transportation infrastructure as a determinant factor.

Some other considerations have emerged from different studies:

- the long-term land use development effects can be a large additional source of increased VMT associated with highway expansion;
- the spatial allocation of development is affected by road infrastructure;
- the development is induced by new road infrastructure. Changes in housing values are an indicator of the increased demand for housing, and they are related to increased road infrastructure with the implication that this induces additional VMT;
- the highway projects may simply redistribute existing growth within a metropolitan area. To a large extent, this growth will be in ex-urban areas that are receiving gains in accessibility at the expense of downtown or older suburban areas.

So, the theory of induced travel cannot be refused and seems to be largely demonstrated, so that the transportation infrastructures probably give other benefits (growth of urbanized areas, if this can be considered a benefit) than the reduction of traffic congestion, and, so they do not decrease travel time. To this consideration should be added a remark on the theory of travel time budget (TTB) that is an important issue for induced traffic, because the rate of longer trips are due to the possibility to live more far than before from job location, not incrementing the time travel and remaining it constant. On the opposite, people could not change residential location and use saved time for other scopes and not to travel.

It is possible to affirm that the capacity increase becomes a tool of transportation policy because, changing the people behaviour (that is translated in change of land use, and so of land prices), can direct the growth of urbanized areas.

This consideration leads to give a look, in the next chapter, to the transportation policy in UK and USA, the countries that have more studied the travel induced concern, to verify if the consciousness emerged from the numerous studies has caused some changes in their transportation policy.

6. Has the transportation policy changed thanks to induced travel findings?

Looking at UK context, in 1998 a new direction of UK transportation policy was established when the Government published the White Paper, A New Deal for Transport: Better for Everyone (Department of Environment, Transport and the Regions, 1998). This document pointed out that the always followed strategy "predict and provide" was no more accepted because unsustainable (too many environmental impacts and too high social costs). The consequent proposals were about the improving of public transport and not-motorized modes, the integration of all modes, the reduction of the need for motorized single-occupant vehicles, so that the existing infrastructures has to be maintained, but not increased in capacity.

So, a new appraisal system, more environment-oriented, was suggested (Price, 1999) against the traditional cost benefit approaches used in UK since 1970s. This leaded to the reviewing of 68 planned trunk road schemes, and 37 were withdrawn or deferred for further analysis after the new appraisal methods were applied (Noland and Lem, 2002).

Also SACTRA (1994) recommended new procedures of cost benefit analysis of road projects to account for induced travel effects, and the procedures were updated in 1997 (Highways Agency, 1997). Following such procedures, small induced travel effects of 5-10% have been found to reduce the benefits of a scheme by anywhere from 20% to nearly 40% (Noland and Lem, 2002).

So, a coordination between land use and transport planning could reduce reliance on private vehicles, encourage modes with less environmental impact, and reduce both the number and length of motorized journeys. An example of goal consistent with White Paper is the promotion of development in centralized and accessible areas by modes other than private cars.

An appropriate land use policy could effectively disconnect the response of developers to changes in the transport network; in such a way, the consequences could be limited to changes in number of trips, routes, destinations, and modes, and not comprising new sprawl development, so that the effect of capacity increasing could become a real time reduction.

The understanding and agreement of the concepts above leaded the UK government to release, in July 2000, a 10-year transport plan (Department of Environment, Transport and the Regions, 2000). This plan contained the proposed investment strategy for surface transport over the next 10 years, and, strangely, this was not consistent with the White Paper's policy proposing a target of widening 5% of the trunk road network, the construction of 30 bypasses, and 80 major schemes to reduce congestion. The Plan seems to disregard potential induced travel effects; anyway it attempts to distribute substantial increases in public spending to many beneficiaries: roads, public transport and rail systems.

Also in USA the trend of US Federal government is towards the integration transportation policy and environmental policy, overall with the Congestion Mitigation and Air Quality program (CMAQ) and the Clean Air Act Amendments (CAAA) of 1990, and, more recently, the TEA-21 of 1998 (continuing the CMAQ program).

Environment Protection Agency (EPA) reviews the environmental impacts of Federal projects thanks to the Environmental Impact Statements (EIS) that are developed by the lead agency (Federal Highway Administration – FHWA – in case of highway projects). The limit is that EIS do not currently conduct a high quality analysis of cumulative effects for highways projects that, often, are also analysed in segments, rather than as an entire corridor, underestimating the potential cumulative effects in the long run.

Regional transportation planning agencies (or the states) generally maintain a system of models to forecast and evaluate the impact of transportation projects and plans, but these do not take adequately into account both short and long run induced travel effects. The feedback mechanism into the models partially corrects this lack and allows for the accounting of the short-run impacts (Johnston and Ceerla, 1996), and some help is given also by some modelling packages available to provide estimates of land development changes induced by transportation and accessibility changes.

The DOT is also incorporating measures of induced travel demand into their Highway Economics Requirements System (HERS) which attempts to determine total financial needs for the US highway system using a cost benefit analysis approach (US Department of Transportation, 1999). This model includes travel demand elasticities of 1.0 in the short run and 1.6 in the long run with respect to total user costs; this allows to estimate VMT growth to respond to changes in recommended investment levels. Anyway, these results seem to not influence the allocation of investment from the Federal government. Noland and Lem (2002) observe that while TEA-21 authorized spending levels for transportation, subsequent annual appropriations of funds have been linked to annual gasoline tax revenues with no consideration of how investment levels may affect VMT growth. Really, US DOT (1999) suggests that investment needed to maintain current conditions, estimated using HERS model, is generally higher than actual investment by both the Federal and State governments.

So, also in USA, as in UK, the theoretical basis of induced traffic seems to be considered, but they are disregarded in term of actual investment, still largely driven by political imperatives (e.g. congestion reduction) and the levels of revenue collected by the Federal gasoline tax.

Conclusions

Nevertheless the evidence of induced travel has been largely demonstrated and the great importance of land use policy is the main element for the transport planning, it seems that the transport policy continue to be driven by the aim of congestion reduction, considering that the capacity increase can solve this problem.

The lack of an incontestable evidence of the causality effect of capacity increase on the VMT growth and some evidence of a biunivocal causality effect related to supply and demand enforce the capacity increase as the unique effective solution to traffic problems, while the land use policy is not sufficiently taken into account to really solve the problem managing transport through land use planning.

It is quite clear that the behavioural responses are the real focus and that an adequate policy on the land use that drives the transport systems is the unique system to have a real sustainable development either of land use or of infrastructures. To manage the transport demand through land use could control the transport demand, deviating it towards sustainable solutions.

In addition, neglecting the induced travel effects leads to underestimate the impacts due to transport systems and to not attain the environmental concerns going to a not sustainable policy, deteriorating instead of improving the quality of life, and so, the liveability either of urban or extra-urban areas.

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