THE PARADOX OF CONGESTION

Kerry Wood MIPENZ

Abstract: This paper re-examines the role of passenger transport in controlling urban congestion, through the little-known Downs-Thomson paradox ('The quality of peak-hour travel by car tends to equal that of public transport'). The paper suggests that the paradox is a useful way to think about traffic and 'car dependence', and a key to more sustainable city transport.

Three broad information sources are used: the theory of and supporting evidence for the paradox; comparative data on 40 cities, gathered in a consistent way; and the experience of cities that have already focussed on improving passenger transport. The assumptions and limits of the paradox are also explored, suggesting that most cities would benefit from taking a Downs-Thomson approach.

The main conclusion is that an important target of urban strategies to relieve traffic congestion should be faster door-to-door trips by public transport.

IPENZ Transportation Group Conference Tauranga 10-10-2007 Published: ipenztg/archives/htm

Introduction

1 This paper reviews the Downs-Thomson paradox, that "the quality of peak-hour travel by car tends to equal that of public transport" (Thomson 1977).

Conclusions

2 The main conclusion is that faster trips by passenger transport (transit), if maintained, will reduce traffic congestion in the long term. Exceptions are probably rare and unlikely in New Zealand cites. Other conclusions are given below.

- The paradox works at a whole-of-journey level and the focus on transit should also be at this level. The key parameter is door-to-door trip speed.
- Transit works best on segregated routes but good results are achievable on-street, using segregated or semi-segregated lanes and junction priority.
- Traffic modellers tend to over-estimate the effect of dedicating road space to transit and under-estimate the extent of mode transfer. While the resulting predictions are "often unnecessarily alarmist", work in Oslo and Copenhagen may offer a new approach.
- Incremental change is possible, although large projects may also be needed.
- Other important effects are subsidised car use, especially for commuting, and the availability and user-cost of car parking.

Three further conclusions can be inferred but are not explored here.

- The scope for improving urban transport sustainability is greater or much greater than might appear.
- Transit needs attention to access, waiting and transfer times as well as vehicle speed.
- A useful research topic might be to repeat the studies by Næss and his colleagues in a New Zealand city.

The Downs-Thomson paradox

3 Næss and Møller (2004) restate the paradox in greater detail.

For each individual there exists an 'equilibrium' ratio of door-to-door speeds of car and transit, but the actual level of this ratio varies from person to person. Among people who have the possibility of choosing between car and transit and who do not have strong ideological or other preferences for any of the modes the equilibrium ratio is likely to be close to 1.0 (provided that the economic costs of travelling are perceived to be similar across modes).

Næss and Møller do not claim that the paradox is a general case, or that it implies equal travel times. Arnott and Small (1994) describe other similar effects including the Braess paradox (paragraph 16).

4 Improvements to transit and roads have differing effects and the Downs-Thomson paradox is created by mode switching arising from the difference. Faster transit tends to encourage positive feedback but increased road capacity tends to encourage negative feedback.

Transit improvements tend to attract passengers. The gains feed back to transit operators as increased revenue and to motor vehicle users as reduced congestion. In contrast, road improvements tend to attract traffic. Mode- and trip-switching creates a 'triple convergence' of new traffic from other routes, other times and other modes. This tends to erode the benefits of road capacity increases (Arnott and Small 1994, Mogridge 1997, Jones 2002, Litman 2005). As much as 50–100% of the expected gains may be lost within 3 years.

These effects tend to continue until the car is, on average, no more attractive than transit, but by then transit is degraded and everyone is worse off.

5 A common assumption is that bus services benefit from increased road capacity but without specific priority they are often disadvantaged.

- Delays in re-entering a fast-moving traffic stream on leaving a stop.

- Delays through consistently missing traffic signals set to give motor traffic a 'green wave'.
- A more indirect route to pick up passengers, such as bypassing a flyover.
- Degraded passenger access because of greater difficulty in crossing the road to reach a stop.

How the paradox works

6 For cars, the 'generalised cost' — monetary cost and travel time — is low in free-flowing traffic but increases as congestion develops, rising very steeply as stop-start flow develops. A generic cost curve is shown in Figure 1(a).

Transit passengers have more rigid generalised costs because of fixed fares and timetables. However, transit operator's unit costs fall with rising demand and this tends to feed back into passengers' generalised costs: more frequent services, better transfers, more routes and greater priority. Trips tend to be faster, easier and more reliable, at least in the medium term. A compromise cost curve — operator's costs plus passenger time — might be appropriate for Figure 1.

7 Figure 1(b) shows the same curves as Figure 1(a) but with the transit curve reversed. The horizontal axis now shows modal split, with increasing car use from left to right and increasing transit use from right to left. The curves cross at the 'Downs-Thomson equilibrium point' which is the predicted modal split for that corridor. The equilibrium point is marked by a circle in Figure 1(b) and the same circle marks the 'before' equilibrium points in Figures 1(c), 1(d) and 1(e).

Assumptions in Figure 1 are that the total number of travellers is constant and that walking, cycling and commercial traffic can be ignored. These are acceptable for a simple explanation but are serious errors in the real world.

8 New road capacity changes the generalised cost curve as shown in Figure 1(c). In effect the cost curve is displaced to the right (greater capacity) but it may also be displaced downwards (greater speed) if speed limits are raised. Transit costs are unchanged. Faster car travel attracts passengers from transit and falling transit demand increases operating costs. Responses may include higher fares, less frequent services and less attractive vehicles. Over time, car costs tend to stabilise at the same higher level as transit.

Næss, Sandberg and Mogridge (2001) give some underlying assumptions.

- Many travellers can choose their travel mode. See paragraphs 10 and 11.
- Travellers place a high value on travel time.
- Some travellers compare travel times between modes and respond to changes.
- The flow/cost curves of cars and transit intersect.

In Figure 1(d) road traffic capacity is unchanged from Figure 1(b) but transit speeds are increased. In effect the curve is displaced downwards. Transit passengers' generalised costs fall and mode-switching equalises the available transit capacity amongst all users. Even converting a general traffic lane to transit-only tends to benefit all road users; the lane's general passenger-carrying capacity is easily exceeded using buses.

Figure 1(e) is the same as Figure 1(c), with increased road capacity, but in this case a congestion charge has been added (Abraham & Hunt 2001). In Figure 1(e) the effect is to restore the original modal split but higher or lower charges are possible.

Evidence for the paradox

9 Evidence for the Downs-Thomson paradox is outlined in paragraphs 10-29 and summarised in paragraph 30. Some cautions are summarised in paragraph 31.

Travel times for cars and transit are expressed as a travel time ratio (car travel time ÷ transit travel time). A ratio of more than 100% indicates that transit is faster than car use. Two definitions of travel time ratio are used, taken from different sources, and are distinguished by subscripts.

- Door-to-door travel time ratio, T_d (Downs-Thomson effects depend on this ratio).
- In-vehicle travel time ratio, $T_{v.}$

Average door-to-door travel times

10 In London, Paris, New York, Washington, Philadelphia, Pittsburgh, Chicago and San Francisco, door-to-door travel times are remarkably similar (T_d, Mogridge 1997; most of these cities are shown in Figure 2). For six sectors of London, over a 20 year period, the average travel time ratio was 92% (range 84–102%, Mogridge 1997).

Jones (2002) affirms Mogridge's London results:

One interesting research finding in situations where there are congested road corridors and suppressed demand, alongside good quality rail provision, is that there is an equilibrium between travel conditions by road and rail. In other words, the average door-to-door travel times by car and train are the same. This has been verified for travel to Central London and in Paris, and leads to the 'Downs-Thomson' Paradox. Namely, that the best way to reduce travel times on the road network is to improve door-to-door rail journey times — thereby raising the equilibrium speed.

Explorers

11 The private vehicles in a commuter peak are not the same every day. In London about 15% of commuters use different modes on different days (Mogridge 1997). Some of them are 'explorers' who switch modes to test which is quickest (Næss, Sandberg and Mogridge 2001). In Oslo, Næss, Sandberg and Mogridge (2001) report much higher switching potential than suggested by Mogridge's London data. Only 6% of Oslo commuters were permanently 'captive' to either mode, plus 12% captive on survey day because of other commitments and 7% captive to 'habit'.

Fast transit is well-used

12 Data from Newman and Kenworthy (1999) and Bachels, Newman and Kenworthy (1999) confirm that cities offering fast transit have low levels of motorisation. See paragraphs 20-24 and Figure 2.

Transit in smaller cities

13 Some authors discuss the paradox in terms of rail-based transit, which is often justified (Mogridge 1997, Jones 2002 and paragraph 5). However, on-street transit can bring Downs-Thomson benefits, and in small cities it may be all that is needed. Effective on-street transit needs measures such as traffic signal priority, bus lanes or semi-segregated routes. There are good examples in Ottawa, Curitiba and Bogotá (Currie 1996) and in many European cities.

Another example is Dublin (DTO 2004), where twelve 'quality bus corridors' have been introduced on existing streets since 1997. By 2004 peak-hour car numbers in the central city had fallen by 21% (range by corridor +12% to -36%). Bus passengers were up 49% and buses were faster than cars on most corridors (T_v range 80% to 181%). Meagher (2005) says most corridors use simple bus lanes, with bus detection at some traffic signals.

14 A note of caution is given by Metri (2006), who points out that excellent results need new thinking and institutional change. The approach he suggests is adapted from the industrial principles of total quality management: some of his points are given below.

- Commit to meeting or exceeding customer requirements.
- Bring in a critical mass of stakeholders.
- A continuous review of processes.
- Exercise strong quality leadership.
- Safety improvements.
- Meet local needs.

Litman (2005a) also highlights the need for institutional change, pointing out that what is not measured is not done and suggesting a range of useful indicators.

Reducing traffic capacity may have little effect

15 There have been many instances of planned, often permanent, road capacity reductions having no apparent effect on congestion (Cairns, Atkins and Goodwin 2002). 'Triple divergence' is possible. Two points help to put these seemingly implausible observations into context.

- Cars are the least space-efficient form of city transport.
- Crashes are an exception, despite their frequency, because they happen without warning and drivers are unable to re-plan their trips.

Cairns, Atkins and Goodwin (2002) found over 70 capacity reduction schemes having good data, with a mean traffic reduction of 22% (range +26% to -146% — in a few cases reduced flows spread to other streets). The authors note that:

... widespread, long-term disruption is hardly ever reported.

The findings suggest that predictions of traffic problems are often unnecessarily alarmist, and that, given appropriate local circumstances, significant reductions in overall traffic levels can occur, with people making a far wider range of behavioural responses than has traditionally been assumed.

When pedestrianisation schemes or wider pavements or cycle lanes or bus (and other priority vehicle) lanes or road closures are introduced, pre-scheme predictions of what will happen are usually excessively pessimistic. In practice, it is rare that schemes result in a significant deterioration of traffic conditions. Traffic levels can reduce by significant amounts, with the average being that perhaps 11% of the traffic on the treated road or area cannot be found in the area afterwards ... The corollary is that it is not appropriate to assume automatically that traffic levels will remain fixed.

These observations are consistent with the Downs-Thomson paradox and imply that road space can often be made available for transit.

16 A large traffic reduction example from central Seoul (Vidal 2006) is that 6 kilometres of highway along the Cheonggyecheon river, carrying 160 000 vehicles/day, was demolished and the previously-culverted river reinstated through a new 400 hectare park. Transit was also improved. A 'before' photograph (CRP 2007) shows four traffic lanes on viaduct and perhaps another eight at ground level. Vidal quotes project leader Professor Hwang:

The tearing down of the motorway has had both intended and unexpected effects. As soon as we destroyed the road, the cars just disappeared and drivers changed their habits. A lot of people just gave up their cars. Others found a different way of driving. In some cases, they kept using their cars but changed their routes."

Vidal reports that a specially developed forecasting model correctly predicted the outcome. Hwang again:

The idea was sown in 1999. We had experienced a strange thing. We had three tunnels in the city and one needed to be shut down. Bizarrely, we found that car volumes dropped. We discovered that it was a case of 'Braess paradox', which says that by taking space away in an urban area you can actually increase the flow of traffic, and by implication by adding extra capacity to a network you can reduce overall performance."

Traffic modelling

17 The Seoul case raises a question: why are paradoxical outcomes rarely noted elsewhere? One study modelled increasing transit speed by 20% with a similar decrease in car speed (Dasgupta 1994). The predicted modal split for car use fell by only 5.7%, but other researchers predict much greater effects.

- Johnstone (2006) refers to 'quite significant' policy evaluations in Europe and describes them as the best ever done:
  Increasing auto costs by 400% reduces [vehicle kilometres] and emissions about one third. (Note that making workers pay for parking or providing cash-in-lieu-of-parking incentives in the US increases 'felt' costs by about 400%, without actually increasing costs, as the parking costs are merely unbundled from wages)
- Figure 3 suggests a motor traffic reduction of 30 - 40% for Dasgupta's simulation, based on commuting studies in Oslo and Copenhagen.

- Wallström (2004) reports on eight European case studies of planned traffic capacity reduction schemes. All achieved at least some 'traffic evaporation'. There was no increased congestion in any of the case studies despite some 'dire' predictions.

18 Wallström's report on Vauxhall Cross (in London) is an instructive example.

Initially computer modelling indicated that excessive congestion would occur if traffic volumes across critical stop lines at the junction were reduced by 20%, the reduction considered necessary to provide the space and capacity needed for the proposed interchange. Vauxhall Cross experiences some of the highest peak period traffic volumes in London: 9000-10 000 vehicles/hr.

The scheme met with considerable resistance from traffic engineers. The argument used to overcome their resistance was in part the research work undertaken by Goodwin, Hass-Klau and Cairns ... [an earlier version of Cairns, Atkins and Goodwin 2002] *... but also the quality of traffic modelling used to validate existing conditions ...*

An on-site experiment ... effectively reduced [traffic capacity] by 15% through a combination of road layout alterations and traffic light sequencing adjustments. No significant congestion or tailbacks occurred and the experiment appeared not to cause any significant problems ... In fact a 2-8% reduction in peak-time traffic was observed and traffic queues were shorter than before.

Jones (1996) says of Dasgupta's results:

It is probable that [Dasgupta's] study has underestimated the long-term effects of such policy packages applied in a consistent way ... long term elasticities can be roughly twice the short term ones used in models of this type. People are more able to adjust to policy measures at times of major decisions, such as a home or job move or replacing a household car ...

19 Several effects seem to be present here.

- Traffic modellers may be unaware of the paradox, or discount it. Goodwin (2006) points out that induced traffic (or triple convergence) was first noted in London in 1925 and the same conclusion has been reached about every ten years since then.
- Long-term changes are often larger than short-term but may be missed in 'after' studies made too soon after the event.
- Transport models are generally designed to simulate motor vehicle movements and seldom mimic transit journeys properly (Hutton 2007).
- Other effects such as 'free' parking (paragraph 29) tend to mask the paradox.

The Downs-Thomson line

20 Figure 2 is a plot of 39 cities, using data from Newman and Kenworthy (1999) and Bachels, Newman and Kenworthy (1999). The Y axis shows the modal split for travel by car and the X axis the travel time ratio (T_v), both expressed as a percentage. A striking feature is that the data falls within two well-defined limit lines.

- A 'Downs-Thomson line' forming an upper right boundary. There are no cities beyond this line, by definition, but at least six plotted cities are on or close to it. This suggests a real boundary. The travel time ratio (T_v) defined by this line is as low as 50% in cities with very high car use (Phoenix) but almost 200% with very low car use (Tokyo).
- A 'slow bus line' forming a left hand boundary. This is less clearly defined and may simply indicate a practical minimum travel time ratio.

The limit lines cross at a point close to the line representing 100% of trips by car, which tends to support their validity. In a hypothetical city at this point any vestigial transit would be very poor, putting the city on the slow bus line, but would attract a few passengers. Transit would reduce car trips, however slightly, keeping the city inside the Downs-Thomson line.

All the cities studied by Mogridge lie close to the line, which suggests that he was choosing a specific city type. The names of the cities he studied are underlined in Figure 2.

21 Figure 2 shows three broad areas of interest.

- Cities towards the top of the diagram, where more than about two-thirds of trips are by car and transit is generally slower than car use (T_v). The presence of Downs-Thomson effects is confirmed by Mogridge (1997) with studies in San Francisco, Chicago, Washington and New York. The three New Zealand cities plotted on Figure 2 are in this area.
- Cities close to the Downs-Thomson line in Figure 2 but with less than about two thirds of trips made by car. Two of these cities, Paris and London, are confirmed as showing Downs-Thomson effects (Mogridge 1997).
- Other cities, lying away from the Downs-Thomson line and towards the bottom left of Figure 2. Cities in this area of Figure 2 are a mixture of poor and wealthy cities with possibly differing conditions, discussed in paragraphs 22 and 23.

22 The first subgroup of cities towards the lower left of Figure 2 is categorised by Newman and Kenworthy (1999) as 'lower-income Asian': Kuala Lumpur, Bangkok, Jakarta, Manila and Surabaya. These cities may be a distinct group and are marked by crosses. Newman and Kenworthy also placed Seoul in this group but in this study it is grouped with the wealthy Asian cities (paragraph 23). The reason is that Seoul has a third of transit passenger-kilometres on rail and a higher travel time ratio than other cities in this group.

In this first group of cities there is little use of passenger rail, with a maximum of 8% of passenger-kilometres (Manila). There is heavy reliance on buses and 'jeepneys', and sheer numbers make transit priority very difficult. Travel time ratios are low, on or close to the slow bus line. Buses are very crowded and transit may be so slow and unpleasant that nobody uses it from choice. If this is the case the generalised cost curves do not cross and there is no paradox.

23 The second group of cities towards the lower left of Figure 2 is mainly European and 'high-income Asian' (Newman and Kenworthy 1999), with generally higher travel time ratios than the developing Asian cities. The plotted cities are Amsterdam, Brussels, Copenhagen (see paragraph 25), Munich, Stockholm, Vienna and Zürich, plus Metropolitan Toronto, Hong Kong, Singapore, Seoul and Tokyo.

Figure 3 (discussed in paragraph 25) shows a strong Downs-Thomson effect in Copenhagen, which suggests that other cities in the group may also show a strong effect.

24 What happens to a city's location on Figure 2 when it adopts a fast-transit policy? The New Zealand city data (1991 and 1996) confirms that fairly rapid movement is possible. A plausible guess is that the modal split changes quickly enough to keep the city inside the Downs-Thomson line, and often well inside. Amsterdam and Hong Kong, for example, have strong transit policies but are well away from the line. More data on changes over time should give a robust answer.

Oslo and Copenhagen

25 Figure 3 shows the probability of a commuter taking the car at any given travel time ratio (T_d), for commuters on the NSB (railway) corridor into central Oslo and for travel to selected employers in inner Copenhagen (Næss, Sandberg and Mogridge 2001, Næss and Møller 2004).

Næss, Sandberg and Mogridge (2001) surveyed 253 commuters working in downtown Oslo and gathered detailed information on travel behaviour.

- Stated and revealed preferences.
- Origin, destination and door-to-door travel times.
- Other factors likely to influence travel decisions.
- Individual travel time ratios, calculated from the actual travel time and a hypothetical travel time for the same trip by the alternative mode.

This data was used to develop a modal split probability curve for a range of travel time ratios using multivariate logistic regression: parking conditions, car ownership, holding a driver's licence, income, education, sex, age, whether the employer covers commuting expenses, errands on the journey home from work, and the proportion of the door-to-door travel time by transit spent within the vehicle. The method is sensitive enough to pick up a Downs-Thomson interaction between buses and cycles (Næss and Møller 2004).

The maximum slopes of the curves in Figure 3 are about -0.85 for Copenhagen (towards the centre of Figure 2 and -0.95 for Oslo (not plotted on Figure 2). Obviously these curves are not generally applicable but what is interesting is their shape, falling continuously from a door-to-door travel time ratio (T_d) of as little as 25% — four times the travel time by car. This is well over to the left of Figure 2, but note that Figure 2 uses in-vehicle travel times (T_v).

26 Previous workers have only been able to speculate on where paradoxical effects might be strongest, but the curves in Figure 3 are objective measurements, separated out from masking effects, and in principle they allow comparisons between corridors and cities. Useful comparisons might be:

- the slope at a given travel time ratio, for corridor comparisons within a city; or
- the maximum slope of the curve for comparing cities.

Copenhagen shows a robust-looking Downs-Thomson effect (Figure 3), yet it is in an area of Figure 2 where a weak effect might be expected, away from the previously-known 'Downs-Thomson' cities studied by Mogridge. Just how robust is the effect in Copenhagen will have to wait for similar studies of other cities.

A quantified Downs-Thomson paradox may offer a solution to the modelling problems raised in paragraphs 17-19. Given a curve such as Figure 3 it should be a simple matter to estimate modal split from the travel time ratio. Further work is needed, both to gather data and to establish whether a single curve can reasonably be applied to an urban area or centre, or whether it needs to be corridor-specific.

27 Travellers in the Oslo study were not 'rational' in the economic sense (Næss and Møller 2004). This is suggested by Figure 3: pure economic rationality would give a much more strongly s-shaped curve. Næss and Møller state that:

... other reasons for the modal choice than saving time or money are obviously also important. As noted in our qualitative interviews, a wish for exercise, environmental considerations and lifestyle signalling were mentioned among the rationales for choosing modes of transportation. Some of the commuters who go by bike or transit in spite of losing time by doing this, may choose these modes for environmental reasons. Others enjoy riding their bikes or walking to and from the transit stops and consider this a health-bringing daily exercise. Others again may prefer transit because this mode enables them to read or write on the train or bus. Conversely, some dedicated car drivers prefer to go by car even if transit is faster.

28 Summarising paragraphs 20-27, the Downs-Thomson paradox seems to be present in most cities, although some cities in developing countries may be an exception. It is strong in cities close to the Downs-Thomson line (Mogridge 1997) and in Copenhagen, and is probably also strong in cities located in about the top third of Figure 2.

Other effects

29 Næss, Sandberg and Mogridge (2001) and Næss and Møller (2004) report other important variables, particularly the availability and cost of commuter parking and any employer contributions to commuter costs.

The level of CBD parking in twenty eight cities is shown in Figure 4, which is a development of Figure 2. Each city is represented by a bar of height proportional to total CBD parking provision — public and private, on-street and off-street — expressed as a proportion of CBD jobs.

For the New Zealand cities there is data for both 1991 and 1996 and the changes are shown as bar extensions: white for an increase, black for a decrease.

Figure 4 shows clearly that cities in the top third of Figure 2 have much greater parking provision that cities relying less on private vehicles, with particularly hight levels in Christchurch and Wellington.

Summary of evidence

30 The evidence for the Downs-Thomson paradox is summarised below (paragraph numbers in brackets):

- The paradox has a logical explanation. (6-8 and Figure 1)
- Peak hour travel times by car are often about the same as by transit, as predicted by the paradox. (10 and 17)
- Some travellers switch modes to see which suits them best, and time saving is an important reason for their choices. (11 and 27)
- Fast transit is well used. (12 and Figure 2)
- The paradox tends to be seen as a rail-based effect (metro or suburban rail) but on-street bus- or light rail-based transit is effective given adequate priority. (13-14)
- Rapid gains are practicable. (13)
- Traffic capacity reductions may have little or no effect on congestion. Predictions to the contrary are 'often unnecessarily alarmist.' (15-16)
- Even drastic traffic reductions may be practicable. (16-17).
- The paradox can be demonstrated by modelling. (16-17)
- A focus on good-quality transit can reduce congestion over a wide range of city types. (21-23)
- The existence and strength of the paradox can be demonstrated by detailed surveys. (25-27)

31 Against this evidence can be set three cautions.

- Traffic modelling often fails to demonstrate the Downs-Thomson paradox, possibly because of faulty assumptions and a primary focus on motor traffic. (17)
- Achieving good results in cities having low transit use, or using bus-only transit, needs a close focus on quality transport. This implies a need to accept new thinking, new targets and institutional change. (14)
- The paradox is difficult to observe directly, although an effective but time-consuming method is now available. (25 and 26)

Comments by others

32 The following comments from other authors suggest the value of a Downs-Thomson approach.

There are perhaps two mistakes that can be made in discussing 'car dependence'. The first is to think that there is no such thing. The second is to accord it such power that it becomes a barrier to any change, however sensible or desirable. (Goodwin 1995)

Jones (1996) draws attention to three conditions for successfully controlling car use:

- *Political and public acceptance of the need for change, and the political will to implement the necessary measures.*
- *Analytical techniques that will enable suitable packages of measures to be devised and evaluated.*
- *A sufficient understanding of the behavioural processes affecting car use that packages of measures can be devised that are reasonably assured of success.*

The only way to reduce traffic problems is to promote public transport. (Heierli 1996)

References

Abraham, JE and Hunt, JD (2001). *Transit system management, equilibrium mode split and the Downs-Thomson paradox.* Downloaded 2005 August from: www.ucalgary.ca

Arnott, R and Small, K (1994). The Economics of Traffic Congestion. *American Scientist* 82:446-455

Bachels, M, Newman, P and Kenworthy, J (1999). *Indicators of urban transport efficiency in New Zealand's main cities.* Perth: Murdoch University, ISBN 0 86905 669 7

Cairns, S, Atkins, S and Goodwin, P (2002). Disappearing traffic? the story so far. London: Proceedings of the Institution of Civil Engineers, *Municipal Engineer,* Paper 1272, March

CRP (2007). Cheonggyecheon Restoration Project. www.metro.seoul.kr/kor2000/chungaehome/en/seoul/sub_htm/4sub_03.htm

Currie, G (1996). Bus transit-orientated development — strengths and challenges relative to rail. *Journal of Public Transportation,* 9(4).

(Dasgupta 1994 cited in Næss and Møller 2004, and Jones 1996)

DTO (2004). *Quality bus monitoring report.* Dublin Transport Office. Downloaded August 2006 from http://www.dto.ie/

Goodwin, P (1995). Car dependence. *Transport Policy (2) 3* Elsevier Science

Goodwin, P (2006). Induced traffic again. And again. And again. London: *Local Transport Today,* 24 August 2006

Heierli, R (1996). European Lecture: transit in Zürich. London: *Proc Inst. Civil Engineers, Transport 117,* November

Hutton, B (2007). We need to fundamentally rethink transport models so they represent the reality experienced by travellers, not network providers. London: *Local Transport Today,* 1 March 2007

Jones, P (1996). *Daily motorised mobility: can it be transferred to other modes?* Paris: ECMT 102nd round table, 9–10 May

Jones, P (2002). Options for reducing traffic congestion: an overview. In *Alternatives to congestion charging — proceedings of a seminar held by the Transport Policy Committee, London Assembly*

Johnston, RA (2006). *Review of US and European regional modelling studies of policies intended to reduce motorized travel, fuel use and emissions.* Victoria: Victoria Transport Policy Institute. Available from www.vtpi.org.

Litman, T (2005). *Generated traffic and induced travel.* Victoria: Victoria Transport Policy Institute. Available from www.vtpi.org.

Litman, T (2005a). *Well measured: developing indicators for comprehensive and sustainable transport planning.* Victoria: Victoria Transport Policy Institute. Available from www.vtpi.org.

Meagher, J (2005) Dublin's quality bus corridors. *Public Transport International* UITP

Metri, BA (2006). Total quality transport through Demming's 14 points. *Journal of Public Transportation,* 9(4).

Mogridge, MJH (1997). The self-defeating nature of urban road capacity policy. *Transport Policy* 4 (1) pp 5-23

Næss, P, Sandberg, SL, and Mogridge, MJH (2001). Wider roads, more cars. *Natural Resources Forum,* 25 (2) May, pp 147-155

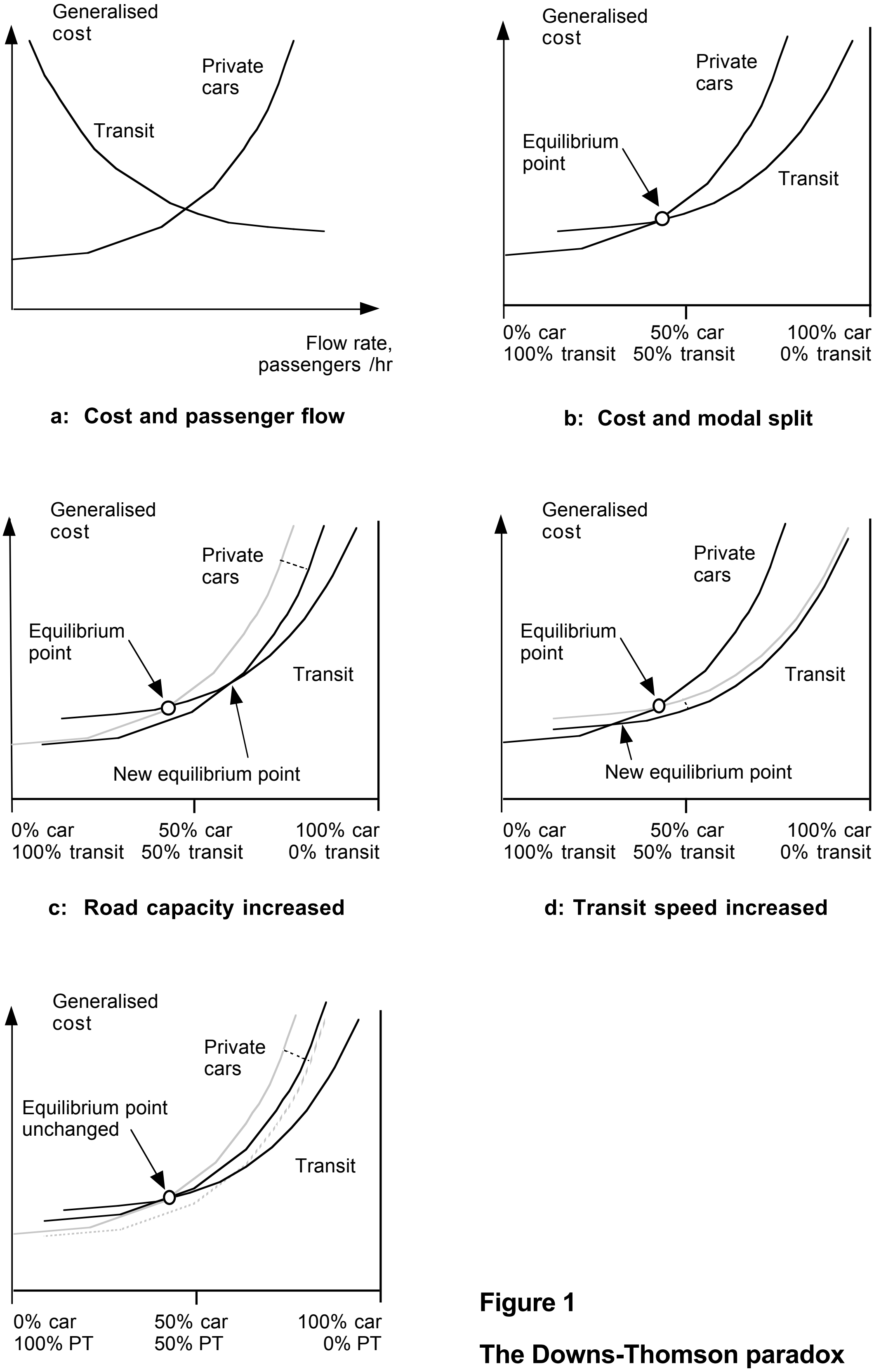
Næss, P and Møller, JS (2004). *Travel speed and modal choice in Copenhagen: the competition between car, transit and bike.* AESOP 2004

Newman, P and Kenworthy, J (1999). *Sustainability and cities — overcoming automobile dependence.* ISBN 1 55963 660 2.

(Thomson 1977 cited in Mogridge 1997)

Vidal, J (2006). Heart and soul of the city. London: *The Guardian,* 1 November

Wallström, M (2004) *Reclaiming city streets for people: chaos or quality of life?* Luxembourg: Directorate-General for the Environment, European Commission, downloaded May 2007 from http://www.udrzatelnemesta.sk/uploads/streets_people.pdf



a: Cost and passenger flow

b: Cost and modal split

c: Road capacity increased

d: Transit speed increased

e: road capacity increased, congestion charge introduced

Figure 1

The Downs-Thomson paradox

After Mogridge (1997) and Abraham and Hunt (2001)

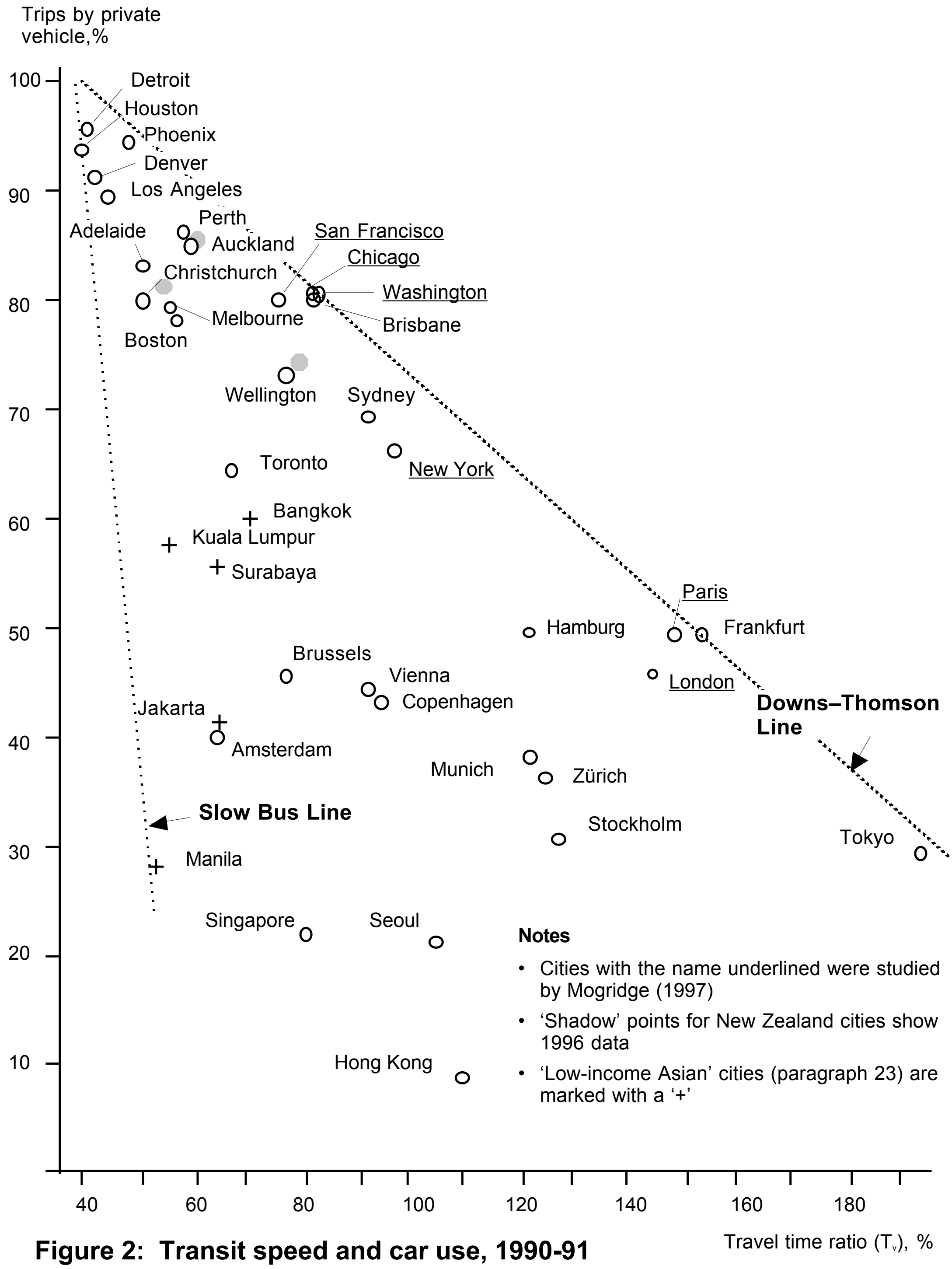


Figure 2: Transit speed and car use, 1990-91

(Also 1996 for New Zealand cities)

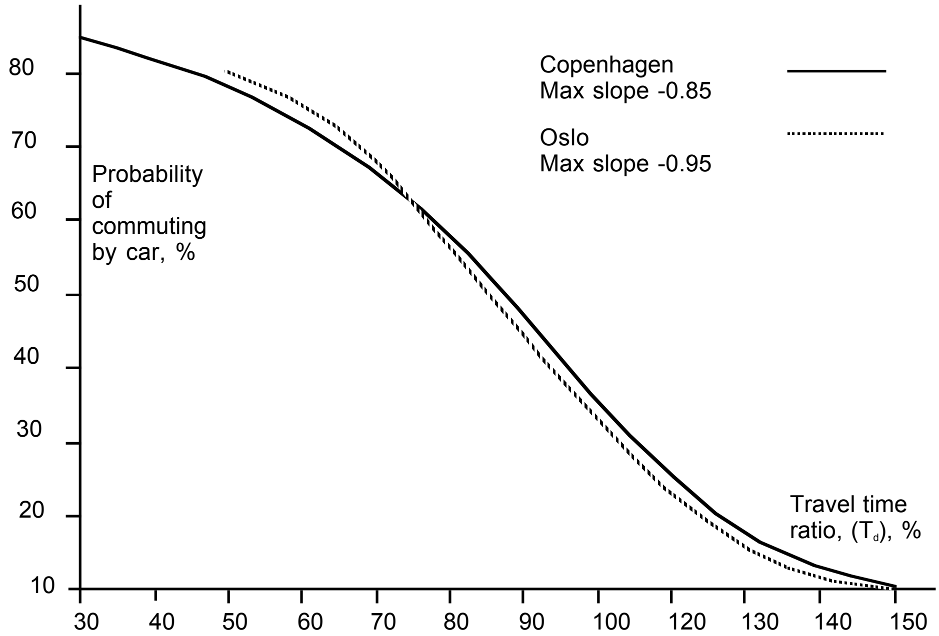


Figure 3: Mode choice probability and travel time ratio

(Næss et al 2001, Næss and Møller 2004, multivariate logistic regressions)

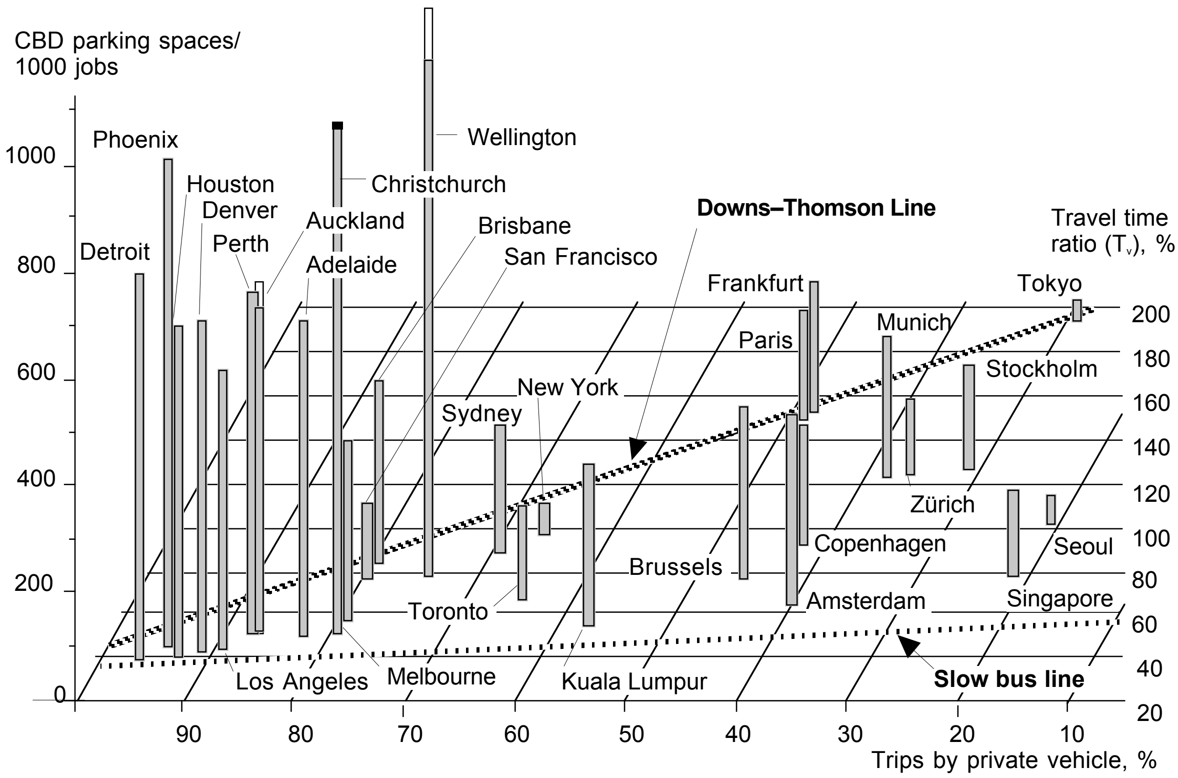


Figure 4: Transit speed, car use and parking, 1990-91

Column extensions for NZ cities represent changes 1991 to 1996 (white = increase, black = decrease)
Some of the cities in Figure 2 have been omitted for clarity