Research into Traffic Peak Spreading

Transfund New Zealand Research Report No. 241

Research into Traffic Peak Spreading

John Bolland & David Ashmore
Booz Allen Hamilton (NZ) Ltd
Wellington, New Zealand

Transfund New Zealand Research Report No. 241

ISBN 0-478-25351-6
ISSN 1174-0574

Bolland, J.*; Ashmore, D.* 2003. Research into traffic peak spreading. *Transfund New Zealand Research Report No. 241.* 53 pp.

*Booz Allen Hamilton (NZ) Ltd, PO Box 10 926, Wellington, New Zealand

Keywords: behavioural research, evaluation, modelling, New Zealand, peak contraction, peak spreading, peak traffic, road, traffic

An Important Note for the Reader

The research detailed in this report was commissioned by Transfund New Zealand. Transfund New Zealand is a Crown entity established under the Transit New Zealand Act 1989. Its principal objective is to allocate resources to achieve a safe and efficient roading system. Each year, Transfund New Zealand invests a portion of its funds on research that contributes to this objective.

Acknowledgments

The authors acknowledge the particular contributions made by:

Fergus Tate, Opus Central Laboratories, who has carried out an earlier study on this subject for Wellington Regional Council (WRC) and who gladly shared experience and data; and by WRC who agreed to sharing this.

Dr John Polak, University College London, who provided extensive information on current work in the UK.

Mr Dick Bullock, Australia, for his constructive suggestions during the peer review.

Booz Allen Hamilton have drawn upon many sources for this report, the major ones being: our global network of transportation experts, specialist libraries, the worldwide web and on-line library catalogues. The assistance received is gratefully acknowledged.

Contents

Executive Summary

Introduction

A research study was undertaken, in 2001-02, of the temporal spreading of traffic peaks, or 'peak spreading', on roads in urban areas in New Zealand, and in other countries. The objectives of the study are to:

- review available evidence of, and research into, traffic peak spreading obtained from cities in New Zealand and elsewhere;
- examine the effect of traffic peak spreading on modelling and evaluation.

The two major purposes of the report are to:

- describe the phenomenon of peak spreading, why it happens, why it is important, and where it has been observed in the world;
- assess how peak spreading, given its importance, has been incorporated in new scheme appraisals by various Governments and how it has been represented in modelling and evaluation.

What Peak Spreading Is

Conventional transport planning indicates that road capacity should be provided to meet the generally experienced levels of maximum traffic demand, i.e. those that occur in the typical peak period or 'rush hour'. The level of demand during the peak period is of crucial importance when estimating the necessary level of road capacity to be provided, and the associated costs to provide and maintain this capacity. The capacity of planned works needs to cater for the maximum level of future demand, and errors in forecasts can lead to an inefficient allocation of resources through the under- or over-provision of capacity.

Two factors need to be considered in forecasting future levels of peak demand:

- Changes in the underlying profile of trip-making, assuming that capacity is unlimited and congestion is not a factor in trip-makers' decision-making.
- The ability of capacity constraints to modify the underlying profile by, for example, shifting trips out of the peak period and into the less congested shoulder periods.

Why Peak Spreading Occurs

Two mechanisms have been identified that cause the peak period to lengthen over time. They are a direct consequence of congestion but have different implications for modelling and appraisal. One is largely driven by network conditions and can be considered as 'passive', the other is a deliberate behavioural response and hence is 'active'.

Traffic Congestion in New Zealand

The level of traffic congestion in New Zealand's two major urban areas, Auckland and Wellington, is such that peak spreading has been discussed in both their Regional Land Transport Strategies. Although traffic congestion occurs in other New Zealand cities, it is unlikely to be so much in excess of capacity that it will cause trips to be re-timed.

The **Auckland** metropolitan area is low density by international standards, with a dispersed population. Moreover the capacity of the existing road network is constrained partly by geography and cost issues. All these factors contribute to the high levels of traffic congestion currently experienced in Auckland during the peak period.

Wellington differs from Auckland in that its more compact central business district attracts a large proportion of commuter trips by public transport. Congestion is by no means as acute as in Auckland, but is noticeable in peak periods particularly around the convergence of State Highways 1 and 2 on other city centre approaches.

Comparison between the two cities confirms that congestion, measured using the one-hour PSER (Peak Spreading Efficiency Ratio), is much greater in Auckland (100% reached before 1990) than in Wellington (95-100% in 2002).

Modelling Peak Spreading Effects

Peak spreading is well documented and of concern to both the transport planner and the policy maker. A number of countries, with most action apparently in the UK, are taking steps to allow for it in the evaluation of urban roading schemes. Ignoring its effects will distort the cost/benefit profiles of new schemes. The two ways in which this can happen are:

- failure to allow for peak spreading in the 'Do Minimum' (usually Do Nothing) option will exaggerate the forecast level of congestion;
- not taking account of the converse effect of peak contraction in the scheme option will understate the level of congestion.

Since transport planning was first practised in the late 1950s, the convention has been to represent trip-making as a four stage process. The stages are:

- Trip generation;
- Trip distribution;
- Modal split;
- Assignment.

Time-of-day choice is conspicuously absent. Research that has been carried out into what actually causes peak spreading to take place, i.e. how people respond to congestion, is discussed.

Accounting for Peak Spreading in Scheme Evaluations

Prescribed evaluation frameworks for schemes such as capacity enhancements increasingly have peak spreading incorporated in the evaluation process. Typically this has been carried out under the heading of 'induced traffic' (i.e. traffic generated because the road is in place).

Conclusions

The phenomenon of spreading of traffic peaks has been clearly identified in New Zealand cities and elsewhere. The sizeable body of research on the subject is largely concentrated in the UK and US.

Despite difficulties in obtaining continuous traffic data for Auckland and Wellington, at one key point in the roading network of each city the morning peak is clearly spreading. On SH1 north of Wellington, the peak currently lasts about one hour, and over the peak 3 hours about 2/3 of the available road carrying capacity is used.

On Auckland Harbour Bridge, traffic levels are now approaching capacity over the full 3 hours from 0630 to 0930. Both pictures contrast with those of 10 years ago.

Several examples have been observed of the converse effect of peak contraction, i.e. when capacity is increased, trips are re-timed to take advantage, leading to a shorter peak.

The traditional four-stage model explicitly excludes any element of time-of-day choice. However, the current thinking is that time of travel is the second most important decision after route choice.

Extensive work is under way in the UK to incorporate time-of-day choice in traffic planning schemes. A similar approach has been reported in the US but appears to be less well developed.

Peak spreading has also been modelled using elasticity approaches, although these often relate to the general issue of 'induced traffic', which may not explicitly include peak spreading. Another approach is to look at how the 'peakiness' over a longer period (typically 3 hours) has changed in the past, and to project this into the future.

Both the Wellington and Auckland Regional Transport Models include a peak spreading module based on elasticities, which moves trips out of the 2-hour morning peak period. In practice, however, as the peak is shorter than 2 hours in Wellington and longer in parts of Auckland, the usefulness of the module may be questionable.

Recommendations

Recommendations for incorporating peak spreading as an integral part of transport planning are made.

- The two key sites, in Wellington and Auckland, although showing evidence of peak spreading, may not be fully representative of traffic as a whole in the respective cities.
- Undertaking a similar analysis at other key sites and possibly also extending it to the evening peak would be highly informative.
- Obtaining historical traffic data has been a significant impediment to the analytical aspects of this study. Therefore better data collection and archiving is supported.
- This study has not attempted to forecast the likely future values of the PSER (as was done previously for Wellington). Further work on this would be informative, particularly in conjunction with examination of other sites.
- In Wellington the Regional Transport Model is currently being updated. This would provide a good opportunity to improve the peak spreading modelling, which could be based on the findings of this study.
- In Auckland, given that the peak already lasts over 2 hours in some locations, the present peak spreading module in the Auckland Regional model would seem to be of dubious value.
- In future scheme evaluations, the effects of peak spreading should be taken into account. This could be achieved by using historical data to determine how the PSER (or a similar measure such as the ratio peak hour:peak period) has changed through time, and to project that forward to the design year. This could then be used to split the all-day matrix into peak and off-peak portions.
- In view of the considerable developments taking place in modelling time-of-day choice in the UK, maintaining a watching brief on the situation there would be very useful.

However, the inclusion or exclusion of peak spreading is only one of the issues which impact on the outcome of any traffic modelling exercise.

Abstract

A research study was undertaken, in 2001-02, for New Zealand and in other countries, of the temporal spreading of traffic peaks, or 'peak spreading', on roads in urban areas. The objectives of the study are to:

- review available evidence of, and research into, traffic peak spreading obtained from cities in New Zealand and elsewhere;
- examine the effect of traffic peak spreading on modelling and evaluation.

The two major purposes of the report are to:

- describe the phenomenon of peak spreading, why it happens, why it is important, and where it has been observed in the world;
- assess how peak spreading, given its importance, has been incorporated in new scheme appraisals by various Governments and how it has been represented in modelling and evaluation.

Recommendations for incorporating peak spreading as an integral part of transport planning are made.

1. Introduction

This report presents the findings of a research study undertaken in 2001-02 as part of the Transfund New Zealand 2001/02 Research Programme. The subject is the temporal spreading of traffic peaks on roads in urban areas, or 'peak spreading' as it is generally known and as used in this report.

As set out in Booz Allen Hamilton's proposal dated March 2001, the objectives of the study are to:

- review available evidence of, and research into, traffic peak spreading obtained from cities in New Zealand and in other countries;
- examine the effect of traffic peak spreading on modelling and evaluation.

This report has two major purposes. The first is to describe the phenomenon of peak spreading, why it happens, why it is important, and where it has been observed in the world. This is covered in Chapters 2 and 3. The second purpose is to assess how peak spreading has been represented in a modelling context (Chapter 4). An evaluation of how peak spreading has been incorporated in new scheme appraisals by various Governments is made in Chapter 5. Conclusions and recommendations are reached in Chapter 6.

Booz Allen Hamilton have drawn upon many sources for this report, the major ones being: our global network of transportation experts, specialist libraries, the worldwide web and on-line library catalogues.

2. Peak Spreading: Characteristics, Significance, Causal Factors & Evidence

2.1 Introduction

This chapter describes the phenomenon of traffic peak spreading and why it is of interest to transport planners. It goes on to explain why peak spreading takes place. The chapter concludes with descriptions of the extent to which peak spreading has been observed in the United Kingdom (UK), Europe, United States (US), Canada and Australia.

2.2 What is Peak Spreading, and Why Is It Important?

Broadly speaking, conventional transport planning indicates that road capacity should be provided to meet the generally experienced levels of maximum traffic demand, i.e. those that occur in the typical peak period or 'rush hour'. The level of demand during the peak period is of crucial importance when estimating the necessary level of road capacity, and the associated costs to provide and maintain this capacity. The capacity of planned works needs to cater for the maximum level of future demand, and errors in forecasts can lead to an inefficient allocation of resources through the under- or over-provision of capacity.

Two factors need to be considered in forecasting future levels of peak demand:

- Changes in the underlying profile of trip-making, assuming that capacity is unlimited and congestion is not a factor in trip-makers' decision-making.
- The ability of capacity constraints to modify the underlying profile by, for example, shifting trips out of the peak period and into the less congested shoulder periods.

The first of these is an on-going process which reflects both social changes as well as the relative importance of different trips. Thus changes in working times (such as the introduction of more flexible hours and the growth of self-employment) will reduce the sharpness of the evening peak in particular, while the large growth in transporting children to and from school by car has affected both morning and afternoon trip profiles. Although some of these changes (e.g. flexible working hours) may be affected by the general level of congestion, overall they occur independently of government intervention.

The second factor, however, can be, and often is, used as a policy tool by planners to delay the costs of providing additional capacity. One example is the Sydney Harbour Bridge (discussed in more detail in Section 2.4.3 of this report), which experienced steadily increasing periods of congestion over a thirty-year period until a parallel Harbour Tunnel was constructed. Such a policy implicitly considers that the disbenefits from not meeting all road user needs instantaneously is less than the cost of providing the additional capacity.

Although both factors can contribute to a flattening of the peak profile, and should be considered in any forecast of transport demand, most professional interest is concentrated on the second factor, because it is a tool that can be employed to shape demand and make a trade-off between investment and congestion. This forms the bulk of the discussion in this review.

Peak spreading can be seen as a natural market correction that allows supply to equate more closely with demand and to remove the need to continually provide extra road capacity or install systems to maximise the existing capacity such as incident management or variable signage systems. Many users and planners, however, see peak spreading as a proxy for delay with all its associated negative qualities, and believe that economic disbenefits result if trip makers are not able to leave and arrive at their chosen times.

Whatever one's perspective, peak spreading is clearly important to those involved in planning transportation systems. The existence of the phenomenon is well researched and documented, and planners are now seeking first to gain a stronger understanding of the factors that lead to peak spreading. Second, they are seeking how these can be modelled and influenced with any degree of certainty, and incorporated into appraisal frameworks.

The forecasting and evaluation of peak spreading as a policy is in its infancy, with two major issues unresolved:

- How sensitive is the trip profile to congestion and capacity constraints? Are trips redistributed or are they suppressed? Does a profile that has been subject to peak-spreading recover its original 'shape' when capacity constraints are removed?
- How can the disbenefits associated with the forced re-timing of trips be evaluated?

2.3 Why Does Peak Spreading Occur?

Two mechanisms have been identified that cause the peak period to lengthen over time. Both are a direct consequence of congestion but have different implications for modelling and appraisal. One is largely driven by network conditions and can be considered as 'passive', the other by deliberate behavioural response or hence is 'active'.

2.3.1 Passive Spreading

Under this mechanism, the trip maker continues to attempt to travel in the time segment of their choice. However, excessive demand causes congestion, which in turn causes delay and leads to the re-timing of trips along their routes.

The representation of passive spreading within a transport model is done by lengthening journey times as a function of the level of congestion with trips 'spilling-over' into a successive time slot for assignment to the network.

2.3.2 Active Spreading

Active spreading occurs when the individual trip maker makes a conscious decision to travel at a different time period, either earlier or later than the most congested period, in order to miss the worst of the rush hour. Thus people trade-off congestion and their preferred travel time, moving out of the peak to reduce the duration of their journeys. However potentially they still are incurring an element of disutility by having to leave home earlier or arrive at work later, compared to their preferred time.

In reality people may not simply trade off congestion and departure time, but also the generalised cost of their trip and departure time. Congestion dramatically increases the generalised cost by incurring time and uncertainty penalties, but monetary costs can also be used to facilitate changes in travel behaviour. The theory behind many urban road pricing schemes is that peak spreading should be encouraged as it represents a better use of existing facilities (Allen 1991). Also by charging for the use of road space by time of day will push people into the shoulder peak periods in their work runs. The evidence on temporal shifts in response to different pricing regimes is inconclusive, however. In some cases peak pricing has resulted in other behavioural changes such as trip suppression or change of destination rather than a shift of trips into the off-peak period (see Gifford & Talkington (1995) for a case study relating to the Golden Gate Bridge).

The majority of trips in the rush hour period relate to travel for either educational (school runs) or employment reasons. On a micro-level the more regimented an employer's adherence to a common start time, the less likely employees of that company/entity will peak spread actively rather than passively.

Conversely employers who subscribe to the concept of alternative work schedules, (AWS, a term first coined by Hagerstrand in 1967), such as flexible working hours, staggered work shifts, working from home, and compressed work weeks, allow employees the option of actively choosing to travel in order to miss the peak period and to incur minimal disutility.

Transportation policy-makers who see active peak spreading as a way of managing highway capacity provision, will more than likely be keen to promote the use of AWS among employees in their cities, and to support Intelligent Transport Systems (ITS) initiatives such as real-time information systems which allow road conditions to be accessed before departure.

Techniques for distinguishing 'passive' from 'active' peak spreading are described by Hounsell (1991) and largely revolve around an examination of the traffic flow in pre-peak intervals or before a link reached capacity. The modelling of active peak spreading raises particular methodological issues that will be explored in Chapter 4.

2.4 What is the Evidence for Peak Spreading?

Incidences of peak spreading taking place are well documented although the major references are often around ten years old. Now the overwhelming evidence is that when the penalty of travelling during the peak hour (either time- or cost-related) becomes excessive, then traffic will spill into the shoulder periods and the peak will spread. In other words proving that 'peak spreading' is a reality is no longer needed. Policy makers are now more concerned with incorporating peak spreading into the appraisal and modelling framework, and assessing how proposed transport initiatives, such as congestion charging or internet-based real-time information systems, are likely to influence patterns of demand.

The occurrence of peak spreading can be directly inferred from either a reducing proportion of trips being in the peak period (which can either be measured directly or indirectly through growth rates), or a demonstration that the busier roads (which are presumed to be more subject to congestion) have a flatter traffic profile through the day. In both cases, part of the observed effect may be due to naturally occurring changes in the peak profile, but the pace of the changes and the widespread documentation of their occurrence suggests that congestion itself can significantly affect the profile.

2.4.1 United Kingdom & Europe

In the UK, the Department of Transport, Local Government and the Regions (DTLR), the research councils, the Universities, and Local Government have all studied the subject extensively. Many of the findings were distilled in Porter et al. (1995). Peak spreading was increasingly recognised as an important phenomenon in the 1980s and early 1990s because congestion levels throughout the country had reached levels that forced motorists to change their driving behaviour. A survey of peak spreading throughout the capital (London) was published in 1989 by Johnson et al. Much of the research to demonstrate the presence of peak spreading took place around this period but more recently research has focused on understanding the factors that influence people to change their journey times and how to incorporate peak spreading within an appraisal and modelling framework.

SACTRA (1994), on the basis of work carried out by the Department of Transport (DOT), now the Department for Transport (DfT), stated that:

> *..... there is evidence to suggest that peak spreading is an important behavioural reaction to changes in road capacity, second only to changes of route.*

The DfT carries out traffic counts on a regular basis across all links on the trunk road network (equivalent to State Highways in New Zealand), and automated counts at select key sites across the country. Porter et al. (1995) cite an unpublished study carried out by Gray (1993) on these data that demonstrates a clear relationship between the volume of traffic (and hence the presumed level of congestion) and the proportion of traffic in the peak period. This is shown in Table 2.1.

Table 2.1 Interpolated median of busiest hour, compared with annual average daily total (AADT) on selected UK motorways, in 1991.

AADT (1000 veh) (traffic volume)	Interpolated median of busiest hour as a proportion of AADT (%)
20-40	9.86
40-60	9.90
60-80	9.83
80-100	9.48
100-120	8.70
120-140	8.58

Source: Porter et al. 1995.

Table 2.2 Traffic increase across a central London cordon, from 1972 to 1993.

am peak (07-10h)	inter-peak (10-16h)	pm peak (16-19h)	All (07-19h)
3%	22%	4%	11%

Times according to 24 hour clock.
Source: Department of Transport (UK DOT 1995).

Table 2.3 Differential growth and peak spreading in Oxford, UK, from 1985 to 1989.

Peak Period (PP)	% Annual Growth 1985-1989	
am peak hour 08-09	0.6	
am peak period 07-10	1.8	
pm peak period 17-18	1.0	
pm peak period 16-19	1.6	
16 hour period 06-22	2.2	
	1985	**1989**
PH/PP am	39.5%	37.7%
PH/PP pm	36.3%	35.5%

PH/PP – peak hour as a percentage of peak period.
Times according to 24 hour clock.

Source: Oscar Faber 1993.

More detailed analysis of the automated data demonstrated that peak spreading was widespread and significant at over half the sites monitored (95% confidence level).

Peak spreading effects have also been monitored on an independent basis in many UK cities including London, Leeds, Oxford, Newcastle, Manchester and Birmingham. In all cases, as traffic volumes have increased, both the longevity of the peak period overall and the volumes within the actual peak hour have grown. The paragraphs below detail the findings in each city.

In London, statistics compiled by the UK DOT (1995), shown in Table 2.2, demonstrates differential growth across a central cordon over a 21-year period (1972-1993). As can be seen, much more growth has occurred in the off-peak periods, implying that little growth in the peaks is possible.

Leeds City Council (2000) monitors traffic flows regularly around the city centre (and the region) and has declared that the peak has spread between 1990 and 2000. The morning peak now lasts 75 minutes compared to only 60 minutes in 1990, while the evening peak has extended from 45 minutes in 1990 to 75 minutes in 2000.

In Oxford (Table 2.3), Oscar Faber (1993) monitored traffic flows on the busy A40 north of the city and also found noticeably higher growth rates in off-peak than peak traffic. This growth resulted in decreasing peak-hour to peak-period ratios over time, i.e. growth was taking place in the peak shoulders rather than at the peak itself. The spread of the peak is less strong or visible in the afternoon period because demand is often more naturally spread in this period. Then school trips usually precede work trips rather than coincide with them as in the morning peak.

Ramsey & Hayden (1995) undertook research into peak spreading in relation to the Tyne Crossing in Newcastle. As shown in Table 2.4, peak spreading was clearly occurring.

Table 2.4 Peak spreading at the Tyne Tunnel, Newcastle, between 1981 and 1991.

Hour ending	Year										
	81	82	83	84	85	86	87	88	89	90	91
07 00	1.7	1.7	1.4	2.2	1.5	1.7	2.2	2.1	2.2	2.3	2.1
08 00	6.9	7.1	5.6	6.2	5.9	6.3	6.9	7.3	7.4	7.5	7.7
09 00	8.5	9.4	9.2	6.9	9.0	9.8	8.4	8.1	7.9	8.0	8.0
10 00	6.9	6.8	7.3	6.0	6.4	7.0	6.6	6.7	6.5	6.4	6.5

Source: Ramsey & Hayden 1995.

Similarly clear evidence that peak spreading was taking place in the Manchester and Birmingham (West Midlands) regions is documented in Stebbings (1988, 1993) and by West Midlands Planning Team (1990).

In Holland, evidence of peak spreading was shown by Tacken & Mulder (1990) who developed a forecasting model that fitted observed data on the basis of Dutch National Travel Survey data, carried out periodically between 1979 and 1988.

Elsewhere in Holland, Kroes et al. (1996) showed that the peak can contract when a bottleneck is removed. The research demonstrated that, when capacity was increased on the Amsterdam ring road, the most significant short-term effect was not extra trips or a diversion from other routes. Instead the major effect was the reversion to departing during the peak hour by those who had got into the habit of leaving slightly earlier or later.

Figure 2.1 shows how, for traffic crossing the North Sea Canal southbound, the proportion of daily traffic occurring in the morning peak period (from 0700 to 0900) increased after the opening of the ring road. This 'reverse' phenomenon of peak contraction is important, particularly in assessing scheme benefits, as will be discussed in Chapter 4.

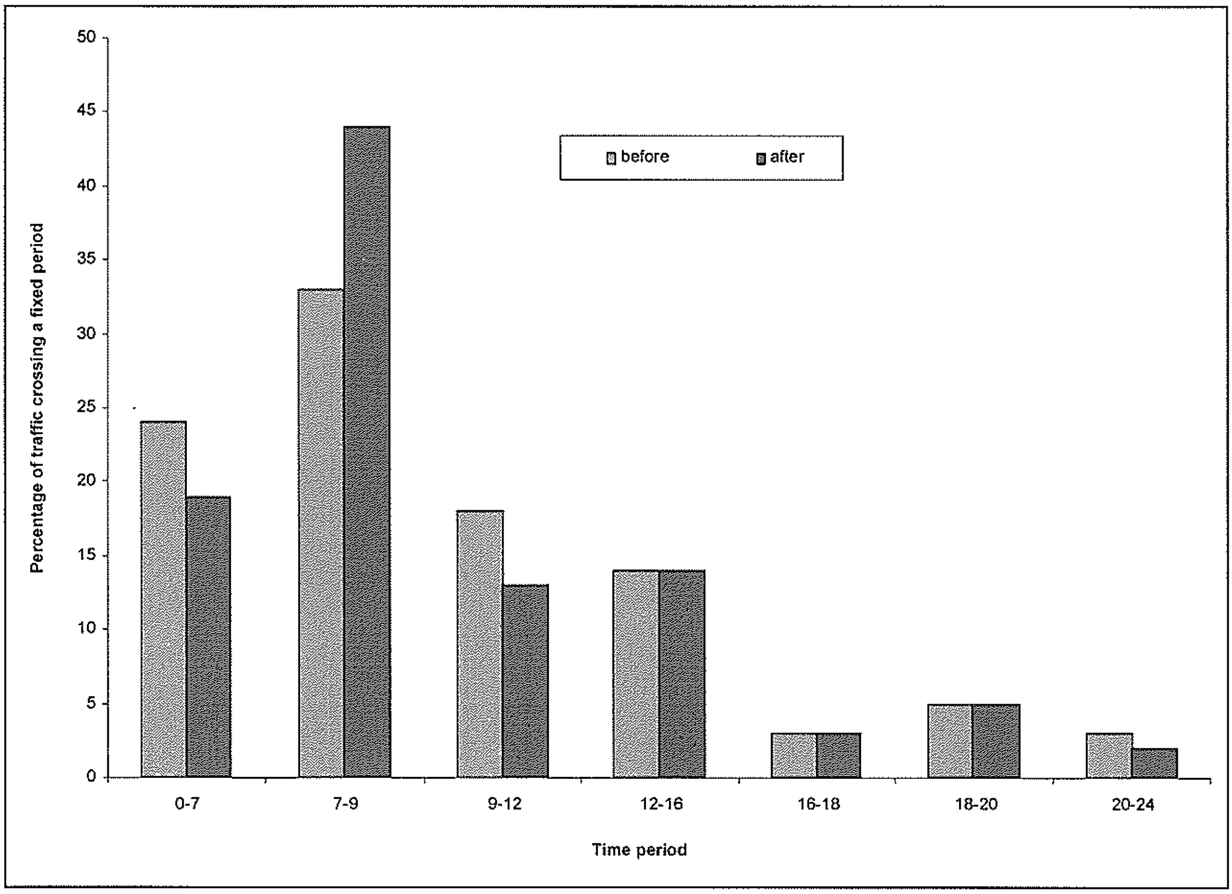


Figure 2.1 Observed changes in crossing time of the North Sea canal.
Source: Kroes et al. 1996.

2.4.2 United States & Canada

Experiences in Europe are also mirrored across the Atlantic and have been well documented. One of the early references on the subject by Gordon et al. (1989), who examined National Personal Transportation Study (NPTS) data in both 1977 and 1983, concluded that:

The Nationwide Personal Transportation Study (NPTS) data for 1977 and 1983 shows very little evidence of peak travel period elongation, so that peak spreading is a poor explanation of the absence of worsening congestion. The peak spreading that occurred was limited to the smaller metropolitan areas where the scope for locational adjustments by households and firms to relieve congestion was much less than in the larger polycentric metropolitan areas. Blue collar and sales workers had more off-peak commutes than other occupations such as professionals, suggesting that institutionalised (i.e. compulsory) work schedules are more effective than voluntary spontaneous *actions. This view is reinforced by confirmation of the well-known household and family restrictions on flexible working hours.*

The key points from Gordon's data are shown in Tables 2.5 and 2.6.

Table 2.5 Peak spreading on urban roads in the US.

City Size (millions population)	Proportion of 24 hour trips % peak hour (peak period in brackets)							
	am peak hour 07-08		am peak period 06-09		pm peak hour 16-17		pm peak period 15-18	
	1977	1983	1977	1983	1977	1983	1977	1983
<0.25	18.19 (0.52)	15.68 (0.48)	34.91	33.03	13.94 (0.44)	10.71 (0.40)	31.76	27.11
0.25-0.50	17.53 (0.52)	12.74 (0.40)	33.96	31.74	13.96 (0.48)	11.95 (0.44)	29.02	26.98
0.50-1.00	15.99 (0.46)	15.68 (0.48)	34.55	32.66	12.60 (0.40)	12.29 (0.41)	31.19	30.28
1.00-3.00	16.23 (0.46)	14.99 (0.46)	35.53	32.86	13.50 (0.43)	13.16 (0.46)	31.23	28.44
>3.00	16.22 (0.47)	13.74 (0.42)	34.86	32.80	14.28 (0.45)	11.84 (0.40)	31.64	29.64

Source: Gordon et al. (1989).

Table 2.6 Changes in peak profiles for two classes of city size, for 1977 and 1983, in the US.

City Size	Peak hour : peak period (am) %		Peak hour : peak period (pm) %	
	1977	1983	1977	1983
<1m	50	45	44	41
>1m	47	44	44	43

Source: Gordon et al. (1989).

However, over the last twenty years, congestion has considerably worsened throughout the US with trip lengths getting longer and trip makers now electing to change departure times. Recent studies demonstrate peak spreading is very much a reality in the US. Individual examples are cited in San Francisco by Purvis (1999), New Jersey by Allen (1991), in Maryland by Levinson & Kumar (1994), in Connecticut by Allaire & Ivan (1999), and in Toronto by Bacquie & Wang (1997). Work carried out by Louden et al. (1988) is cited by Porter et al. (1995), and describes a project which investigated the ratio of peak hour to peak flows at 32 freeway sites in the US. They found evidence of peak spreading at 29 of these sites. It would appear therefore that more recent evidence disagrees with Gordon's (1989) findings.

2.4.3 Australia

In Australia, ACT (1997) documented instances of peak spreading in the John Dedman Parkway Corridor and Environmental Study. Anecdotally RACQ (2000) states that in Brisbane:

> *... inadequate road capacity for traffic demand at peak times on most radial arterials into the CBD .... (are) leading to peak spreading and continual high volumes throughout the rest of the day.*

Figure 2.2, provided by New South Wales Department of Transport (NSW DOT), Transport Data Centre (2001), shows the number of Sydney residents travelling on a weekday in 1991 and 1999. The graph demonstrates an increase in volumes, but these volumes start earlier, and finish later, especially in the evening peak. Correspondence with the NSW DOT indicates that this spread could be due to either a lack of capacity or changes in working habits, but they are unsure what is driving the spread. In addition to the above, the Sydney Harbour Tunnel Environmental Impact Statement as documented in Beder (1991) contained evidence presented by prominent academics in Australia that peak spreading was occurring at certain points in the metropolitan area.

In Adelaide a report by the South Australian Energy Research Associates (1989) goes as far as to debate how the State Government could encourage temporal flexibility in order to encourage peak spreading.

Independent work by Mr R. Bullock (pers.comm. undated) showed the build-up of peak traffic, in the form of peak spreading, crossing Sydney Harbour Bridge in the morning peak. It further demonstrates that contraction of the peak took place when additional capacity was provided by the Harbour Tunnel.

Figure 2.3 shows percentage of traffic on the Bridge by time of day (both directions) for a number of years since 1967. The constrained capacity in the morning peak is clearly seen. At this time, the Bridge was generally operated with six northbound and two southbound lanes. Five of the lanes were generally at capacity (around 2250/hour) with the outermost lane at 1600/hour. The diagram shows that morning peak (0700 to 0900) trips decreased as a proportion of overall trips but this trend was changed in 1994 following construction of the Tunnel.

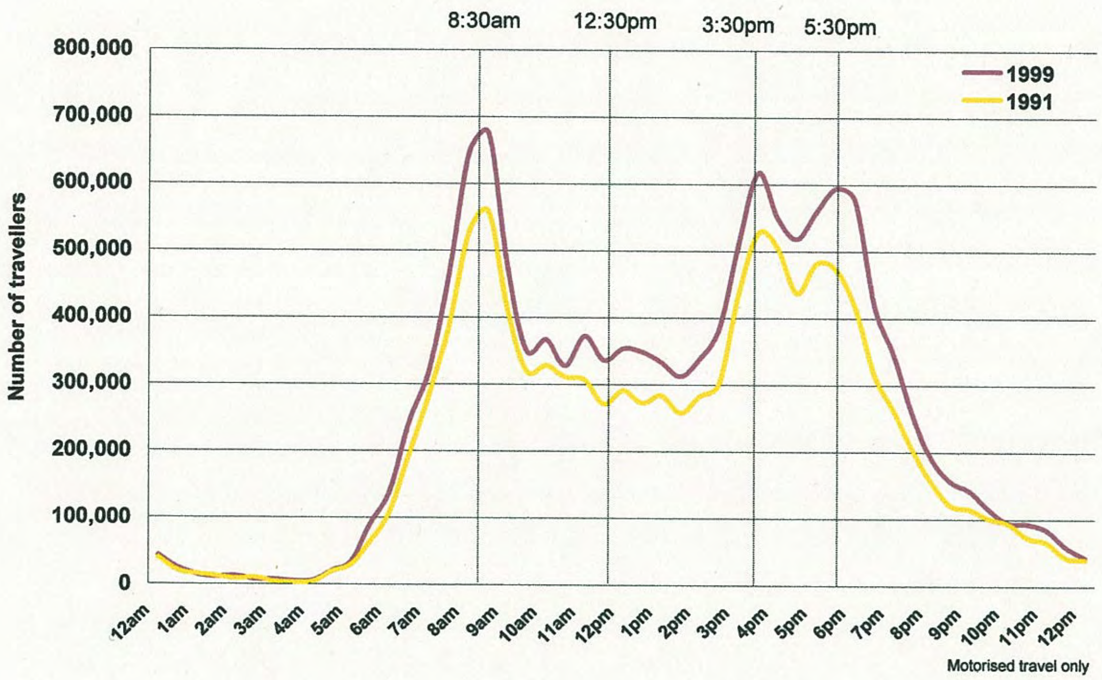


Figure 2.2 Number of Sydney residents travelling on an average weekday, 1991 and 1999, to CBD.

Source: Transport Data Centre (2001).

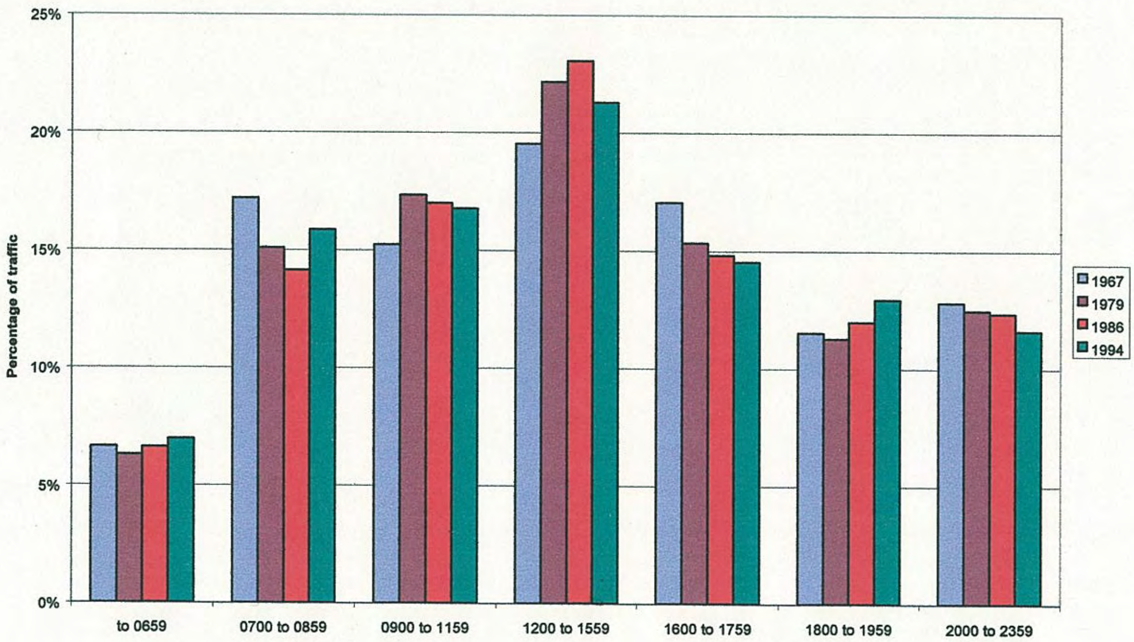


Figure 2.3 Percentage of daily traffic by time of day (over 24 hours), for Sydney Harbour Bridge, for the years 1967 (left), 1979, 1986, 1994 (right column).

Source: Bullock, pers.comm.

3. Traffic Peak Spreading in New Zealand

3.1 Introduction

The level of traffic congestion in New Zealand's two major urban areas, Auckland and Wellington, is such that peak spreading has been discussed in both their Regional Land Transport Strategies (ARC 2001, WRC 1999). Although traffic congestion occurs in other cities in New Zealand, it is unlikely to be sufficiently in excess of capacity that it will cause trips to be re-timed. For the purposes of simplicity only Auckland and Wellington are discussed in this chapter.

A general problem with monitoring the trend in peak spreading in the two cities is obtaining detailed time series data at key locations. Both Regional Councils and Transit New Zealand monitor traffic at certain key sites using a variety of collection methods: manual surveys, telemetric sites and, more recently, ATMS[1] sites. While current data collection and recording is robust, the collection of high quality historic data (from more than 5 years ago) in a consistent format has required considerable efforts, and a number of gaps in the data remain.

A further difficulty is that in most urban situations, measures have been taken to improve capacity, such as the Moveable Lane Barrier on Auckland Harbour Bridge and the Newlands Interchange on SH1 north of Wellington. Experience elsewhere, cited in Chapter 2 (Amsterdam Ring Road, Sydney Harbour Tunnel), indicates that in these circumstances peak contraction can be expected to occur. This was borne out by the Opus study of peak spreading in Wellington (Opus 1997), where the interpretation of users' behaviour over a long period of time was made difficult by capacity improvements.

3.2 Measuring Peak Spreading

The study by Opus (1997) of peak spreading in Wellington identified the Peak Spreading Efficiency Ratio (PSER) as a means of measuring the extent of peak spreading and how it changes through time.

For a given period of time (e.g. 0700 to 0900), the PSER is defined as the ratio
total traffic in period : maximum possible flow in period.

The denominator is calculated as the maximum flow recorded within a shorter interval (e.g. 15 minutes) multiplied by the number of such intervals.

Thus, in a typical urban congested situation:

- for short periods (e.g. 0800 to 0900) the PSER would be expected to be close to 100% (i.e. there is no spare capacity);

[1] ATSM Active Traffic Management System

- as the period of measurement becomes longer, for a given year, the PSER gets smaller;
- when the rate of change of the PSER from year to year is zero, no further peak spreading is possible within that period.

These points are illustrated in Section 3.3 in relation to Auckland.

Also the PSER is similar to measures which have been used to model and forecast the extent of peak spreading. This subject is addressed in Chapter 4.

Typically these studies look at a period (e.g. 0630 to 0930) outside which peak spreading is unlikely to occur and measure the ratio:

Volume of traffic in busiest hour : volume of traffic in 3 hours.

While the numerator in this ratio will remain roughly constant because of capacity constraints, the denominator will increase over the years because of increasing traffic volumes in the peak shoulders. Hence over time, the ratio will decrease. Historic data can be used to determine the rate of this decrease and projections for the future can be based on this.

3.3 Peak Spreading in Auckland

3.3.1 Background

Auckland Regional Council (in its Auckland Regional Land Transport Strategy (ARLTS 2001) notes that the Auckland metropolitan area is low density by international standards, with a dispersed population. This has contributed to Auckland having one of the highest car ownership rates in the world. The capacity of the existing road network is constrained partly by geography and partly by cost issues, and these contribute to the high levels of traffic congestion currently experienced in Auckland during the peak period.

According to the Auckland City Council (2000):

> *....as the capacity of the corridors is reached especially during the peak period, travel behaviour changes. One of these changes may involve travelling to work earlier or later to avoid the congestion. This results in the spreading of the peak period, potentially creating congestion outside this time....... Due to the limited capacity of the city's roads and the growth in vehicular traffic, there is evidence from traffic monitoring that the traditional peak periods are being extended. This is known as peak spreading and in some corridors the peak periods are longer than two hours.*

3.3.2 Analysis of Auckland Traffic Data

Analysis of peak spreading based on historic traffic flow data on key radial roads leading into the Auckland CBD was not possible as:

- no data for a single month was available for comparison over a number of years;
- data was not sufficiently disaggregated (e.g. into quarter hour periods) in order to carry out meaningful analysis.

Only one site was possible to look at in detail: Auckland Harbour Bridge (AHB) but, while the data for it had been available since 1990, again gaps in the data made comparing a particular month over a number of years difficult.

The AHB is one of the worst bottlenecks in Auckland and hence not representative of the network as a whole. Thus, if peak spreading is occurring on the AHB, the same can be expected to be happening elsewhere in the city, even if variables such as the length of the peak are different from place-to-place.

3.3.3 Results

Figure 3.1 shows the flow profile of southbound traffic volumes across the AHB for an average weekday between 5am (0500) and 11am (1100), in quarter-hour intervals. For the most part, the data relate to weekdays in May, but for 1999 and 2002 data from adjacent months have had to be used. While the data are not easy to interpret in this form, in general the peak can be seen to start earlier and finish later if later years are compared with earlier ones. Even at this level of aggregation, there is clearly considerable statistical noise, and an overall conclusion is not easily reached. The picture is also clouded by the introduction, around 1995, of the moveable lane barrier.

The effects of peak spreading can be seen more succinctly in Figure 3.2, which shows the PSER since 1990 for one-, two- and three-hour periods. Smoothing has been used to reduce the effects of noise and present the outcome more clearly. Given that a PSER >95% effectively represents capacity, a number of conclusions can be drawn:

- for the one-hour period 0730 – 0830, traffic had been at capacity levels since before 1990;
- for the two-hour period 0700 to 0900, capacity was reached in the mid-1990s, and certainly no spare capacity exists now;
- the PSER for the three-hour period 0630 to 0930 has increased from 80% – 85% in 1990 to around 95% now.

While the rate of growth of the 3-hour PSER is slowing, clearly within a few years effectively no spare capacity will be available on AHB southbound lanes between 0630 and 0930.

The figure demonstrates graphically that peak spreading is occurring, supporting anecdotal evidence. Measures to increase supply or reduce demand, such as the North Shore Busway, would appear to be the only alternatives to the peak spreading even further.

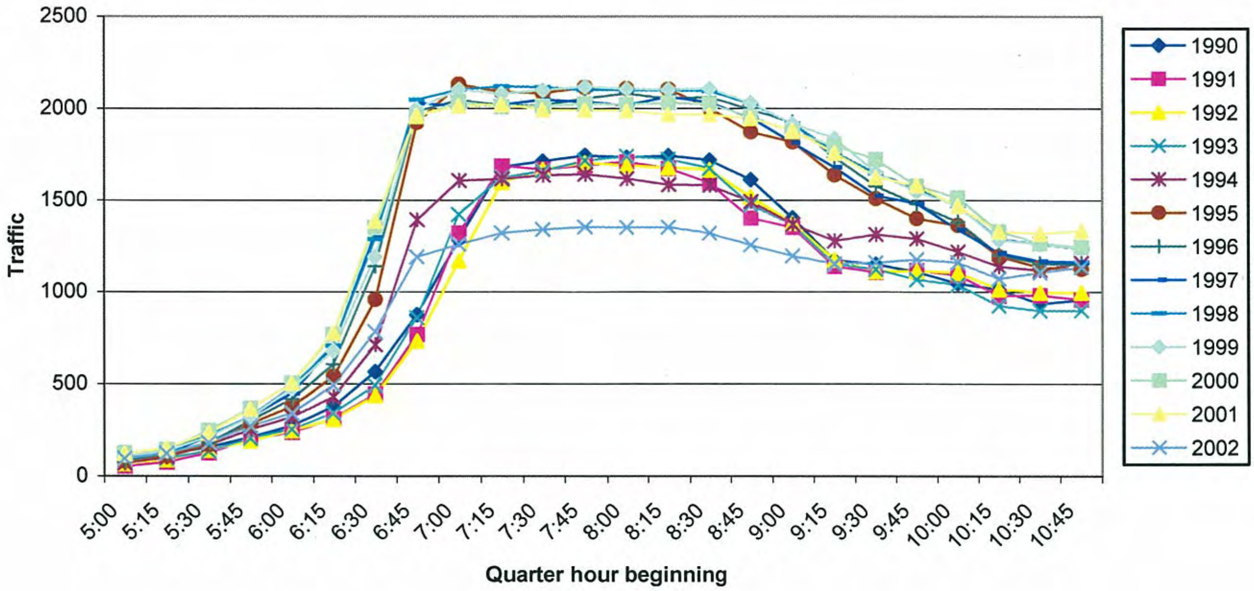


Figure 3.1 Auckland Harbour Bridge weekday average traffic for the month of May in years 1990 to 2002.

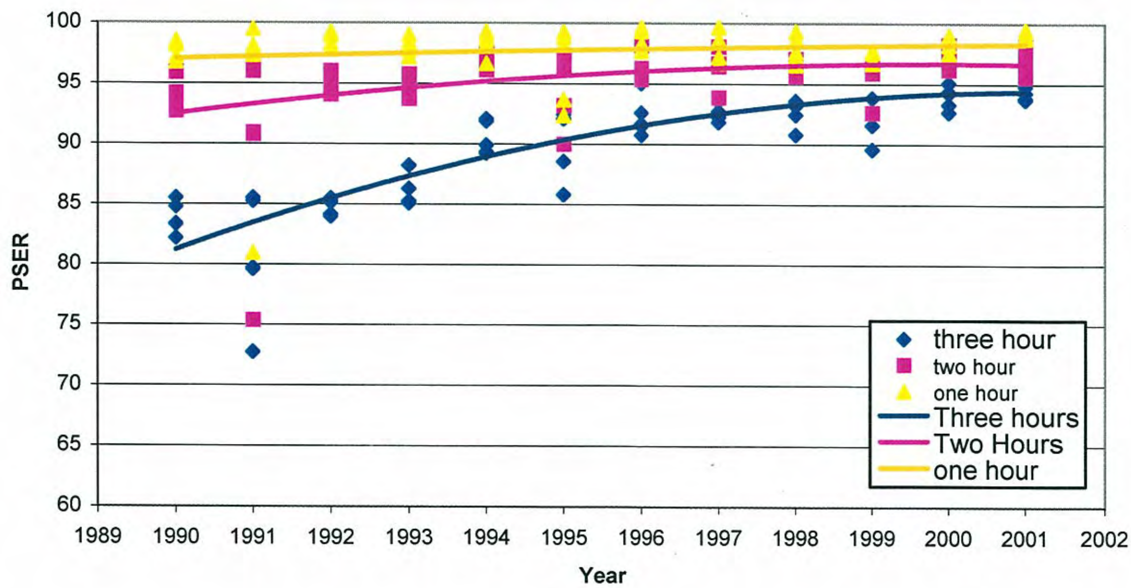


Figure 3.2 One-, two- and three-hour PSER values (smoothed) for the Auckland Harbour Bridge, for years 1990-2002.

3.4 Peak Spreading in Wellington

3.4.1 Background

Wellington differs from Auckland in that its more compact central business district attracts a large proportion of commuter trips by public transport. Congestion is by no means as acute as Auckland, but is noticeable in peak periods particularly around the convergence of State Highways 1 and 2 on the city centre approach. For a synopsis of transport in Wellington see Wellington City Council's Transport Strategy (1994).

3.4.2 Previous Studies in Wellington

The most detailed work on peak spreading undertaken to 2002 was carried out by Opus Consultants (1997). Opus examined traffic flows at three points on the state highway network: SH2 Petone to Ngauranga Gorge, SH1 Johnsonville Bypass, and SH1/2 Ngauranga interchange. Using an extrapolative forecasting method, they then estimated at what point in the future the peak would spread from one hour, to two and three hours, in the morning peak period. Particular attention was given to deriving the Peak Spreading Efficiency Ratio (PSER).

Anecdotal evidence suggested that data collection problems affected the final results of the studies and network improvements also masked the results. Based upon the data used, Opus predicted two-hour peaks occurring around 2004, and three-hour peaks around 2012, but in their recommendations the consultants expressed caution about the robustness of their predictions. They concluded:

> *.....it is recommended that Wellington Regional Council discuss with Transit New Zealand a strategy aimed at collecting a greater quantity of reliable data (at key sites) .... The analysis of peak spreading is potentially a very valuable planning tool, however a lack of data and the questionable quality of the available data have seriously limited the depth of this analysis.*

Another piece of work was undertaken by Booz Allen & Hamilton (1999) on the effects of improvements to the Newlands Interchange flyover on SH1, which were fully opened in June 1998. A fully grade-separated interchange replaced a signalised 'T' junction, so a significant increase in capacity was achieved. Evidence collected during the study indicated that a reduction of 5-10 minutes in peak journey times had been achieved between the CBD and locations to the north of the interchange (including Newlands itself) as a result.

The objective of the study was to survey morning peak period travellers on SH1 into Wellington CBD in order to ascertain their response to the improvement. The survey questions covered:

- changes in travel time;
- variability of travel time;
- timing of trips;
- re-routeing.

Of the respondents surveyed 29% took advantage of the reduced congestion to leave home later and arrive at work at the same time as before. In other words as a result of capacity improvements the peak contracted. The study does not explain whether those who did not re-time their trips received any other benefits, for example arriving earlier but then leaving earlier in the evening.

A summary of the results of the Newlands survey is given in Table 3.1. The phenomenon of peak contraction, which (as described in Chapter 2) has been observed at the aggregate level elsewhere, can be seen here at the individual, behavioural level.

Table 3.1 Adjustment of trip timing into Wellington CBD after Newlands Interchange was opened (1998) (number and % of respondents).

Travel Timing	Whitby		Tawa		Newlands	
	No.	%	No.	%	No.	%
Arrive same time, traffic faster	20	37.7	12	22.6	13	24.5
Depart same time, traffic faster	24	45.3	29	54.7	17	32.1
Traffic less congested, travel preferred time	3	5.7	2	3.8	1	1.9
Traffic more congested, adjust time to avoid	0	0.0	2	3.8	8	15.1
No re-timing	6	11.3	8	15.1	14	26.4
Total	53	100.0	53	100.0	53	100.0

Source: Booz Allen & Hamilton (1999).

3.4.3 Analysis of Wellington Traffic Data

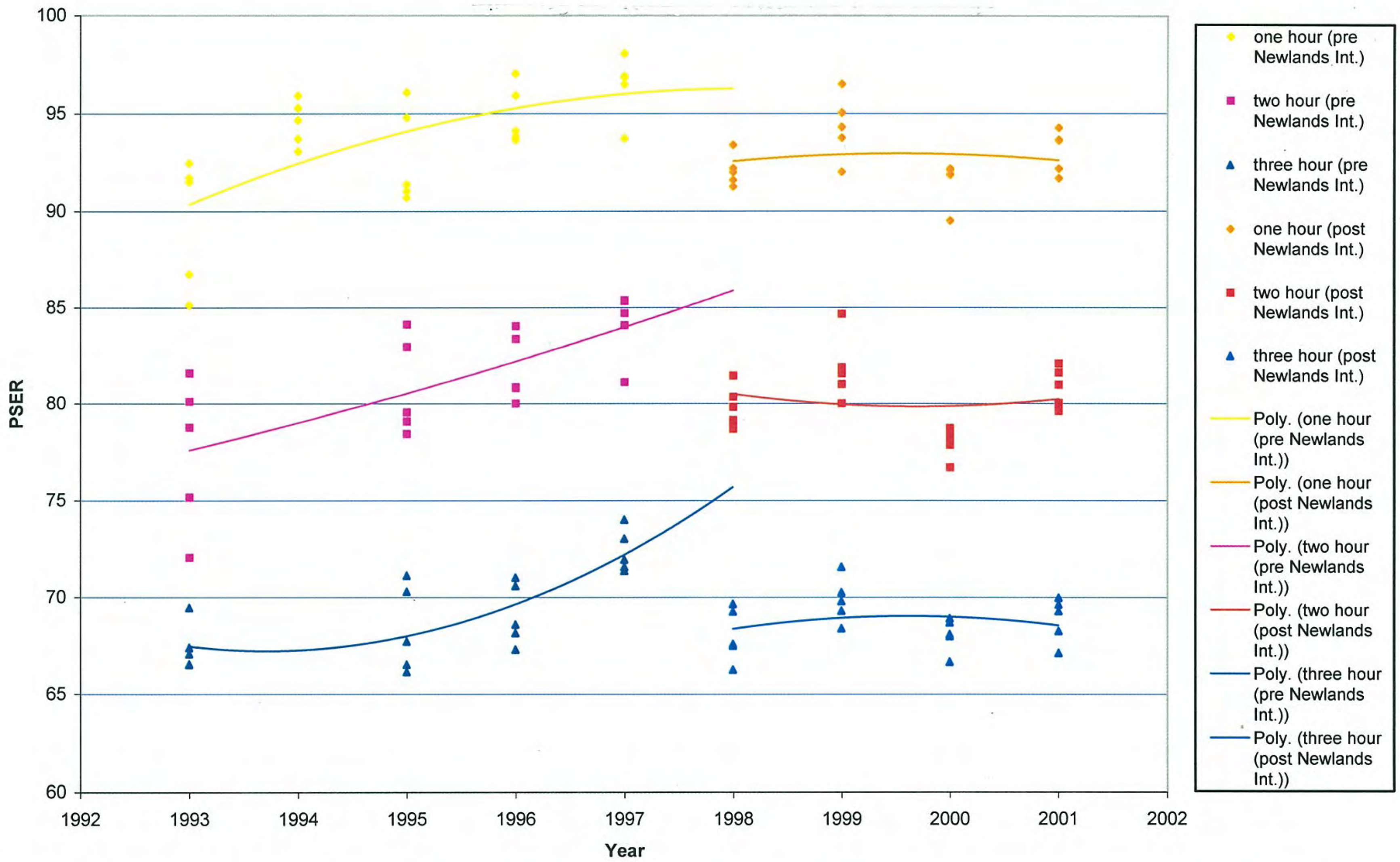
As in the case of Auckland, comprehensive historical data stretching over a reasonable number of years proved to be particularly elusive. Even at the single most important site, SH1 just north of the merge with SH2 (at the bottom of Ngauranga Gorge), Wellington, considerable effort was necessary to produce a useable data set.

The PSER at the SH1 site has been computed for the years 1993 to 2001 (inclusive) for 1-, 2- and 3-hour periods. The Opus study showed a discontinuity in the PSER when capacity is increased, and the results of the Newlands survey (see Section 3.4.2) also suggested that the opening of the interchange would have an effect on peak spreading.

The data was therefore split into two sets of years: up to and including 1997, and 1998-2001. Smoothing for the two sets was done separately, although this considerably reduced the number of data points in each set, so thus the margin of error will be greater.

The outcome is presented in Figure 3.3 which, for each time period (1, 2 and 3 hours), shows the smoothed PSER in two sections, pre- and post-Newlands. As far as a comparison is possible, the figures agree with the results of the Opus study (1997).

Figure 3.3 One-, two- and three-hour PSERs for Ngauranga Gorge, Wellington, showing the effect of opening (in 1998) the Newlands Interchange.



The following conclusions can be drawn:

- the Newlands interchange caused a 'lag' of perhaps 3-4 years in the growth of peak spreading, whichever period (1, 2 or 3 hour) is used for the PSER; i.e. the value in 1998 is similar to what it was around 1994/5;
- after approaching unity in 1997, the 1-hour PSER is now close to 1 again (another consequence of the above);
- the 2-hour PSER has remained in the range 80-85% since 1995, with a generally upward trend but a drop related to opening of the Newlands Interchange;
- similarly, the 3-hour PSER is in the range 65-75%.

Comparison with the Auckland data in Figure 3.2 confirms that congestion, as measured by the PSER, is much greater in Auckland than Wellington. In the latter the 1-hour PSER is currently around 95-100%, whereas 100% PSER was reached in Auckland before 1990. The 2-hour PSER, which in Auckland has been close to 1 since 1996, is only now around 85% in Wellington. The 3-hour PSER presents a similar picture.

4. Modelling of Peak Spreading Effects

4.1 Introduction

As shown in Chapter 3, peak spreading is well documented and of concern to both the transport planner and the policy maker. A number of countries, with most action apparently in the UK, are taking steps to allow for it in evaluations of urban roading schemes. Otherwise ignoring the effects of urban roading will distort the cost/benefit profile of new schemes. The two ways in which this can happen are:

- Failure to allow for peak spreading in the 'Do Minimum' option will exaggerate the forecast level of congestion.
- Similarly, not taking account of the converse effect of peak contraction in the scheme option will understate the level of congestion.

In either case the gap between the Do Minimum (Do Min) and the scheme options will be narrower if peak spreading/contraction is included and the congestion-related benefits will be less. This is illustrated in Fig 4.1.

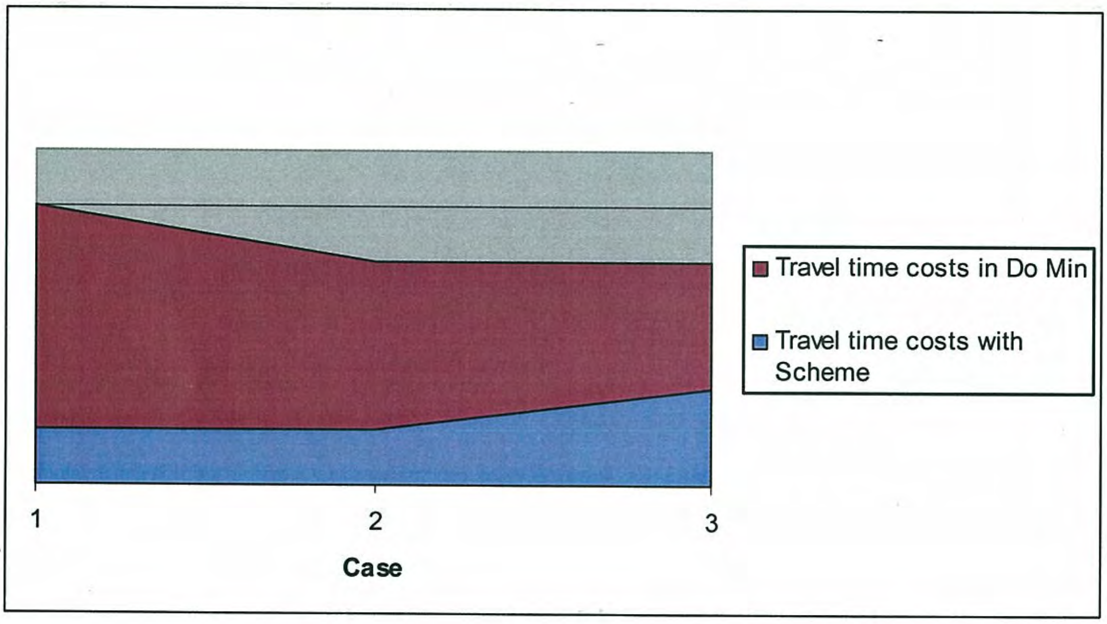


Figure 4.1 Effect of peak spreading and contraction on the benefits of urban roading schemes, based on total costs of travel time for 3 cases.

Travel time benefits are the difference between the Do Minimum and the scheme in the forecast year. Case 1 illustrates the 'conventional' approach, with no peak spreading or contraction. In Case 2, peak spreading has been allowed for in the Do Minimum, thus reducing the forecast travel time costs and hence the benefits. Case 3 then takes further account of the impact of peak contraction with the scheme. It is clear that the congestion-related benefits in Case 3 are less than in Case 1, although the extent of this will vary with the specific scheme.

Current evaluation procedures, however, do not take account of any disbenefit incurred by travelling at a time other than the preferred one. This would add to the benefits of the scheme.

The traditional modelling approaches used to evaluate schemes do not easily lend themselves to the inclusion of temporal trip variations. A number of current modelling developments are trying to address the issue.

An article in *Local Transport Today* (1998) underscores the above argument, claiming that the majority of existing traffic models, by ignoring the phenomenon, over-estimate forecasts of peak hour queuing and delays, therefore magnifying the congestion reducing benefits of new road schemes to existing users. The inclusion of peak spreading into the modellers' toolkit and in turn into scheme evaluation is therefore critical if Governments are to provide appropriate and affordable levels of road capacity.

Allen (1991) goes further and cites a common allegation levelled at transport planners:

> *........planners are often accused of ignoring a simple rule of transportation systems: demand cannot exceed capacity for a given period. As a theoretical illustration of travellers' desire to use a particular facility, volume : capacity ratios over 1 can be useful. However, design-hour volumes in excess of capacity have no basis in reality.*

Against this, it could be argued that a volume:capacity ratio greater than 1 is a modelling representation of demand in a given period exceeding capacity, resulting in queuing at the end of the period.

Following a review of how peak spreading fits into the usual modelling framework (Section 4.2), the latest research relating to the behavioural aspects that underpin peak spreading is synthesised in Section 4.3, and assesses whether or not the findings can easily be represented analytically. The last Section 4.4 then describes current modelling options for peak spreading and how successfully these have been applied in different countries.

4.2 The Four Stage Model

Since transport planning was first practised in the late 1950s, the convention has been to represent trip-making as a four stage process. The stages are:

- Trip generation: the number of trips attracted and generated in each modelled geographical zone, depending on economic factors such as number of households and level of employment.
- Trip distribution: establishing the origin–destination pattern of trips, depending on the 'attractiveness' of the zones and the cost of travel between them.
- Modal split: the choice between private and public modes and possibly also sub-modes such as bus or train.
- Assignment: the choice of route, given a particular pattern of trip movements.

Of these, assignment is almost always used as it is the basis for forecasting the level of traffic which can be expected on the different parts of the network. Depending on local factors, such as data availability, and study budget, other stages are often omitted. Where they are included, usually an element of iteration is incorporated or (in more recent studies) stages are performed simultaneously. Time-of-day choice, which is what drives peak spreading and contraction, is conspicuous by its absence.

Notwithstanding the 'traditional' approach, recent evidence of peak spreading and its impact is leading to a much increased emphasis on the time-of-day aspects of the decision process as discussed elsewhere in this report. It is summed up well by the UK DTLR (1997) (emphasis added by Booz Allen Hamilton):

> *Departure time choice is an important, and in practice too often ignored, element in the demand model process. Empirical evidence indicates that,* ***after re-routeing*** *(assignment),* ***trip re-timing is the most likely response to changes in network costs.***

While this omission is now being addressed, the development of modelling approaches is still in its infancy relative to the other stages, and their application is almost non-existent. The issue is made more complicated by the fact that it is now considered most robust to model time-of-day choice as part of the route choice or assignment stage.

4.3 Behavioural Research Underpinning Peak Spreading

Bates (1996), in his appraisal of time-of-day choice modelling, summarises the research that has been carried out into what actually causes peak spreading to take place, i.e. how people respond to congestion. A summary of that research by various authors follows in Sections 4.3.1 – 4.3.6.

4.3.1 Study by Small (1982)

The first major investigation into why people switch travel times was undertaken by Small (1982) in the San Francisco Bay Area. Small made use of a well researched sample of 527 car commuters who each reported their preferred and actual arrival times. In all cases respondents had an official work start time. Using network-based observations, supplemented by some observations from cars in the traffic stream, travel times were estimated for 12 intervals of 5 minutes each. The first eight slots represented early arrival, the ninth on-time arrival, and the remaining three late arrival. Coefficients for the choice model (multi-nominal logit) were estimated by assuming a discrete choice among the twelve possible arrival times grouped around the official start time.

According to Bates (1996), the resulting model coefficients imply that the disutility per minute of early arrival is equivalent to 0.61 minutes of in-vehicle travel time. Therefore people are willing to be 10 minutes early to save 6 minutes of travel time. For late arrival the corresponding value is 2.4. In addition an implied penalty of 5.5 minutes of travel time is incurred for late arrival *per se*. More detailed specifications suggest that the late parameter may be more significant once lateness exceeds a selfreported flexibility level. This bears out what one would consider intuitive, in that people are generally more willing to arrive at work early to save travel time, while lateness is an option but only up to a certain threshold.

No other work has been found which attempted such a revealed preference-based approach. However, several notable exercises have been carried out using stated preference techniques.

4.3.2 Study by Mahmassani & Chang (1986)

Mahmassani & Chang (1986) built a simulation model to estimate arrival times at a central work location, with speed being a function of volume and capacity. To generate an arrival time for each respondent a real time experiment was set up with 100 volunteers, each of whom was taken as representative of the 20 vehicles on the network. These respondents were assigned to various origins, told the free flow speeds and asked to choose their departure time, given a fixed work start time. On subsequent days all participants were informed of their simulated arrival times on the previous day and asked to reconsider their departure times. This was repeated until no one changed their departure times (which took around 25 days).

Rather than analysing the data on the basis of utility maximisation, Mahmassani & Chang postulated that respondents would stop shifting once they were indifferent to their preferred arrival time. The aim of the analysis was to predict the width of this band of indifference. This band represents the range at which the respondents' maximum utility is consistent.

According to Bates, this exercise, while useful, did not fulfil its potential because it did not identify the reasons behind the indifference band, i.e. no schedule-disutility function was developed that could identify the indifference band.

4.3.3 TRRL Study (Bates et al. 1987)

Bates et al. (1987) described a more conventional study carried out by TRRL, that collected detailed information about the circumstances surrounding 350 drivers' journeys to work, with a particular focus on journey time variability. In terms of possible changes in departure and arrival times, the questionnaire asked about possible constraints at both home and workplace so that the respondent could be reminded of them in subsequent decisions.

The emphasis in this study was journey time reliability, so little analysis of shifts in departure times was carried out. Bates, and Polak in 1996 (unpublished), re-analysed the data and demonstrated that people seem more willing to shift their departure time to avoid lateness, rather than shift their arrival times, bearing out Small's findings.

This analysis went further by showing that segments of the commuting market are constrained in terms of arrival time, departure time, or both. Peak spreading by definition occurs more when the traveller is freer to choose not to sit in traffic. This will not be the case for all parties, and therefore schedule disutility will vary with the number of constraints.

4.3.4 Price-related Stated Preference Studies

Given that preferred arrival times (PATs) are traded off against travel time, within a constrained environment, they can also be traded off against cost. This supports the theory behind road space charging schemes, in that users will trade off time, cost, reliability and a variety of other factors.

Bates et al., in 1990, looked at this issue in the Netherlands in relation to road pricing. Journey time shifts were related to changes in both travel time and cost. After some experimentation the schedule utilities seemed in most cases to be linear in the amount of the shift. Travellers were loosely categorised as arrival- or departure-constrained on the basis of their responses to a set of questions. Commuters in the morning peak period were largely shown to be arrival-constrained (conversely leisure activities in the afternoon peak were largely departure-constrained).

The report concluded that:

> *In the morning travellers who must arrive by a certain time are much more reluctant to travel later and effectively regard travelling x minutes later to correspond to an increase of x minutes in their departure time ...... in the afternoon leaving arrangements are generally more flexible ...... are quite prepared to make quite large negative (time) shifts to save a minute of journey time.*

More detailed analysis of the coefficients obtained elicited the comment:

> *In many cases there was a tendency for the schedule utility per minute of shift to increase with the size of the existing travel time and the centre of the peak. Thus for example persons already travelling before the centre of the peak were much more reluctant to shift earlier by one minute than were those currently travelling in the centre of the peak .... Cases were also found where a shift in the direction of the centre of the peak yielded benefit per se ... implying that the utility from shifting travel times in a given direction need not be monotonic (one way) – it needs to be related to the preferred arrival time.*

Work carried out by Polak et al. in Trondheim (1991) and by Polak & Jones in London (1994) reinforced the above findings.

4.3.5 Study by Arnott, de Palma & Lindsey (1969)

Arnott et al. (1969) took a different approach, extending the work of Vickrey (1969) and assuming, on the supply side, a bottleneck formulation involving a deterministic queuing formula for travel time delay, so that delay on arrival at the queue is directly proportional to the length of the queue. The length of the queue is in turn determined by the departure profile and the level of demand. A single origin, destination and route were assumed with time being treated as continuous.

The work in effect provided a theoretical underpinning for peak spreading. The final model obtained demonstrated that the difference between the longest travel time and the free flow travel time is directly proportional to the total demand relative to capacity. This means that, as total demand increases, the maximum travel time increases and the length of the congestion period expands.

In 1992, Small introduced an element of constraint to his framework, by assuming a bottleneck formulation on the supply side. This demonstrated that the earliest arrival time is earlier than the first desired arrival time by an amount proportional to the difference between the feasible arrival span and the desired arrival span. This means that, as the gap between when a trip maker would like to arrive and can arrive gets wider, more people begin arriving earlier.

4.3.6 PATSI model (Polak & Han 2000)

While preferred arrival times (PAT) seem to hold the key to the phenomenon of active peak spreading, their collection is difficult. The latest model developed to overcome this is the Preferred Arrival Times Synthesized by Imputation (PATSI) model developed at Imperial College London by Polak & Han (2000).

The approach taken in PATSI is to infer PATs from actual arrival times (AATs) by means of a simple theory linking the two which results in an explicit relationship between PAT and AAT. The statistical estimation of the parameters of this relationship is based on data from one of the few UK studies in which both AAT and PAT information was collected. Once the parameters have been calibrated it is possible, using a sample of AATs, to calculate the associated PATs.

4.3.7 Summary

The above discussion highlights the basis of understanding peak spreading, of how trip-makers compromise their preferred arrival times in order to save travel time. Generally speaking most trip-makers are indifferent between early arrival and being on time, but late arrival causes more concern. The degree to which a user can modify their behaviour is a function of a number of personal or road constraints. Uncertainty is a key factor in the behaviour because, in conditions of certainty, very little shifting from preferred arrival times would appear likely to take place. The work of Small (1992) shows how, in highly constrained uncertain conditions, people will begin to start arriving much earlier at the workplace to avoid lateness. Put simply if there is a high likelihood of being fired for lateness (or failing to catch a plane or whatever) and we are unsure of the traffic delay to be encountered, then we will leave home much earlier for psychological comfort, thus increasing the probability that we will arrive early.

The above raises questions concerning the current methods by which travel demand is modelled. Using PATs as the basis for trip timing is a radically different approach from conventional transport modelling methods, and the data collection requirements would also need to shift from a basis of unconstrained to constrained travel. Modelling would need to take place at a very disaggregate level and the data required to calibrate the model would be difficult and time consuming to obtain.

Difficulties associated with transferring the above research into analytical models are discussed in Section 4.4.

4.4 Current Modelling for Peak Spreading

4.4.1 Translating Research Findings into Analytical Models

A Round Table Discussion Group organised by consultancy MVA in the UK came to the conclusion that:

> *Although it may be intuitively reasonable to discuss route and time of day shifting in the same breath, we note that route choice is a standard tool of transport modellers while time-of-day choice is in its infancy.*

SACTRA (1994) stated that:

> *One response that may require different treatment in the appraisal of traffic reduction mechanisms is the choice of when to travel...traffic reduction mechanisms can be designed to specifically encourage time shifting ... and as a result may have more substantial effects on time of travel than many other interventions ... ... this requires a more important change of emphasis in the modelling of certain measures ... in the case of infrastructure schemes the most important question is to what extent will micro-time shifting or peak contraction or spreading occur? We are aware that techniques to represent this kind of effect are under-developed and that the Department [DTLR] currently has research into them in hand.*

A clearer understanding why peak spreading takes place, as described above, has not yet filtered through into a more accurate modelling of the process. Computational difficulties and the temporal nature of the modelling process appear to be at the forefront of the reasons. *Local Transport Today* (1998) highlights two key problems:

- Many theoretical models relate to a single link whereas urban networks can contain thousands of links.
- The modelling of micro-effects requires time slices of five minutes or less whereas many conventional assignment packages average the driver behaviour over a 1- or 2-hour period.

The US Department of Transportation (1994) offers a solution to the dilemma posed by Allen (1991) – that volume cannot exceed capacity – by advocating the use of dynamic assignment that changes as the capacity is reached. This can be done using a dynamic assignment procedure but again this is as yet impossible for large network models.

John Bates (pers.comm) of the UK DLTR is of the opinion that it will be some time before software is available that can accurately model micro-shifting within acceptable run times. That said, attempts have been made to incorporate peak spreading in scheme evaluation, and these are described in Sections 4.4.2 – 4.4.4 with a particular focus on the UK and the US.

4.4.2 United Kingdom Modelling

While computational issues are being resolved, in the interim the DfT has taken the view that it is better to represent peak spreading in a simple fashion than to assume a fixed profile that, in effect, ignores it.

The UK Department of Transport *Design Manual for Roads and Bridges* (1997) offers an overview of potential methods for modelling peak spreading. They include:

- Creating uniform relationships between the proportion of peak period traffic that occurs in the peak hour and an index of peak period traffic growth (similar to the PSER described in Section 3.2).
- Calculating the relationships between the ratio of flows in the two half-hour periods adjacent to the peak to the flow in the peak hour itself – peakiness factor – and the average traffic speed.
- Count-based methods to estimate the relationship between peak flow and peak period flow using the volume to capacity ratio as an explanatory variable.
- Proportionate models using stated preference techniques to determine the proportion of drivers who would set off earlier to avoid specified levels of congestion.
- Incremental logit models of departure time choice, which rely on changes in travel costs to govern the spread of demand over the peak period.

The manual does not advocate a particular method and each technique has drawbacks and advantages. The resulting forecasts can also differ between techniques. According to Van Vuren et al. (1995), count-based models are easier to apply, with incremental logit models the most 'elegant'. However it is acknowledged that each technique has its drawbacks.

In the UK and continental Europe, these methods have been applied with varying degrees of success. The Greater Manchester Transportation Unit (GMTU) used the derived relationship between the percentage of overall peak traffic occurring in the peak hour and the daily or peak period traffic growth (Stebbings 1988). The Hague Consulting Group's Netherlands Transport Model was one of the first large scale models to include a behaviourally based time-of-day choice (Daly et al. 1990). Halcrow's Contram model for Aylesbury in the UK also included a peak-spreading component (Halcrow Fox 1999, DTLR 2002).

The latest thinking on the subject from the UK has only emerged within the last few months and is the outcome of a wide-ranging study commissioned by the Government. The resulting model is called HADES: Heterogeneous Arrival and Departure Times based on Equilibrium Scheduling Theory (DTLR 2002).

Many previous models have approached the departure time process as a discrete one. For example the choice may be between travelling in two different time periods (0700 – 0800 or 0800 – 0900, peak or off-peak). However, with certain simplifying assumptions the problem can be approached as a continuous time process.

With the HADES approach, travellers choose their departure time in order to minimise a generalised cost which has two components:

- travel time, as in 'conventional' assignment models;
- schedule delay, the difference between a traveller's Preferred Arrival Time (PAT) and their actual arrival time (AAT).

Further advantages of HADES are:

- network costs can be derived computationally (e.g. from assignment);
- it allows for a PAT indifference band (e.g. the traveller is prepared to arrive between 0850 and 0900);
- different user classes (e.g. with different sensitivity to delay) can be accommodated.

A number of early applications have been reported, using models of two middle-sized UK towns and a number of software platforms. As would be expected, the models are data hungry but this can be overcome to some extent with PATSI, which allows Preferred Arrival Times to be inferred from readily available traffic data (see Section 4.3.6).

4.4.3 United States Modelling

Another good synopsis of ways that the current modelling techniques can accommodate temporal responses to congestion, and their drawbacks, is offered by the US Department of Transportation (1997) Travel Model Improvement Program which describes how time-of-day assignment can be incorporated into the traditional four-stage model of generation, distribution, mode choice, and route assignment. More innovative approaches are also detailed which are also found in the UK DTLR's (2002) suggestions:

- Link-based peak spreading – diverting trips to the shoulders (used in Arizona by its State Department of Transportation (1988), outlined below);
- Trip-based peak spreading – spreads the number of trips for a given origin–destination (OD).

All these methods, and others, have been used with some degree of success in various appraisal projects. As early as 1988 the Arizona State Department of Transportation developed a model to estimate peak spreading using historical data from 49 freeway and arterial facilities in Arizona, California and Texas. A functional relationship was developed between the volume to capacity ratio and the peak hour factor (i.e. the ratio of traffic volumes in the peak hour to the traffic volumes in the three highest hours).

More recently in the US, Cambridge Systematics (1999), who undertook much of the above work in Arizona, reduced the peak hour trip pattern to reflect network capacity constraints. Selective reduction, rather than global reduction, was used in order to keep volumes in road corridors realistic. This method was used in work carried out for Boston's central artery/tunnel project for the Massachusetts Highway Department.

In Phoenix, Arizona, the same company used a peaking factor function for each road link to estimate revised travel times during the assignment procedure. This apparently resulted in "*significantly more realistic estimates of future traffic volumes and speed on congested highways*".

Purvis (1999) documents a model developed for the San Francisco Bay area by the Metropolitan Transportation Committee (MTC). In this, two modelling approaches to spread the peak were attempted. First, the use of traditional peaking factors to convert daily non-work trips into peak period vehicle trips. The complication that arose here however was that often excessive traffic levels were pushed into the shoulders of those peaks resulting in peak speeds in excess of those found in the shoulder periods. The second method was the use of a multinomial departure time choice model that has the peak, the shoulder and other hours of the day in a three-alternative model.

The Dulles Corridor Transportation Study (Dulles Transit 1997) used an interchange-based logit model that used congestion as the independent variable, with the data being stratified by purpose. Allen (1991) used a Poisson model to analyse peaking at the link level in New Jersey. The trip spreading method described by the US DOT (1997) was used in Contra Costa County, California, and in the Central Artery model in Boston.

More recent work (Van der Zijpp & Lindveld 2001) proposes an approach similar to HADES, in which departure time choice is modelled simultaneously with route choice. The paper avers that departure time choice can be viewed as route choice in a suitably defined hypernetwork, with the 'conventional' trip matrix further broken down by preferred departure time. A method for estimating the demand matrix that will reflect PATs is proposed. The mathematical problem arising from this is formulated and solved in the paper, but whether the approach has been applied practically is not clear.

US DOT (1997) concludes with a description of emergent modelling approaches:

> *The peak spreading approaches described in the previous section do not fully address travel response to system changes and, thus, cannot be used to fully analyze policy changes or effects of travel demand management actions. Emerging approaches intend to model traveler response to congestion in much the same way that mode choice is modeled. While there are no working models at present, there is potential for implementation of this procedure within the traditional four-step modeling process.*
>
> *Several MPOs [Metropolitan Planning Organisations], including MTC (San Francisco Bay Area), Metro (Portland, Oregon), and SACOG (Sacramento), have proposed explicit time choice components for proposed travel demand model system updates. These proposals include the following:*
>
> - *A model of time-of-day [TOD] choice that predicts the period of travel as a function of variables such as free flow and congested travel times,*

transit level of service, trip purpose, and area type variables. This can be a logit model that could be applied after mode choice.

- *A model of whether peak period trips occur in the peak hour or not. This can also be implemented as a logit model as part of a 'variable demand' multiple vehicle class assignment. Use of a variable demand assignment guarantees that the results of the peak hour models are in accord with the congestion resulting from the assignment. Off peak vehicle trips would still be assigned using a traditional static demand assignment.*

- *A model based on a combination of traditional TOD factors and a binary time-of-day choice model. The choice model will be based on congestion represented by peak/off-peak travel times, delays, etc. The underlying hypothesis is that relatively higher congestion during peak time results in a higher likelihood of off-peak choice.*

4.4.4 New Zealand Modelling

Only two examples have been found where peak spreading is included in transport models in New Zealand, and they are in the Auckland and Wellington regional models. These both operate at a strategic level, with a relatively coarse zoning system and a limited network. In each case the morning peak model represents the average traffic pattern within the 2-hour period between 0700 and 0900.

In both cases 'peak spreading' is taken to mean trips which transfer out of the modelled morning peak itself. Because of the average approach which is adopted, no attempt is made to transfer trips between different parts of the peak. It could be argued that, particularly in a congested situation such as Auckland, the latter would be a more useful application; however this would call for a major revision to the overall modelling approach.

The peak spreading modules were introduced in both models around 1997, partly in reaction to the debate which was current in the UK at the time on the subject of induced traffic. Based on the advice then being given by the UK Department of Transport, an elasticity-based model was used with an elasticity value agreed by a group of experts, as being appropriate and also fitting in with other parts of the model. The final number of trips in the trip matrix is derived iteratively, as this depends on the generalised cost of travel which, in turn, depends on the number of trips.

For the Auckland model, using the chosen elasticity with respect to generalised cost of –0.45, the inclusion of trip re-timing in the model was found to lead to a drop in the total number of trips of almost 5% with the 2021 Do Minimum network. As would be expected, this changed with the elasticity value used. Experimenting with the model established a number of results, none of them counter-intuitive:

- as the retiming elasticity is increased, the mode share for public transport falls because there is less congestion;

- more trip re-timing occurs in more congested corridors;
- using a network with extensive expansion of the road network reduces the amount of trip re-timing (from 4.8% to 1.7%).

In the case of Wellington, where congestion levels are lower, the model has been found to behave similarly but the extent of this re-timing is smaller.

As noted elsewhere in this report, the elasticity approach (which some would argue was introduced in the UK as a 'kneejerk' reaction to induced traffic) is now no longer favoured. It has been replaced by schedule-based approaches, albeit that these are much more complex and data-hungry. Also noted is that the impact of trip re-timing in the New Zealand models is relatively small and must be within the bounds of error from other sources such as land-use forecasts. Furthermore, the transfer of trips **from** the peak period is probably less important than transfer **within** the peak. Overall, then, the inclusion of this elasticity approach in the two strategic models may be of questionable use.

That said, peak spreading can clearly be observed in both Auckland and Wellington, as shown in Chapter 3 of this report. The data presented there indicate that there is a case for the Auckland model to be extended to cover a 3-hour peak period. Therefore a case is suggested for the inclusion of peak spreading in an appropriate study in which a time slicing approach, involving at least some of the techniques now being advocated in the UK, is adopted.

5. Evaluation of Peak Spreading Effects

5.1 Requirements for Peak Spreading in Scheme Evaluations

Now that Government Agencies are taking notice of peak spreading, their prescribed evaluation frameworks for schemes such as capacity enhancements have begun to incorporate it in the evaluation process. Typically this has been carried out under the heading of induced traffic (traffic generated because the road is in place). This is a term coined in the UK by SACTRA in 1994 who stated:

> *We conclude that induced traffic can and does occur, probably quite extensively, though its size and significance is likely to vary widely in different circumstances.*
>
> *These studies demonstrate convincingly that the economic value of a scheme can be overestimated by the omission of even a small amount of induced traffic. We consider that this matter is of profound importance to the value for money assessment of the Road Programme.*
>
> *Induced traffic is of the greatest importance in the following circumstances:*
>
> - *Where the network is operating or is expected to operate close to capacity.*
> - *Where traveller responsiveness to changes in travel times or costs is high, as may occur where trips are suppressed by congestion, then released when the network is improved.*
> - *Where the implementation of a scheme causes large changes in travel costs.*
>
> *We recommend that scheme appraisals must be carried out within the context of economic and environmental appraisals at the strategic area-wide level which takes account of induced traffic through variable demand methods. Much more emphasis needs to be placed on the strategic assessment of trunk routes within a corridor or regional or urban context.*

Peak spreading and induced traffic are often dealt with together as a consequence of both being demand-driven responses to road conditions, although this is not always the case. The following sections of the report offer national synopses as to whether or not peak spreading is accounted for in scheme evaluation and, if it is, what method is proposed.

5.2 Evaluation Procedures in the United Kingdom

The *Design Manual for Roads and Bridges* details the procedures for scheme evaluation set out by the UK DTLR (1997). Induced traffic is dealt with specifically in its Volume 12, Section 2, Part 2. Trip re-timing is explicitly mentioned on several occasions, and methods for its modelling are suggested, as described in Section 4.4.2 of this report.

However there does not yet exist a list of criteria for new schemes based, for example, on factors such as flow volumes, complexity or geography, which make the inclusion of peak spreading mandatory. Though a starting point for this occurs in Annex B, B3, where simple, intermediate and complex schemes are defined, and an indication as to whether or not induced traffic effects (which includes trip re-timing) should be considered in each.

5.3 Evaluation Procedures in the United States

According to Da Souza & Cohen recently (2000), the Federal Highway Administration (FHWA, www.fhwa.dot.gov) showed that the role of highway capacity expansion in increasing highway travel has been small relative to other factors. However, the paper concluded that "*..the inducement of travel due to highway capacity expansion is an issue that needs to be and can be addressed...*" FHWA Department of Transportation has underway a Travel Model Improvement Program, which is attempting to develop improved modelling techniques for use in addressing issues such as the magnitude of induced travel.

The Highway Capacity Manual (HCM) does not require peak spreading to be addressed.

5.4 Evaluation Procedures in Australia

The Australian Roads Research Board (ARRB 1997) produced a report that dealt with the issue of induced demand and road investment, but not trip retiming. The executive summary states that " *demand changes in ... trip start times are not regarded as induced traffic ... their impact in a network could be very significant but they are different from induced traffic*".

Consultation with Booz Allen staff and other consultants within Victoria, Australia, indicates that there is no requirement to include peak spreading in scheme appraisal. This also seems the case in Queensland where an inspection of its Department of Main Roads appraisal manual (1999) makes reference in its Section 4.1 to induced traffic. There it describes how the CBA4 software used for road scheme appraisal can account for it. Peak spreading, however, does not appear to be mentioned explicitly. In New South Wales the roads appraisal manual is, at the moment (2002), in the process of being updated and our correspondence with those responsible indicates that peak spreading is not a mandatory part of the appraisal process.

5.5 Evaluation Procedures in South Africa

Booz Allen staff from South Africa indicated that no official requirement has been made to build in peak spreading when evaluating new urban road or road improvements in South Africa. Usually the consultant builds in the peak spreading effect themselves if necessary and appropriate, depending on the project.

5.6 Evaluation Procedures in Japan

The Japanese Government's guidelines for the evaluation of road investment projects (Japan Research Institute 2000) has a reasonably lengthy process described for modelling demand for a new road. No mention of either peak spreading or induced travel is made.

5.7 Evaluation Procedures in New Zealand

Section A2.6.2 of Transfund's Project Evaluation Manual (1997) stipulates that *"in general it shall be assumed that projects do not induce new trips or cause redistribution to new destinations. If there are cases where the effect of excluding induced or redistributed trips seriously affects the evaluation, then a variable matrix approach should be adopted".*

This variable matrix approach is mentioned in Section A3.5 in Appendix A3, which documents that if there is either:

- Adequate levels of service for future year traffic volumes in the project option, but not in the do minimum option, or
- High congestion in both the do minimum and project options,

then variable matrix options should be used as described in its Section A11.

Section A11 of the Manual deals explicitly with induced traffic and how it can be evaluated. Section A11.2 deals with the application of peak spreading and states that *"peak spreading procedures may be used to spread traffic from the busiest part of the peak period to the peak shoulders"*. It goes on to say:

> *At present there are no universally established procedures for peak spreading – advice will be given in future revisions of this appendix. In the interim analysts are advised to use their own discretion in developing a peak spreading method but should ensure that the resulting retiming of trips is reasonable.*
>
> *In general the following points should be kept in mind:*
>
> - *The analyst needs to decide whether to apply peak spreading uniformly or to specific parts of the trip matrix. This decision will depend upon the extent of congestion in the network*
> - *Unless evidence suggests otherwise it is recommended that the transfer of trips from the peak to inter-peak or off-peak periods be not more than 5% of the total peak traffic*
> - *If appropriate the traffic profile during the peak period may be adjusted but it is advisable that the reduction of the peak traffic intensity be no more than 10%*
> - *It is recommended that analysts seek information on local traffic profiles and trends in traffic growth for different time periods such as peak shoulder and business periods to support their assumptions.*

Checks for reasonableness are offered in its Appendix A11.12, which stipulates that the analysis should be carried out when there is evidence of heavy peaking or a decline in speeds during the peak period relative to the shoulders.

Appendix A3 of PEM, which pre-dates A11 and covers travel time estimation generally, specifies that peak spreading shall be considered if either:

- the average delay is 15 to 24 minutes per vehicle and there is an alternative route; or
- the average delay per vehicle is 25 minutes or over.

The basis for this (which in reality can be considered unlikely) is not clear; however it is probable that Appendix A11 now takes precedence.

The New Zealand PEM therefore goes further than most in incorporating peak spreading into the evaluation framework. While it recognises that the modelling techniques at the moment are limited, there is at least some indication, albeit subjective, of when it should be accounted for, along with guidelines for the analyst. To date however, other than indirectly through the regional models, it would appear that peak spreading has not been applied in project appraisal.

6. Conclusions & Recommendations

6.1 Conclusions

This research into the spreading of traffic peaks has found considerable evidence of the phenomenon, both in New Zealand and elsewhere. There is also a sizeable body of research on the subject, largely concentrated in the UK and US.

Peak spreading has been clearly identified in a number of UK cities in studies which were done more than 10 years ago. Its existence cannot therefore be questioned. In the New Zealand cities of Auckland and Wellington it has proved particularly challenging to obtain continuous traffic data that allows peak spreading to be analysed. Nonetheless, at one key point in the roading network of each city it has been possible to identify clearly how the morning peak is spreading. On SH1 north of Wellington, the peak currently lasts about one hour and over the peak 3 hours about 2/3 of the available capacity is used. On Auckland Harbour Bridge, traffic levels are now approaching capacity over the full 3 hours from 0630 to 0930. Both pictures contrast with those of 10 years ago.

In Wellington it appears that the Newlands Interchange has led to some peak contraction and this finding has been borne out at the level of individual travellers.

Several other examples have been observed of the converse effect of peak contraction: when capacity is increased, trips are re-timed to take advantage, leading to a shorter peak. This has been previously documented in the cases of the Amsterdam Ring Road and Sydney Harbour Tunnel.

The traditional four-stage model explicitly excludes any element of time-of-day choice. However, the current thinking is that the time of travel is the second most important decision after route choice. Extensive work is under way in the UK to address this, with the main emphasis on models which combine the two choice mechanisms: i.e. the generalised cost of a trip comprises both the usual elements relating to travel time, and the scheduling delay. Trialling of the approach looks promising but is not yet complete, and the potential impact on scheme benefits has not been assessed. A similar approach has been reported on in the US but appears to be less well developed.

Peak spreading has also been modelled using elasticity approaches, although these often relate to the general issue of 'induced traffic', which (depending on the context) may not explicitly include peak spreading. Another approach is to look at how the peakiness over a longer period (typically 3 hours) has changed in the past, and to project this into the future.

Both the Wellington and Auckland Regional Transport Models include a peak spreading module based on elasticities, which moves trips out of the 2-hour morning peak period. In practice, however, the peak is shorter than this in Wellington and longer in parts of Auckland. The usefulness of the module may therefore be questionable.

Taking account of peak spreading will affect the economics of a scheme, in two ways. First, in the future Do Minimum, peak spreading may reduce the level of congestion below what is forecast. Second, peak contraction after the scheme is in place may mean that the full predicted benefits are not realised. Both these will act to reduce the actual benefits below those forecast. Despite this, only in New Zealand and the UK has reference been found to the need for including peak spreading in project evaluations in the documents which set out the Government's approach.

6.2 Recommendations

Recommendations for incorporating peak spreading as an integral part of transport planning are made.

- The study has concentrated on two key sites, one each in Wellington and Auckland. Although the evidence of peak spreading at those sites is clear, they may not be fully representative of traffic as a whole in the respective cities.

- Undertaking a similar analysis at other key sites and possibly also extending it to the evening peak would therefore be highly informative. The latter is important because in many evaluations the evening peak benefits are assumed to be the same as those in the morning. However the accuracy of this will depend on (among other things) whether the extent of peak spreading is the same.

- Obtaining historical traffic data has been a significant impediment to the analytical aspects of this study. While the quality of more recent data has improved, there is still some way to go. This will limit the extent to which further analysis is possible. Therefore better data collection and archiving is supported.

- This study has not attempted to forecast the likely future values of the PSER (as was done previously for Wellington). Further work on this would be informative, particularly in conjunction with examination of other sites. Given that the peak in parts of Auckland is already approaching 3 hours' duration, and given the typical lead times for major transport infrastructure projects, pointers as to the likely length of the peak in the future would inform decision-making.

- In Wellington the Regional Transport Model is currently being updated. This would provide a good opportunity to improve the peak spreading modelling, which could be based on the findings of this study.

- In Auckland, given that the peak already lasts over 2 hours in some locations, the present peak spreading module in the Regional model would seem to be of dubious value. In relation to specific schemes, it would be surprising if the modelled benefits were not affected by peak spreading.

- In future scheme evaluations, the effects of peak spreading should be taken into account. This could be achieved by using historical data to determine how the PSER (or a similar measure such as the ratio peak hour : peak period) has changed through time, and to project that forward to the design year. This could then be used to split the all-day matrix into peak and off-peak portions.

- In view of the considerable developments taking place in modelling time-of-day choice in the UK, maintaining a watching brief on the situation there would be very useful.

However, the inclusion or exclusion of peak spreading in traffic models is only one of a number of issues which impact on the outcome of any traffic modelling exercise.

7. References

ACT (Australian Capital Territory). 1997. *John Dedman Parkway Corridor Selection and Environmental Study*. Canberra, ACT (Australian Capital Territory), Australia. http://www.palm.act.gov.au/planning_and_development/other_planning/jdpaa/planning/sumreport.html

Allen. W. 1991. Analysis of corridor traffic peaking. *Transportation Research Record 1305:* 50-60. Transportation Research Board (TRB), National Research Council, Washington DC.

Allaire, S., Ivan, J. 1999. *Factors influencing peak spreading on Connecticut freeways: A preliminary investigation.* Presented at Annual Meeting of Transportation Research Board, Washington DC, January 1999.

Arizona Department of Transportation. 1988. *Analysis of temporal demand shifts to improve highway speed modelling.* Report by Cambridge Systematics Ltd, Berkeley, California.

Arnott, R., de Palma, A., Lindsey, R. 1990. Departure time and route choice for the morning commute. *Transportation Research 24a (3):* 209-228.

Auckland City Council (ACC). 2000. *Transportation.* http://www.akcity.govt.nz/about_auckland/the_environment/monitoring_and_reporting/

Auckland Regional Council (ARC). 2001. *Auckland Regional Land Transport Strategy (ARLTS), 2001.* http://www.arc.govt.nz/pubs/rltsanrpt2000-01.pdf

Australian Roads Research Board (ARRB). 1997. *Induced demand and road investment – an initial appraisal. ARR 299,* ARRB, Victoria, Australia.

Bacquie, R., Wang, J. 1997. *Peak spreading – temporal changes in travel demand in the GTA.* Presented at the Transportation Planning Session of the XIIIth IRF World Meeting, Toronto, Ontario.

Bates, J. 1996. *Time period choice modelling – a preliminary review.* Final report for Department of Transport, Heta Division, UK.

Bates, J., Dix, M., May, A.D. 1987. Travel time variability and its effects on time of day choice for the journey to work. *Proceedings PTRC (Planning & Transport Research & Computation) Summer Meeting.*

Bates, J., Shepherd, N., Roberts, M., van der Hoorn, A. 1990. A model of departure time choice in the presence of road pricing surcharges. *Proceedings PTRC Summer Meeting.*

Beder, S. 1991. *Who Pays the Toll? The Sydney Harbour Tunnel Environmental Impact Statement.* University of Sydney Television Service, University of Sydney.

Booz Allen Hamilton. 1999. *Newlands Interchange Survey.* A report to Transit New Zealand and Wellington Regional Council.

Cambridge Systematics Inc. 1999. Time-of-day modeling procedures: State-of-the-Art, State-of-the-Practice. *DOT-T-99-01,* US Department of Transportation, Washington DC.

Daly, A.J., Gunn, H.F., Hungerink, G., Kroes, E.P., Mijjer, P. 1990. *Peak period proportions in large-scale modelling.* Presented to PTRC Summer Annual Meeting, 1990.

Da Souza, P., Cohen, H. 2000. *Accounting for induced travel in evaluation of urban highway expansion.* http://www.fhwa.dot.gov/steam/doc.htm

Dulles Transit. 1997. *Dulles Corridor Transportation Study.* Final report. www.dullestransit.com/pdf/links/dulles.pdf

Gifford, J.L., Talkington, S.W. 1995. Demand elasticity under time-varying prices: case study of day-of-week varying tolls on Golden Gate Bridge. *Transportation Research Record 1558.*

Gordon, P., Kumar, A., Richardson, H. 1989. Peak spreading: how much? *Transport Research 24a (3):* 165.

Gray, P. 1993. Private communication APH 2/4/022, cited in Porter et al. (1995).

Hagerstrand, T. 1967. *Innovation as a spatial process.* University of Chicago Press, Chicago.

Halcrow Fox. 1999. *Modelling peak spreading and trip retiming.* Phase II – HADES case study test report: Aylesbury.

Hounsell, N.B. 1991. Peak spreading and congestion: techniques for distinguishing 'passive' from 'active' responses by road users. *Transportation Planning Systems 1(3):* 39-46.

Japan Research Institute. 2000. Guidelines for the evaluation of road investment projects. *Japan Research Institute publications.*

Johnson, R., Bates, J., Roberts, M. 1989. A survey of peak spreading in London, methodology and initial results. *Proceedings of PTRC Summer Annual Meeting: 318.*

Leeds City Council. 2000. *Leeds Monitoring Report.* http://www.leeds.gov.uk/lcc/highways/various/traff_home.html

Levinson, D.M., Kumar, A. 1994. Operational evidence of changing travel patterns: a case study of Montgomery County, Maryland. *ITE Journal, April 1994.*

Local Transport Today. 1998. Have modellers missed out peak spreading and magnified the cost of congestion? *Local Transport Today, 21st May 1998:* 9. London.

Louden, W.R., Ruiter, E.R., Schlappi, M.L. 1988. Predicting peak spreading under congested conditions. *Transportation Research Record 1203:* 1-9.

Kroes, E., Daly, A., Gunn, H., Van der Hoorn, T. 1996. The opening of the Amsterdam Ring Road – a case study on the short-term effects of removing a bottleneck. *Transportation 23:* 71-82.

Mahmassani, H., Chang, G. 1986. Dynamic aspects of departure time choice behavior in a commuting system – theoretical framework and experimental results. *Transportation Research Record 1037:* 88-101.

NSW Department of Transport (DOT), Transport Data Centre. 2001. *Household Travel Survey Summary Report 2001.* Sydney Statistical Division, NSW DOT Transport Data Centre, Sydney.

Opus International Consultants. 1997. Wellington Regional Council State Highways 1 and 2: Peak Spreading. *Central Laboratories Report 97-529502.*

Oscar Faber TPA. 1993. Revision of peak/off-peak to 16 hour factors, A40 North of Oxford. Traffic Working Note.

Polak, J., Jones, P., Vythoulkas, P., Meland, S. 1991. The Trondheim ringroad – results of a stated preference study of travellers responses. *Euronet Deliverable 17,* Transport Studies Unit, University of Oxford.

Polak, J., Jones, P. 1994. A more general model of departure time choice. *Proceedings PTRC Summer Meeting.*

Polak, J., Han, X. 2000. *PATSI – Preferred Arrival Times Synthesised by Imputation.* Report to UK DLTR by Centre for Transport Studies, Imperial College, London.

Porter, S., Field, M., Van Vuren, T. 1995. *Evidence of peak spreading in the UK.* Paper presented to the European Transport Forum, University of Warwick.

Purvis, C. 1999. *Peak spreading models – promises and limitations.* Presentation at 7th TRB Conference on Application of Transportation Planning Methods, Boston, Massachusetts, March 1999.
http://www.mtc.dst.ca.gov/datamart/research/boston2.htm

Queensland Department of Main Roads. 1999. *Cost Benefit analysis manual for road infrastructure investment, manuals and software.* 2nd edition, Queensland Department of Main Roads, Brisbane.

Ramsey, B., Hayden, G. 1995. An investigation into peak spreading in relation to the Cross Tyne Study. *Traffic Engineering and Control 36:* 139-141.

Royal Automobile Club Queensland (RACQ). 2000. *Transport vision for South East Queensland.* www.racq.com.au/04_club/transport_vision.pdf

SACTRA. 1994. The Standing Advisory Committee on Trunk Road Assessment *Trunk Roads and the Generation of Traffic Manual.* HMSO, UK.

SACTRA. 1999. The Standing Advisory Committee on Trunk Road Assessment. *Transport and the Economy.* HMSO, UK.
http://www.roads.detr.gov.uk/roadnetwork/sactra/report99/index.htm.

Small, K. 1982. The scheduling of consumer activities: work trips. *The American Economic Review 72(3):* 467-479.

Small, K. 1992. Trip scheduling in urban transportation analysis. *Transportation Economics,* AEA papers and proceedings, May 1992.

South Australian Energy Research Associates. 1989. Temporal flexibility as a peak spreading strategy – a report to the Director General of Transport, South Australian Sources for History and Social Science. *SASS Record Number PO168.*
www.unisanet.unisa.edu.au/research/condon/sass/

Stebbings, F. 1988. Forecasting peak spreading. *Greater Manchester Transport Unit Note 52.*

Stebbings, F. 1993. Further peak spreading. *Greater Manchester Transport Unit Note 234.*

Tacken, M., Mulder, J.C. 1990. Peak hour travel in the period 1979 – 1988. Delft University of Technology, OPSA Institute of Urban Planning and Architecture, *Report Number 30.*

Transfund New Zealand. 1997. *Project evaluation manual* (PEM). Vol. 2. Transfund New Zealand, Wellington, New Zealand.

UK Department of Transport (UK DOT). 1995. *London Transport Monitoring Report.* HMSO, London, UK.

UK Department of Transport, Local Government and the Regions (UK DTLR). 1997. *Design Manual for Roads and Bridges.* HMSO, UK.

UK Department of Transport, Local Government and the Regions (UK DTLR). 2002. *Using HADES to model departure time choice in continuous time: a good practice note.* http://www.roads.dtlr.gov.uk/roadnetwork/hades

US Department of Transportation (US DOT). 1994. *Short term travel model improvements*. Final report October 1994. http://ntl.bts.gov/DOCS/445.html

US Department of Transportation (US DOT). 1997. *Time of day modeling procedures: state of the practice, state of the art.* Final report February 1997. http://tmip.fhwa.dot.gov/clearinghouse/docs/time-day/

Van der Zijpp, N.J., Lindveld, C.D.R. 2001: Estimation of origin-destination demand for dynamic assignment with simultaneous route and departure time choice. *Transportation Research Record 1771:* 75-82.

Van Vuren, T., Porter, S., Sharpe, A. 1995. *Advice on the modelling of changes in peak profiles for road scheme appraisals.* Paper presented to European Passenger Transport Conference, University of Warwick, UK.

Vickrey, W. 1969. Congestion theory and transport investment. *American Economic Review 59:* 251-261.

West Midlands Planning Transportation Sub-Committee, Joint Planning and Transportation Data Team. 1990. *Transportation Data Review. Report 90.4.*

Wellington City Council (WCC). 1994. *Transport Strategy. WCC, Wellington, New Zealand.* http://www.wcc.govt.nz/policy/archive/transport/transport_strategy

Wellington Regional Council (WRC). 1999. *Wellington Regional Land Transport Strategy 1999-2004.* WRC, Wellington, New Zealand.