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Abstract

SETTING PUBLIC TRANSPORT SERVICE STANDARDS – AN ECONOMIC APPROACH

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The merits of investment in improving urban public transport systems are typically evaluated in terms of their benefits and costs to society as a whole, using social cost-benefit analysis (SCBA) techniques. However, service standards on existing routes are usually based loosely on historic custom and practice, without specific consideration of social costs and benefits.

This paper describes a new approach to setting service frequency levels for urban public transport routes, using SCBA techniques to select the optimum economic service frequency. This optimum frequency depends on the trade-off, as frequency varies, between operator costs (including vehicle capital costs), user (generalised) costs and externality costs (congestion and environmental costs).

This approach has been translated into an economic model in the context of Melbourne's public transport system (bus, tram and train services). The model has been applied to examine how economic costs vary with service frequency, and hence to derive optimum frequencies, for generic routes for each mode and for a range of individual routes. This has led to some 'rule of thumb' generalizations based on the key 'drivers' affecting optimum frequencies. The model has also been applied in developing recommendations on enhanced bus service frequencies as part of Melbourne's Metropolitan Bus Plan. As such recommendations have a sound economic base, consistent with evaluations of other transport investment projects, they should assist Government in more informed decision-making on program and funding priorities.

The views expressed in this paper are those of the authors and do not necessarily represent those of Monash University, the Department of Infrastructure or Booz Allen Hamilton.

1. INTRODUCTION

All public transport systems world-wide are faced with the problem of determining the service levels they offer to the community. Inevitably the customer demands higher frequencies, longer spans of service and more direct, reliable and faster routes. Broader transport policy considerations also tend to support higher service levels, given the environmental and congestion relief benefits which public transport can provide. However financial constraints require a balancing of these demands against the costs of providing higher levels of service. This can become a difficult and sensitive issue for government transport authorities and public transport operators to address.

Given the universality and sensitivity of this issue, it is somewhat surprising to find that the quantitative measures generally used to determine appropriate service levels are based more on geographic, demographic and sometimes patronage factors than on a wider consideration of the economic, environmental and social impacts. As our analysis will show, the pervading service level determination methodologies consider service levels in the context of the existing market rather than having regard to the environmental, economic and social benefits of improved services.

This paper presents a new approach to determining public transport service levels based on a social cost-benefit analysis (SCBA) approach. This approach was developed by the Department of Infrastructure Victoria in association with consultants Booz Allen Hamilton. The focus of the analysis to date has been on methods to determine appropriate service frequencies. While methods have been developed for bus, tram and train services in the Melbourne context, for reasons of brevity this paper focuses on the methods and their application relating to bus services

The paper is structured as follows

- Determining Service Frequency Standards – A Review of Practices (Section 2)
- Outline of the Social Cost-Benefit Analysis Approach (Section 3)
- Results (Section 4)
- Conclusions (Section 5).

2. DETERMINING SERVICE FREQUENCY STANDARDS – A REVIEW OF PRACTICES

2.1 AUSTRALIAN PERSPECTIVES

Table 1 presents a summary of bus service level standards specified for major Australian cities (but noting that these standards are not adhered to in all cases). While all major cities in Australia have such standards, it needs to be recognised that the purpose and uses of these standards differ between cities, according to the regulatory model applying, eg:

- In Adelaide and Perth, while service changes may be initiated by the operator, the state government has to approve any substantial service changes. Thus the

Table 1 : Summary of Bus Service Level Standards in Major Australian Cities

Aspect	Sydney	Canberra	Adelaide	Perth	Brisbane	Melbourne
Minimum Service Frequencies	Using MSL Methodology - Peak 20-60mins - Interpeak 20-120mins - Evening 30-60/0mins - Saturday 20-60/0mins - Sun/P Hol 30-120/0mins	Line Haul/Feeder Services - Peak 5/30mins - Interpeak 0/60mins - Evening 30/90mins - Saturday 30/60mins - Sun/P Hol 60/90mins	- Peak 10/15/20/30mins - Interpeak 15/30/60mins - Evening 0/30/60mins - Saturday 15/30/60mins - Sunday 0/30/60mins	- Peak 20/30mins - Interpeak 60mins - Evening 120mins - Saturday 120mins - Sunday 120mins	- Peak 15mins - Interpeak 30/60mins - Evening 30/60mins - Saturday 30/60mins - Sunday 30/60mins	Standard/ Developmental - Peak 45/60mins - Interpeak 60/90mins - Evening 60/90mins - Saturday 60/90mins - Sunday None
Maximum Loading Standards	In cases of heavy demand capacity to cater for at least 15% spare licensed capacity required for each route each hour	Based on minimum frequency for pax per hour Implies max of 52/bus/hour	Average peak loading is 55 per rigid bus	Average peak loading is 55 per rigid bus	Maximum permissible load is 70 rigid bus and 100 articulated bus.	Not to exceed 70% of max capacity (over 30 pax vehicle) on 3 days in succession or more than twice a week on 2 successive weeks.
Route Coverage	95% within 400m 95% within 800m for infrequent routes	Weekday – within 500m for 95% residents 85% employment/ retail areas Weekend less	Mond-Sat within 500m of 95% residents Evenings/Sundays within 1000m 95% residents	Weekday Daytime 400m for 90% residents Other times 600m for 90% residents	Citybus/School within 300-400m Express bus 500-600m	95% of houses within 400m of standard bus svce Low density areas – 95% within 500m Medium density – 70% within 400m
Route Circuitry	Route not to exceed 25% more than most direct path between 2 points	Weekday – at least 85% of pax trips not to exceed 20% of most direct path Weekend – 85% not to exceed 50%	Daytime – 90% pax not to exceed 20% - Route deviation not to exceed 8mins round trip time Other periods lower	Routes to CBD/ Interchanges not to exceed 35% of shortest path	City Bus – route distance not greater than 30% shortest path City Express – 5%	None?
Service Spans	Using MSL Methodology Weekday 0600-2330 Some 0600-2130 Saturday 0600-0030 Some 0830-1730 Sunday 0800-2200 Some No Service	Weekday 0600-2400 Saturday 0645-2400 Sunday 0815-1845	Weekday 13 hr day 5 hr evening Saturday 12hr day 5hr eve Sunday 16 hours	Weekday 0600-2330 Saturday 0600-2330 Sunday 0900-1930	Weekday 0530-2330 Saturday 0700-0130 Sunday 0730-2200	Standard/Developmental Weekday 0600-0700/ 0600-0700 Saturday 0700-0600/ 0900-0500 Sunday None

Source : Booz Allen Hamilton (1999)

standards perform more of a ‘guideline’ role, rather than an absolute requirement.

- By contrast, in Sydney, government does not have a role in relation to specific service changes and hence is entirely dependent on the minimum standards to determine services. Further, in this case, the minimum standards also fulfil the demanding function of regulating operator profitability.

Thus any appraisal and comparison of standards needs to have regard to their purposes and objectives.

It is of interest to compare the service frequency standards between states, although recognising that the operating circumstances where they are applied and their method of application vary by city. Typically there are differences in how minimum frequency standards are applied to particular situations:

- In Melbourne standards vary according to the level of urban development or residential dwelling densities
- Most systems differentiate between major line haul trunk bus services and local feeder services.

It is notable that all cities have a set of maximum loading standards, related to vehicle capacity. Typically, in peak periods, service frequencies will be determined by these standards, and thus related closely to demand. However, at other times, the minimum service frequencies are likely to be relevant, and hence service frequencies will bear no relation to demand.

The most complex set of minimum service level (MSL) standards is that adopted in NSW. These standards are designed to fulfil a variety of roles, including appropriate levels of service, coverage of services within an area, equity of services between areas, a means of progressively increasing service levels, and a means of profit regulation: together these are very demanding requirements from a single policy instrument.

The NSW standards were developed in 1990-91 in conjunction with the NSW Passenger Transport Act. They were in large measure defined to more-or-less replicate the then levels of service of private operators in areas of western Sydney that were judged to have reasonably acceptable standards of service. Standards were defined for two types of routes (‘primary’ and ‘secondary’) for eight different service level grades (A1 to D), as shown in Table 2. The service level grade for each contract area is determined from its ‘Net Patronage Potential’: this is derived according to the (Total population – Total cars) in the contract area, with various adjustments then made for ‘competing’ train services and bus services from other contract areas.

While the NSW approach appears sophisticated, it was a number of somewhat simplistic and inconsistent features. Arguably, as noted above, it has been given an impossible task of meeting so many differing requirements .

Table 2 : Minimum Frequency and Service Span Standards – NSW Minimum Service Level Standards

Service Frequencies (mins) Primary Routes – Secondary Routes in Brackets	Service Level Grade Category[2]						
	A1	A2	A3/B1	B2	C1	C2	D
Weekdays							
Peaks (0600-0830 & 1530-1830)	20 (30)	30 (30)	30 (30)	30 (60)	30 (60)	30 (60)	60 (60)
Interpeak	20 (45)	30 (60)	45 (90)	60 (120)	60 (90)	60 (120)	120 (120)
Evening (1830-2130)	30	45	60	60	60	60	-
Evening (2130-2330)	60[1]	60[1]	-	-	-	-	-
Saturdays							
Early (0600-0830)	30	45	60	-	60	-	-
Day (0830-1730)	20 (60)	45 (120)	60 (120)	60 (120)	60 (120)	60 (120)	-
Evening (1730-1930)	30	60	60	-	-	-	-
Evening (1930-0030)	60	60	-	-	-	-	-
Sundays							
Day (0800-1800)	30	60	60	120	-	-	-
Evening (1800-2200)	60	60	-	-	-	-	-

Note: ***[1]Services continue to 0030 on Fridays***
[2]Based on population, car ownership and service area size criteria
Source: ***Booz Allen Hamilton (1999)***

2.2 INTERNATIONAL PERSPECTIVES

The US Transit Scheduling Manual (TRCP,1998) identifies three main approaches to determining service frequencies:

- **Type 1 - Policy or Minimum Frequencies** – where an agency determines a given level of service is appropriate based on its attractiveness to the community rather than any direct consideration of its usage
- **Type 2 – Demand-Based Frequencies** – where level of service is directly related to demand; and
- **Type 3 – Performance-Based Frequencies** – where frequency setting is goal based. Hence a given frequency must meet patronage, cost or profitability criteria

The type 1 approach is that used in the Australian examples (Table 1) to determine minimum service frequencies. Internationally the type 2 (or type 3) approaches are often used to define maximum and minimum frequencies and loading standards. Table 3 shows such an approach developed for off-peak services in Wellington. These standards are defined so that:

- Frequencies are broadly related to patronage
- No passengers would normally have to stand
- All services would have at least a minimum number of passengers and hence a minimum level of cost recovery.

It is evident that, unlike the Table 1 standards, the Table 3 approach goes a long way to ensuring minimum levels of patronage performance (eg. average passengers per bus) and of cost recovery performance on all services. This may be particularly important where cost recovery cannot be assessed directly (eg. in the case of integrated ticketing systems, as in Melbourne).

Table 3 : Off-Peak Bus Service Standards Developed for Wellington

The following total patronage levels per trip averaged over both directions for the relevant period on an average weekday are to be adopted:

(A) Maximum patronage:

- Interpeak 30 passengers/trip
- Evening/weekend 20 passengers/trip,

Provided in both cases that no passenger has to stand on the average day. If these guidelines are exceeded, then frequencies should be increased (or larger vehicles considered).

(B) Minimum patronage:

- Interpeak 10 passengers/trip
- Evening/weekend 5 passengers/trip.

If these guidelines are not attained, then frequencies should be reduced (or smaller vehicles considered).

In cases where two or more routes bifurcate, if patronage on any leg beyond the point of bifurcation is less than 5 passengers/trip (average both directions), then consideration should be given to reducing service frequency or deleting the service concerned over the relevant period.

Source: Booz Allen Hamilton

2.3 SUMMARY AND APPRAISAL OF APPROACHES TO SERVICE FREQUENCY STANDARDS

From the foregoing, four main approaches to determining bus service frequency standards have been identified:

(1) **Social/policy basis.** This is the type 1 approach, where uniform minimum standards are defined based on social/community judgements, independent of the level of demand. This approach appears common in Australia.

(2) '**Good practice' basis**. This is where standards are drawn from what appears to be 'good practice' in particular areas. The resulting standards would usually have some demand-related component. The NSW MSL standards are an example.

(3) **Performance basis.** This is where frequencies bear a more direct relationship to loadings, so as to ensure minimum patronage and/or financial performance. The Wellington standards (Table 3) are an example.

(4) **Capacity basis**. This is where frequencies are set so that buses will not be overloaded. This is a common feature of frequency standards, but is typically mainly applicable to peak period services.

The benefits of public transport provision in urban areas are often categorised under three headings:

- Economic – to address the inefficiencies and delays resulting from traffic congestion. Public transport is seen as a more efficient transport mode for carrying people in congested circumstances.
- Environmental – to provide a more environmentally sensitive basis for transport in urban areas.
- Social – to act as a transport 'social safety net' for those with limited private transport alternatives.

It is notable that none of the four approaches to frequency standards takes explicit account of the economic benefits (focusing on urban traffic congestion) or the related environmental benefits. This suggests the need to reappraise the basis of setting service standards.

In addition, it is common practice (in Melbourne, New Zealand and elsewhere) to appraise public transport investment projects through SCBA and/or a triple-bottom-line methodology (incorporating SCBA). Logic and consistency would indicate that a similar approach should be applied to appraising alternative levels of service.

3. OUTLINE OF THE SOCIAL COST-BENEFIT APPROACH

3.1 OVERVIEW

The work reported in the rest of this paper focused on developing an improved approach to determining service frequency standards, based on assessing the optimum (economic) frequency of a public transport route, as a function of the level and pattern of demand on that route.

The optimum (economic) frequency is that frequency which **minimises the total economic cost** (for a given level and pattern of demand). Total economic cost comprises three main terms:

- **Net operator costs,** comprising costs of bus operation (including any economic capital charges) less fare revenues.
- **User (generalised) costs**, which include passenger travel time and fares components.
- **Externality costs**, typically comprising road system costs (including travel time, accidents and environmental costs) associated with people switching between car and public transport travel.

It should be noted here that only **changes** in these terms as service frequency varies are relevant to the analyses. Hence any components which do not vary with frequency may be ignored (eg. depot operating costs, user access/egress time, 'base' road environmental costs). Further, we note that fare revenues may be ignored, being a transfer payment: the fare paid by additional users is calculated as a positive user cost off-set by an equal but negative net operator cost.

A spreadsheet-based model was developed to calculate each of the three terms for a specified bus route, for different service frequencies. Hence the optimised frequency, which minimises the net economic costs, may be derived for any specified demand; and hence the optimum frequency expressed as a function of demand.

Key features of the model include the following:

- Model relates to a specified bus route: each route is specified in terms of length, average operating speed, layover.
- Vehicles are specified in terms of total passengers/hour (at defined service frequencies), proportion of passengers in each direction, and average on-bus trip length. Average passenger walk (access/egress) time is also specified.
- The model runs separately for a typical peak 1 hour and a typical off-peak 1 hour, ie. it relates to all bus trips starting the route over the 1-hour period, plus their return trip back to the start.
- The model estimates, for a given total demand level (passengers/hour) and range of service frequencies:
  - User costs
  - Operator costs
  - Operator revenues
  - Externality costs
  - Total economic costs (net sum of above).
- Hence, for a given demand level, total economic costs can be calculated over a range of service frequencies, and the minimum total cost frequency established.

3.2 MODEL INPUTS

The key inputs to the model are set out in Table 4, with additional brief comments as follows.

3.2.1 Demand and User Costs

A 'conventional' user generalised cost (or generalised time) function is used, as shown in Table 4. The two features of particular note are:

- Effective passenger waiting time for a bus is expressed as:

Wait time = 0.72*(Headway) ^0.75.

This function, derived from review of a number of international studies, allows for both the actual waiting time at the stop and the 'inconvenience factor' of longer headways (even if not waiting at the stop).

- The value of in-vehicle time is based on 'standard' values for seated passengers, twice these values for standing passengers.

The combined effect of these two features is that, as headways increase (ie. frequencies reduce), effective waiting times increase and the passenger

Table 4 : Economic Model - Input Parameter Values And Functions

Module	Items	Sources [1]	Notes
User Cost Function	User (generalised) cost function is: GT = Walk time * 2.0 + Wait time * 2.0 + In-vehicle time * (1+% standees) + Fare/VOT. GT = generalised cost (minutes) Walk time = input (set at 15 mins, can be varied) Wait time = 0.72* (Headway) ^0.75		
	Walk/wait time factor = 2.0	IAEG Table B6	
	In-vehicle time = distance/Ave speed	Ave speed from route database	
	In-vehicle distance (bus) = 7.0 kms average	Transport Research Centre 1996	
	IVT Factor = (1+% standees), allowing for higher value of time for standing passengers (factor = 1.0 for seated, 2.0 for standing).	International evidence/practice: standing time value = 2.0* seated value.	
	Fare = $0.65 per bus boarding	BAH analyses of DoI 2000/01 system patronage and revenues.	Excludes GST
	VOT = $0.142 per minute	IAEG Table B6 ($8.50/hour).	
Demand Function	PT patronage varies as a function of GT: $P_i/P_o = (GT_i/GT_o)^E$ where P_i = patronage, GT_i = generalised cost, E = generalised cost elasticity.		
	Gen cost elasticity (E) = -1.0 peak, -1.5 off-peak	BAH review of international evidence	
Unit Operator Costs - Bus	Bus Kilometre = $0.60	IEG p.44 (Economic Costs)	
	Bus Hour = $24.85	IEG p.44 (Economic Costs)	
	Peak Bus – Operations = $20,870 Peak Bus – Capital = $38,385	$34,895 average over bus life *1.1 to allow for spare buses.	
Diversion Rates	50% of additional PT trips assumed would otherwise be car driver trips	IEG p.45	50% on the high side of international evidence (35 – 40% may be more appropriate average, but differs by mode, trip length etc).
Road System Externality Cost Rates	Congestion cost rates: Peak – heavy congestion 90¢/vkm Peak – moderate congestion 60¢/vkm Peak other/off-peak 16¢/vkm	IAEG Table 4.2	Assumed to cover travel time, accidents, VOC per incremental car km (refer IEG p.41). Strictly should also allow for congestion costs of additional buses.
	Environmental cost rates – total 2.4¢/vkm	IAEG Table 4.2 (covers items quantified in that table)	Costs per incremental car km in urban situation.

Notes: (1) IAEG = Investment Appraisal and Evaluation Guidelines, DoI, June 2002.
(2) IEG = Investment Evaluation Guidelines 2002/03, DoI, Draft, Nov 2001.

valuation of in-vehicle time may increase (once bus loads are greater than seating capacity).

Total public transport demand varies as a function of generalised (door-to-door) travel cost or time, using a power elasticity function as shown in Table 4. The generalised elasticity values have been selected based on review of the international literature. In approximate terms, this function implies that a 10% decrease in generalised time results in an additional 10% of passengers in peak periods, an additional 15% in off-peak periods.

To model the inter-relationship between patronage and generalised time, an Excel macro (Visual Basic) was developed to iterate both patronage and generalised time to a stable solution, given inputs of base patronage and frequency.

3.2.2 Operations, Costs and Revenues

A bus operating cost module was developed, expressing operating costs as a function of bus kilometres, bus hours and total bus requirements (peak only). In estimating bus kilometres and bus hours, the 'base' (route) statistics were increased by 25% peak, 5% off-peak to allow for dead running.

Unit bus operating costs including annualised capital costs were taken from the DoI's Investment Appraisal and Evaluation Guidelines, IAEG (DoI 2002 and 2001) and other DoI sources.

Vehicle-related costs (applying only to peak period services) were converted into an average cost per bus hour by assuming 1,250 peak hours per year.

Bus fare revenue was calculated as patronage * average fare, with average fares (per bus boarding) estimated from DoI sources.

3.2.3 Externality Costs

Road system externality costs, associated with people switching between public transport use and car (driver) use as generalised costs vary, are based on parameters in IAEG, ie:

- 50% of any change in public transport users switch to/from car driver mode
- Associated congestion externality rates were $0.90/$0.60/$0.16 per peak car km (according to level of congestion), $0.16 per off-peak car km. These values represent the impact of reduced road congestion on road travel quality, reduced vehicle running and accident costs.
- Allowance was also made for environmental cost rates, totalling $0.024 per car km.

4. RESULTS

The findings from the economic modelling of bus service frequencies are discussed in two groups:

- Generic Results – where the optimum frequencies on a typical route have been identified for a range of demand levels. This includes an analysis of the sensitivity of results to a range of key route parameters.
- Specific Route Applications – where the model was applied to examine optimum frequencies for a series of actual Melbourne bus routes.

4.1 GENERIC RESULTS

4.1.1 Optimum Frequencies by Demand Level

Generic modelling results were generated for a 'typical' bus route with the following characteristics:

- Route length: 20 kms
- Average speed: 20 km/hr
- Proportion of passengers in dominant direction: 75% peak, 50% off-peak
- 'Base' frequency: 10 min peak, 20 min off-peak
- Moderate level of congestion (peak periods).

Model runs were undertaken to determine the optimum frequency for the range of 'base' patronage levels shown in Table 5. In each case, a full range of frequencies was tested and the optimum frequency (ie. which minimises total economic costs) was established. A check was made to exclude any cases where the services would be over-loaded (ie. loading greater than the total bus capacity): such cases were defined as not acceptable in selecting the final optimum frequency.

Table 5 presents a summary of results for the typical route and demand profile, showing the optimum frequency (peak/off-peak) for varying levels of base demand. The results are shown graphically in Figure 1 (peak) and Figure 2 (off-peak). (Note that the demand at the optimum frequency generally differs from the base demand, as demand varies with frequency).

The following features of these results should be noted:

- The frequency v base demand functions are reasonably linear.
- The optimum off-peak frequency for a given demand level is somewhat higher than that in peak periods, over the range of off-peak demand levels tested. This result reflects, in part, the higher costs of providing additional services in peak periods.
- In peak periods, optimum frequencies are such that, at higher levels of demand, buses are almost loaded to capacity (60 passengers) in the peak direction.
- In off-peak periods, optimum frequencies involve much lower loadings (25-30 passengers/bus at maximum load point), with no standing passengers.

TABLE 5: OPTIMUM FREQUENCIES V BASE DEMAND – GENERIC RESULTS [1]

Base Demand [2] (Total passengers/hour)	Optimum Frequency (Services/hour)	Optimum Total Demand (Total passengers/hour)	Average Demand/Service - Dominant Direction [3] (Passengers)
Peak Periods			
100	1.4	80	42
200	2.7	178	46
300	4.3	279	48
400	6.7	410	46
500	6.7	511	58
600	8.6	641	57
700	10	765	58
800	12	897	57
900	15	1043	54
Off-peak Periods			
25	1.0	17	9
50	1.4	41	14
75	1.9	67	18
100	2.4	95	20
125	2.9	124	22
150	3.3	153	23
175	3.3	179	27
200	4.3	215	25
225	4.3	242	28

Notes:
(1) For route with length 20kms, average speed 20km/hr, peak direction passengers 75%
(2) Demand based on 10 min peak frequency (6 buses/hour), 20 min off-peak frequency (3 buses/hour)
(3) 75% of total passengers in peak, 50% of total passengers in off-peak

Figure 1: Generic Route Optimum Frequencies – Peak

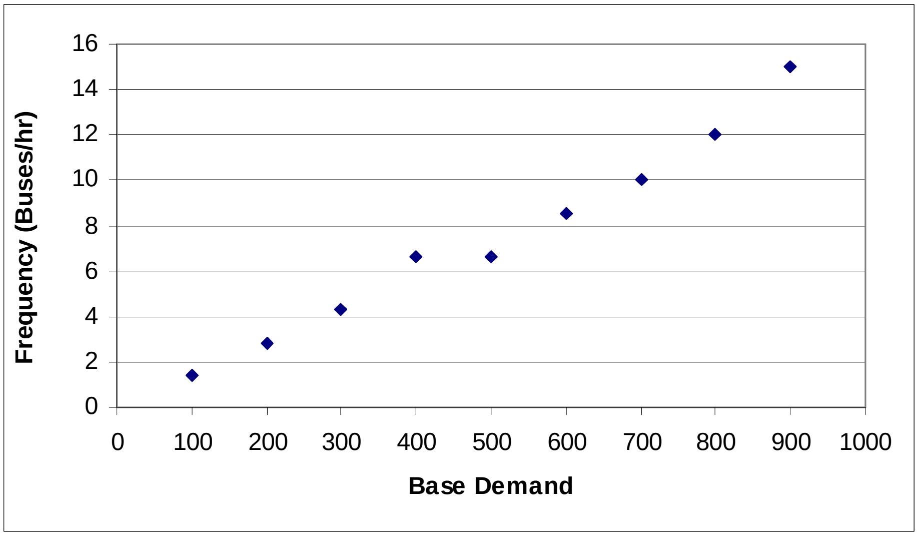
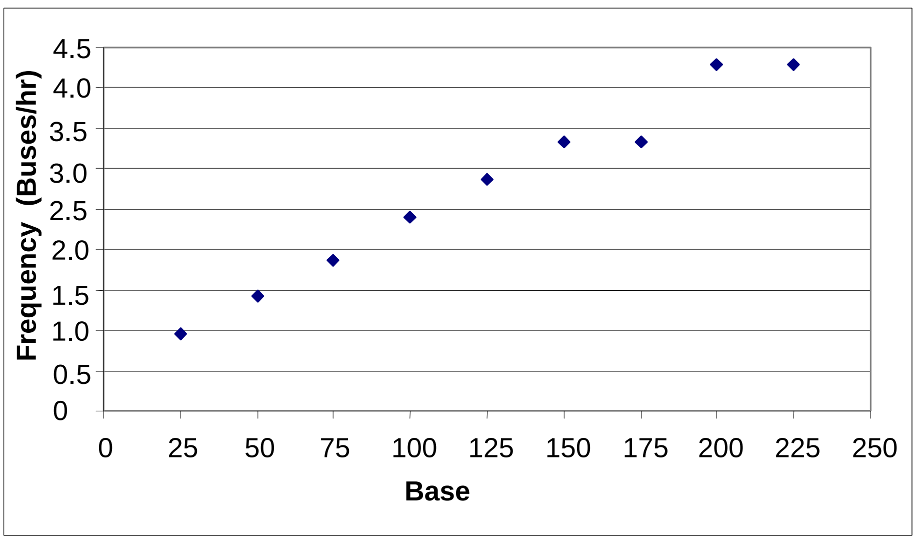


Figure 2: Generic Route Optimum Frequencies – Off-peak



4.2 SENSITIVITY TESTS

A series of single variable sensitivity tests was also undertaken, to examine how the optimum frequency results were affected by changes in the main 'supply' and 'demand' drivers, ie:

- Proportion of passengers in peak direction (range 50% to 100%). Optimum frequency was found to be moderately sensitive to this proportion: as the peak direction proportion increases, the proportion of passengers that may have to stand increases, and hence higher frequencies may be warranted.

- Route length (range 10 km to 50 km). Optimum frequency was moderately sensitive to route length: for a given base demand, longer routes involve higher operating costs and hence lower optimum frequencies.
- Average operating speed (range 15 km/hr to 50 km/hr). Optimum frequency was not very sensitive to average operating speed, within the range of speeds typically encountered.
- Level of peak congestion (heavy/moderate/other). Optimum frequency was relatively insensitive to the level of congestion.

More detailed results from these tests are given in Appendix A.

4.3 SPECIFIC ROUTE APPLICATIONS

The economic model was applied to 30 existing bus routes in Melbourne using data specific to their existing operations (demand, current frequency, route length, average speed and proportion of peak direction passengers). Optimum frequencies were derived for each service and these compared to existing frequencies.

Figure 1 compares the existing and 'optimised' frequencies for each route for the peak period. Figure 2 shows the comparable analysis for the off-peak. In both figures we also show the regression lines for the existing and optimum frequencies against demand.

The following conclusions may be drawn:

- There is considerable scatter in the pattern of optimum frequency v base demand results. This reflects the range of factors influencing the relationship, as examined in the sensitivity analyses noted in the previous section.
- On average, the results are generally consistent with those found in the generic analysis (Section 4.1).
- For peak periods, current service frequencies are on average generally above the optimum for low levels of demand (100-150 passengers/hour): but for higher demand levels, as experienced on most existing routes, current frequencies are below the optimum. At the highest levels of demand, optimum frequencies are on average more than 50% above the existing frequencies.
- For off-peak periods, optimum frequencies are somewhat (up to 25%) higher than existing frequencies. However, there are substantial differences (positive and negative) on individual routes.

Figure 1: Optimum and Existing Frequencies v Demand Levels, Selected Melbourne Bus Routes – Peak Period.

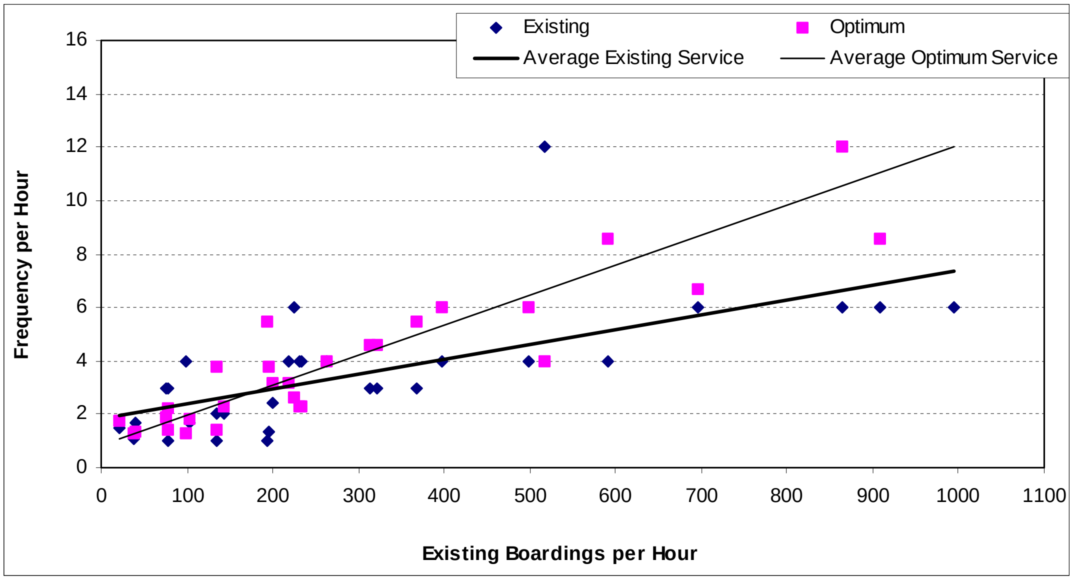
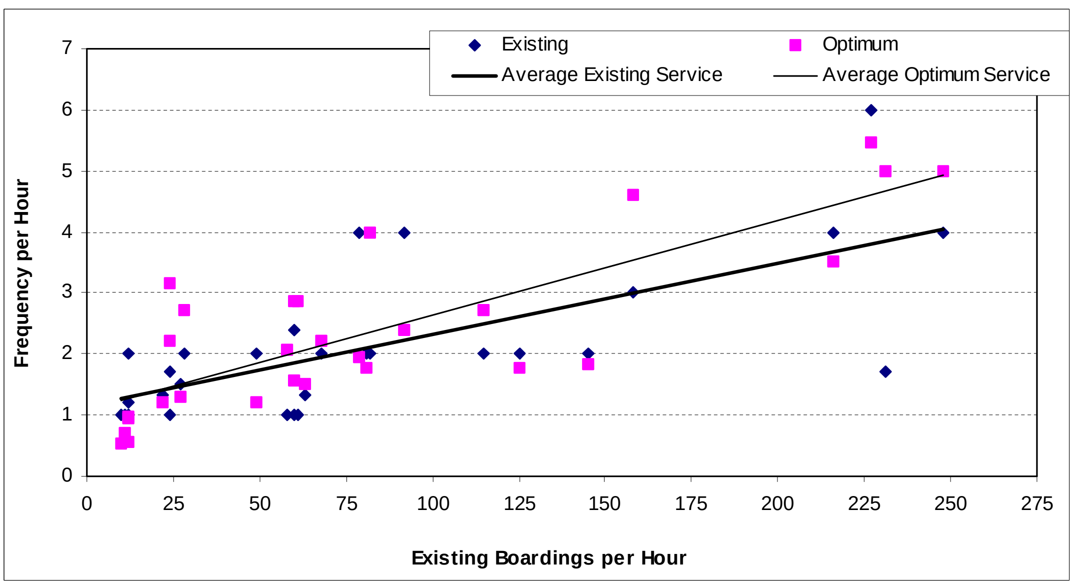


Figure 2: Optimum and Existing Frequencies v Demand Levels, Selected Melbourne Bus Routes – Off-peak Period



5. CONCLUSIONS

This paper has presented a new approach to determining optimum service frequency standards for bus routes in relation to levels of demand. This optimisation approach is based on social cost-benefit analysis, taking account of operator financial impacts, user (generalised) cost impacts and road system externality impacts (congestion, accidents and environment). The approach has been applied to 'generic' routes and also to a range of specific bus routes in Melbourne (where it indicates that optimum frequencies are generally higher than current frequencies). While the paper only covers the results for bus mode, equivalent modelling has been undertaken for Melbourne's tram and train services.

The SCBA model used is spreadsheet-based and, once developed, can be readily applied either generically or to specific routes. The approach has the significant advantage that it is consistent with the social cost-benefit approach used by many authorities (including DoI Victoria) to appraise urban public transport investment projects. Somewhat surprisingly, such an approach to determining public transport service standards does not appear to be used in other cities, either in Australasia or internationally.

6. REFERENCES

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APPENDIX A: GENERIC MODEL – SENSITIVITY TEST RESULTS

This appendix presents the results of the sensitivity tests on the generic model results, which are summarised briefly in Section 4.2.

A series of single variable sensitivity tests was undertaken, to examine how the optimum frequency results were affected by changes in the main 'supply' and 'demand' drivers, ie:

- Proportion of passengers in peak direction (range 50% to 100%)
- Route length (range 10 kms to 50 kms)
- Average operating speed (range 15 km/hr to 50km/hr).
- Level of peak congestion (heavy/moderate/other)

The results from these tests are summarised graphically in Figures A1 - A4.

The main findings may be summarised as follows:

Peak Direction Proportions (Figure A1)

- Optimum frequency is moderately sensitive to the proportion of passengers travelling in the peak direction: as the peak direction proportion increases, the proportion of passengers that may have to stand increases, and hence higher frequencies may be warranted.
- At a typical total peak (base) demand of 500 passengers/hour, optimum frequency almost doubles as the peak direction proportion increases from 50% to 100%.
- In the off-peak, the proportionate frequency increases are rather smaller as the peak direction proportion increases.

Route Length (Figure A2)

- Optimum frequency is moderately sensitive to route length: for a given base demand, longer routes involve higher operating costs and hence lower optimum frequencies.
- For a typical peak base demand of 500 passengers/hour, optimum frequency halves from 12 services/hour for a 10 kilometer route to 6 services/hour for a route of 40 kilometres or more.
- In the off-peak, optimum frequency is somewhat more sensitive to route length than in the peak.

Operating Speed (Figure A3)

- Optimum frequency is not very sensitive to average operating speed, within the range of speeds typically encountered. Increases in average speeds tend to reduce operating costs and hence increase optimum frequencies somewhat.
- At a typical peak base demand of 500 passengers/hour, optimum frequency increases from 6.6 services/hour at operating speeds of 10-20km/hr to 10 services/hour at speeds of 40km/hr or greater.

4 At a typical off-peak base demand of 150 passengers/hour, optimum frequency increases from 2 services/hour at an operating speed of 10 km/hr to about 4.4 services/hour at an operating speed of 50 km/hr.

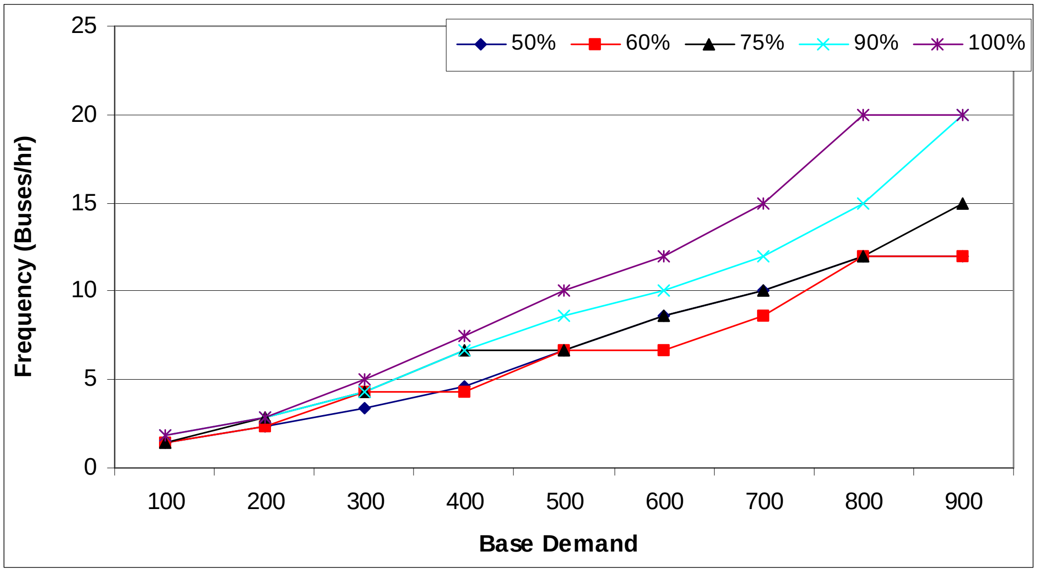
Level of Congestion (Figure A4)

4 Optimum frequency is generally not sensitive to the level of congestion, as much as this affects the unit benefits of people transferring to/from car travel.

4 At most levels of base demand, optimum peak frequency (as expressed by headways, in integer minutes) does not vary with the level of congestion; although in some cases higher levels of congestion result in somewhat higher optimum frequencies.

Figure A1: Optimum Frequency v Peak Direction %

(A) Peak



(B) Off-peak

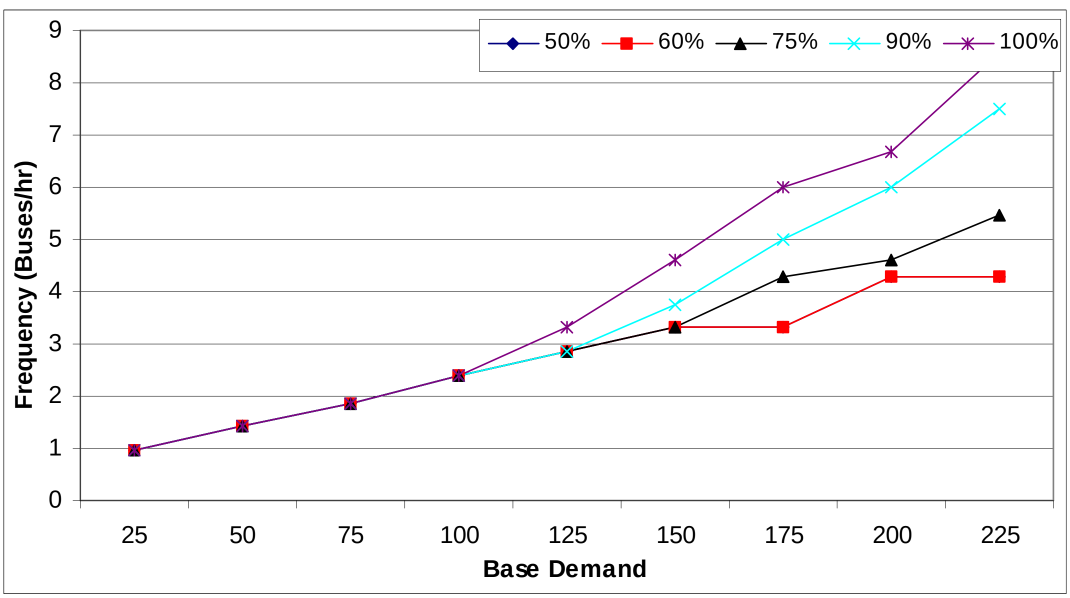
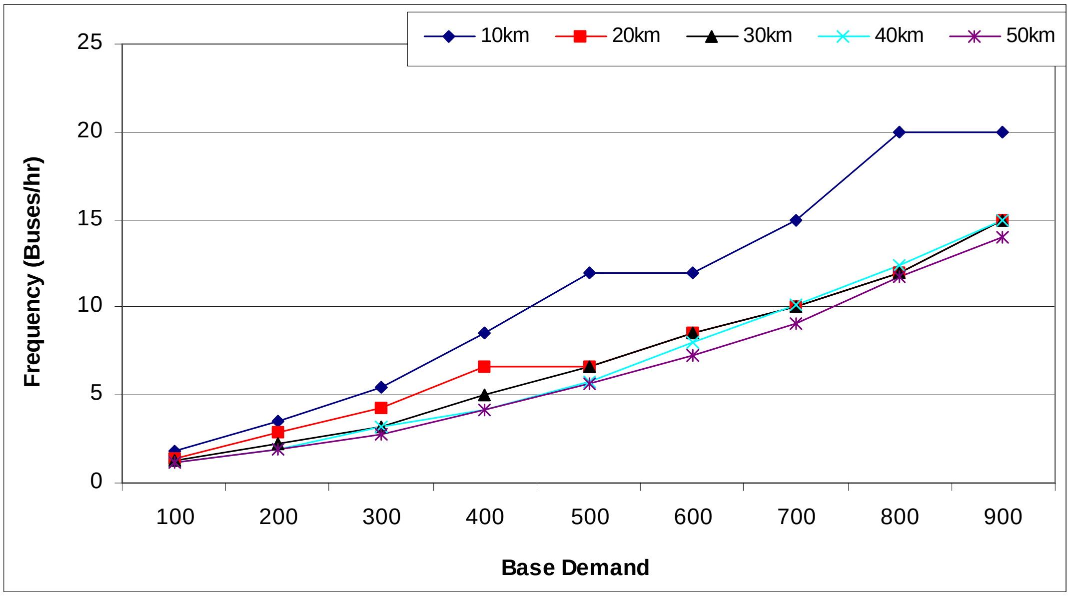


Figure A2: Optimum Frequency v Route Length

(A) Peak



(B) Off-peak

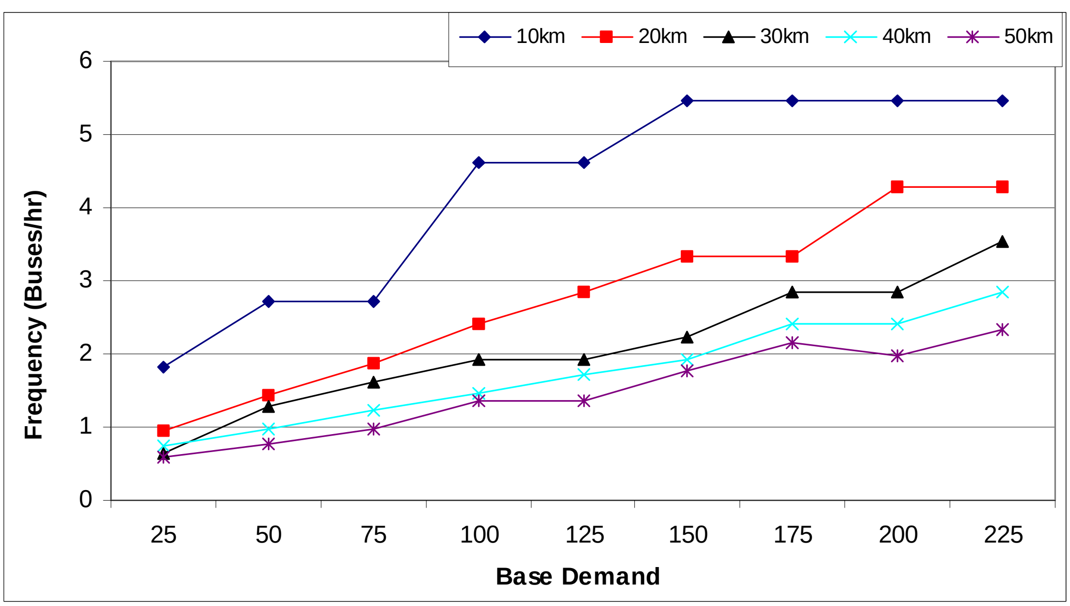
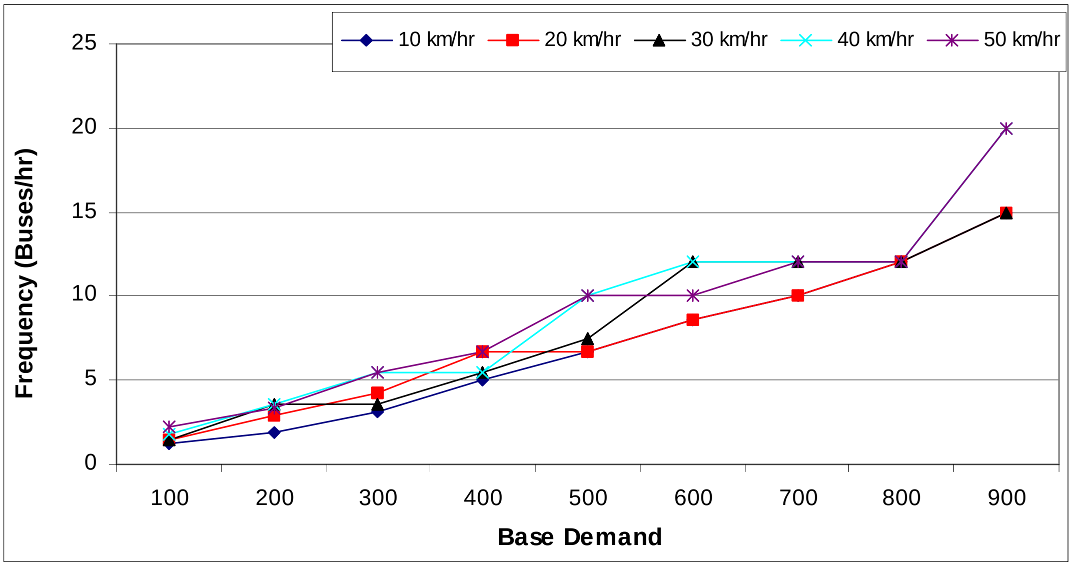


Figure A3: Optimum Frequency v Operating Speed

(A) Peak



(B) Off-peak

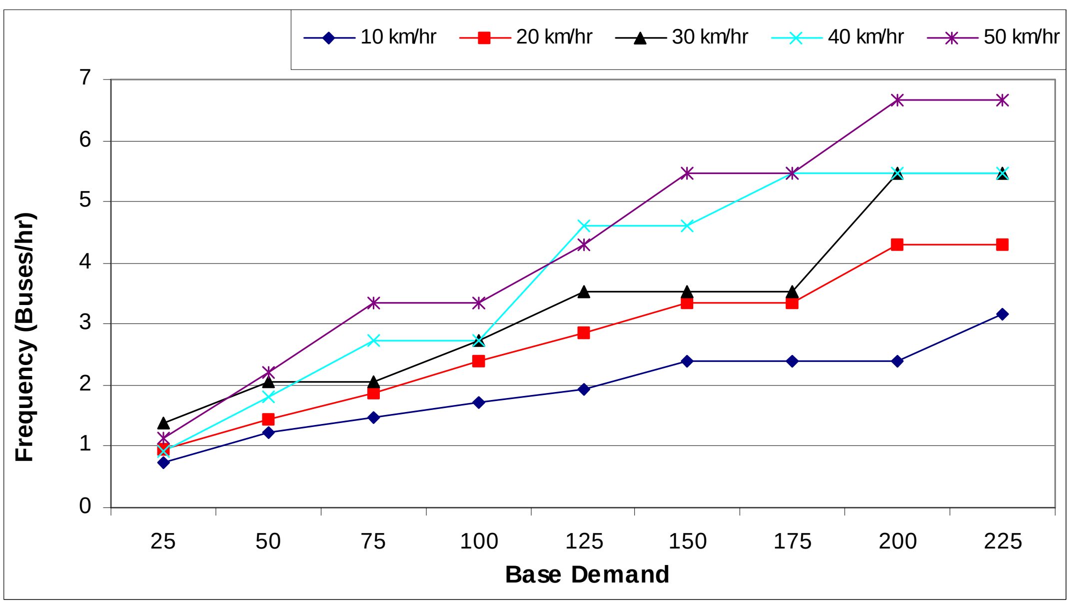


Figure A4: Optimum Frequency v Level of Congestion

Peak