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Passing Opportunities at Slow Vehicle Bays

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Abstract

Recent research investigated ways of analysing and providing for improved passing opportunities on rural highways in New Zealand. This paper focuses on the studies of the performance of slow vehicle bays. Field surveys at eight sites identified the effect of different features on usage and bunching reduction. The surveys observed higher levels of use than found overseas, however the effect on vehicle bunching was generally not significant. Minimum desirable lengths for slow vehicle bays were also reviewed and safety effects considered. From this, project evaluation methods using either simplified procedures or TRARR simulation modelling were developed.

1. Introduction

New Zealand's relatively rugged terrain and low traffic volumes have meant that virtually all its rural strategic routes have been built as two-lane highways. As traffic volumes have increased, increasing pressures have been placed on maintaining an adequate level of service. Passing opportunities, such as passing lanes and slow vehicle bays, provide a means to relieve these pressures and their construction is greatly encouraged by the general public.

Passing opportunities generate economic benefits by reducing travel times, as they release impeded vehicles from platoons[1]. Released drivers may then travel at their desired speed until they once again become trapped in slower moving platoons. When drivers are unable to overtake slower vehicles through lack of passing opportunities they are likely to become frustrated. This can lead to an increase in unsafe passing manoeuvres that can lead to crashes.

Some overseas national or state jurisdictions justify passing opportunity construction by means of warrant requirements. However Transfund New Zealand's project evaluation requirements (Transfund 2001) mean that specific benefits must be calculated, usually by means of a rural road simulation model, such as ARRB Transport Research's TRARR[2] package (Shepherd 1994).

1.1 Research Outline

Opus Central Laboratories carried out research for Transfund New Zealand to investigate ways of analysing and providing for improved passing opportunities on rural highways in New Zealand (Koorey & Gu 2001). The main objectives of this research were:

- To assess the effectiveness of no-overtaking delineation using modified (horizontal curve) warrant criteria. This was done using field surveys of driver overtaking behaviour on sections of limited passing sight distance, together with simulation models of proposed changes in criteria.
- To improve the Transfund simplified procedures for passing lane analysis using field surveys and TRARR modelling. In particular, the predicted passing demand was compared against observed vehicle bunching and willingness-to-pay for driver frustration was reviewed.
- To investigate the use and performance of slow vehicle bays using field surveys. These were then compared with TRARR and theoretical models.
- To develop a framework for future development of detailed rural simulation modelling in New Zealand. This was based on a review of TRARR and other common simulation tools available.

This paper focuses on the slow vehicle bay investigations, and subsequent analysis and suggested project evaluation procedures for them. Further details on this and the other research objectives can be found in the related research report (Koorey & Gu 2001).

2. Slow Vehicle Bays

Slow vehicle bays (SVBs) are the formalised use of very short lengths of widened, unobstructed sealed shoulder on two lane rural roads, to allow slow moving vehicles to pull out of a traffic lane and give following vehicles an opportunity to pass. Drivers of vehicles in SVBs do however have to ensure that their way is clear before they can re-enter the traffic lane. In New Zealand, SVBs are commonly used where the terrain and traffic volumes cannot justify construction of a full passing lane; and more than 70 have been built around the country, mainly on state highways.

Previous New Zealand research into driver frustration and simplified passing models (Tate 1995, Koorey *et al* 1999) has been primarily concerned with the provision of passing lanes. Other means of providing passing opportunities, including SVBs, were not specifically addressed. It was recommended that, in the interim, SVB evaluations should be done using the same techniques as for

[1] Platoon – moving group of queued vehicles led by a slower vehicle, also known as a "bunch".
[2] TRARR – **TRA**ffic on **R**ural **R**oads, computer model package for rural road simulation.

passing lanes (i.e. treated like a short passing lane). However separate research to assess the performance and appropriateness of these alternative passing measures was recommended.

To investigate these issues further, a number of approaches were taken:

- Recent overseas and local studies were reviewed to assess likely benefits from SVBs.
- Field data at a number of SVB sites were collected and analysed. This was compared with simplified models of the equivalent sections.
- TRARR models of the surveyed sites were used to confirm field data findings.

3. Literature Review

Transit New Zealand (2000) recommends some minimum lengths for SVBs, in relation to mean traffic speed on the road in the vicinity of the bay, and these are given in Table 1.

Table 1 Current minimum lengths for slow vehicle bays

Mean Traffic Speed (km/h)	Minimum Length (m) of SVB * (excluding entry/exit tapers)
30	60
40	60
50	70
60	80
70	100
80	135
90	175

*Minimum bay length is based on the assumption that a vehicle will enter a SVB travelling at least 8km/h slower than the mean speed of traffic on the section of road and it will be able to stop, if necessary, within half the length of the bay while using a deceleration rate not exceeding $3m/s^2$.

Transit also recommends that SVBs should not be longer than 300m, because drivers may then treat them as a conventional passing lane (which ideally should be at least 800m in length). Similarly FHWA (1987) recommends that SVBs (called "turnouts" in the US) should be no longer than 600ft (190m). The implications of this in terms of performance are discussed in Section 5.3. Another recommendation by Transit is that SVBs should not be mixed with passing lanes along a route, again to minimise driver confusion. Having said that, there are instances in New Zealand where existing SVBs have been converted to exceptionally short passing lanes to meet this policy.

3.1 Operational Effectiveness

SVBs can be useful in providing passing opportunities on two-lane highways, although they are not as effective as passing lanes. Harwood & St John (1985) concluded that a single well-designed and well-located SVB can be expected to provide 20% to 50% of the number of passes that would occur in a 1.6 km passing lane in level terrain.

At sites that were surveyed by Harwood & St John (1985), the percentage of platoon leaders using the SVB ranged from 9.5% to 29.5%. The results are in agreement with the range of SVB usage (2.8% to 36%) observed by Rooney (1976).

In a passing lane, the passing vehicles represent self-selected drivers with higher desired speeds than their immediate platoon leader. By contrast, at a SVB, the passing drivers may or may not have higher desired speeds; they may simply continue downstream as a new platoon leader. Thus, a SVB may not provide as much reduction in bunching per passing manoeuvre as a passing lane.

3.2 Safety Effectiveness

Rooney (1976) found no evidence that a significant number of crashes occur at SVBs. Sixteen SVBs in California were found to have only one crash per 80,000 SVB users (not all vehicles).

Harwood & St John (1985) evaluated 42 SVBs in three US states and found that typical SVBs experience only one crash every 5 years. At seven SVBs where usage rates were observed, the evaluation found only one crash per 400,000 SVBs users. A safety comparison between the SVB sites and adjacent sections of conventional two-lane highway found that the SVB sites had crash rates that were approximately 30% lower than the adjacent untreated sites.

Field observations by Harwood & St John found that 5% to 10% of SVB users caused a traffic conflict (such as braking by a following vehicle) when re-entering the highway from a SVB, but the crash experience associated with this manoeuvre was minimal. This finding suggests that following drivers anticipate the possible return of the SVB users to the through lanes and that their braking is a controlled response that does not indicate the likelihood of a collision.

Transit New Zealand commissioned a safety review of ten SVBs on SH29 over the Kaimai Ranges (Nicholson & Brough 2000). Field observations showed that 10% to 42% of overtaking manoeuvres involved perceivable vehicle braking. At most sites only 0%-2% of overtaking manoeuvres involved the hard braking which may potentially cause crashes. The highest proportions of hard braking were found at two sites (with 10% and 18% respectively). Both sites did not have adequate forward sight distance from the merge point, and the design of the merge area was poor.

Nicholson & Brough found that vehicles catching up to slow vehicles near the end of the SVBs had difficulties slowing to fall in behind, and seemed almost obliged to continue on and overtake at or past the merge area. Often the overtaking vehicles were observed to cross the centreline to pass a slow vehicle. However, as forward sight distance was good in most cases with an opposing passing lane present and low traffic volume, this manoeuvre was not considered a major safety problem.

During the survey, a proportion of drivers were observed using the SVBs when not being followed and this may indicate that drivers may perceive them to be the same or similar to passing lanes. This perception may have implications for safety because the SVBs generally have lower geometric standards than passing lanes (i.e. more suited to lower speeds). This may be a driver education issue that needs to be addressed in New Zealand.

4. Field Surveys

To establish the typical use of SVBs locally, field surveys were carried out at a number of sites. These monitored the proportion of vehicles using the SVBs and amount of overtaking occurring, and the change in the proportion of bunched vehicles.

A range of lengths, gradients and traffic volumes were sought where possible. Over 70 sites were originally identified. From these, eight sites were selected, listed below in Table 2. The last three (Kaimai) sites were surveyed together to assess the effect of a series of SVBs.

Table 2 Slow vehicle bay sites monitored in the field surveys

Site Name	Location	SH RS/RP	Length	Grade	AADT	%HCVs
Towai	South of Kawakawa	SH1N 113 / 10.1-10.0	90m	+2%	5200	17
Waikoau Hill	North of Whirinaki	SH2 608 / 5.2-5.7	100m	–7%	1600	18
Kilmog	North of Dunedin	SH1s 667 / 14.2-14.7	450m	–10%	3900	11
Rahu Saddle	East of Reefton	SH7 152 / 5.9-6.0	90m	+7%	1900	20
Palmers Mill South	North of Wairakei	SH5 111 / 9.7-9.9	250m	+5%	3200	12
Kaimai Deer Farm	West of Tauranga	SH29 21 / 19.1-18.8	200m	–8%	5900	15
Old Kaimai Road	West of Tauranga	SH29 21 / 15.9-15.7	200m	–5%	5900	15
Cannonball Deer Farm	West of Tauranga	SH29 21 / 15.0-14.6	150m	–9%	5900	15

SH – State Highway number; RS – Reference Station; RP – Route Position (km)

AADT – Annual Average Daily Traffic volume; HCV – Heavy Commercial Vehicles.

4.1 Methodology

Between June 2000 and January 2001, field surveys were conducted at the eight sites. Two surveyors were used at each SVB site to collect observation-based information. One surveyor recorded the proportion of following (i.e. bunched) vehicles immediately before the SVB, and the level of use of the SVB, i.e. which vehicle types were using it. Another surveyor collected bunching information at some distance after the end of the SVB. In the initial four surveys the vehicles were classified into "cars" and "trucks"; later a "recreational vehicle" category was also used for the Palmers Mill South and three Kaimai sites. This last category was designed to cover the likes of campervans and towing vehicles. Previously, towing vehicles were included with "trucks".

For the three closely-sited Kaimai surveys, automated (MetroCount) vehicle classifiers were also set up ~100m before each SVB and ~500m after the last one. These measured the individual vehicle classes, speeds and headways (vehicle spacings). Survey periods lasted for 2-4 hours, with half-hour recording intervals.

4.2 Results

Survey results from the eight sites are summarised overall in Table 3. For the Rahu Saddle site, the traffic volume was very low (about 10-15 veh/hr). The likely reason was that at Rahu the AADT is very seasonal and the tourist season was over at the time of the survey.

Table 3 Summary of survey results from slow vehicle bay sites

Site Name	No. of Vehicles (one-way)	%Trucks, Recreation Vehicles	% Bunching Before	% Bunching After*	%Veh Using SVB	%Trucks and Recreation Vehs Using SVB
Towai	542	14.0	40.2	***40.9***	7.0	35.5
Waikoau Hill	255	23.5	29.8	20.1	10.2	31.7
Kilmog	475	10.7	32.2	24.8	19.4	84.3
Rahu Saddle	60	25.0	1.7	***5.2***	40.0	80.0
Palmers Mill South	516	17.2	22.7	***29.8***	20.9	74.2
Cannonball Deer Farm	504	22.2	43.8	***44.1***	9.9	40.2
Kaimai Deer Farm	433	21.9	34.9	31.2	15.0	62.1
Old Kaimai Road	422	24.9	45.7	43.2	13.5	46.7

* %Bunching After values that are higher compared with %Bunching Before, are ***italicised in bold***.

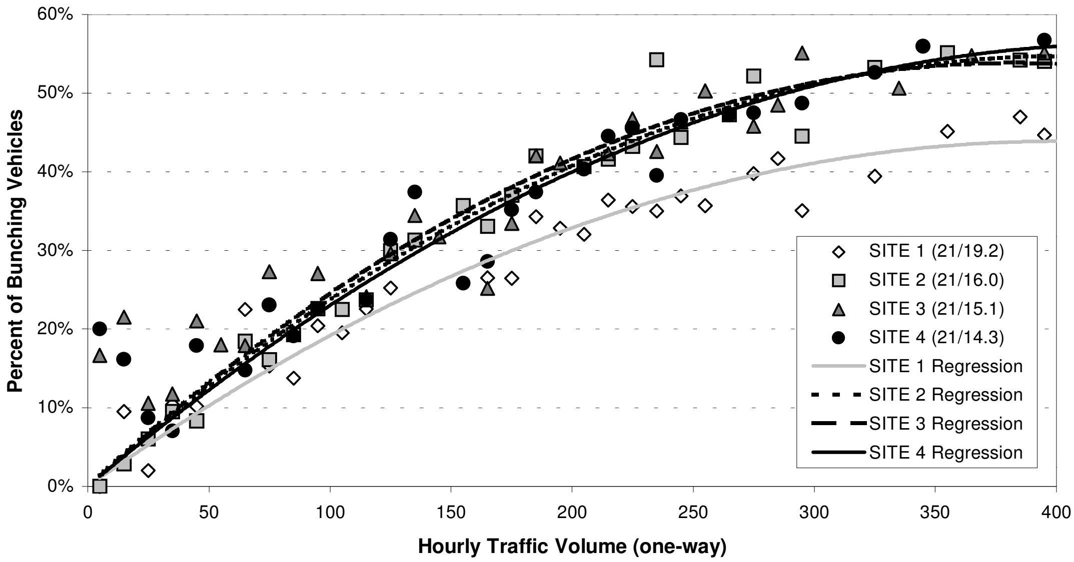
Rather disappointingly, only four of the surveyed SVBs appeared to reduce the proportion of following vehicles downstream (although only Palmers Mill showed a significant rise). However this may be because the downstream survey locations were not far enough away to allow overtaking vehicles to clear the overtaken vehicles. The fact that generally 10%-20% of all vehicles used the SVB suggests that the true proportion of following vehicles likely to benefit is probably greater.

Harwood & St John (1985) had also found only a 2% reduction in bunching on average immediately downstream of a SVB, and possibly up to another 4% in the following 450m. However if the alignment is fairly steep or winding downstream, bunching may not reduce any further or may even increase. The very nature of many SVB locations often provides only very short-term benefits.

This short-term benefit is confirmed by the automatic classifier surveys on the Kaimai sites (SH29). The four classifier sites provided before and after data for the three SVBs investigated, over a distance of about 5km. For each site, the level of bunching was related to the traffic volume in hourly increments. Figure 1 shows how the bunching rate varies at those four sites with changing traffic volumes.

If these three SVBs performed in a similar manner to passing lanes, the proportion of bunching vehicles should decrease from Site 1, through Sites 2 and 3, to Site 4. However, there is no discernible trend between the latter three sites. Only Site 1 (located before all of the SVBs) is significantly different, and in fact displays lower bunching levels than the succeeding sites.

Figure 1 Bunching levels at Kaimai SVB sites



The greater physical gap between this site and the remaining three sites may explain this difference; and the winding alignment between the sites is likely to have caused the increased bunching levels. The remaining SVBs have only succeeded in keeping the status quo in terms of bunching.

It must be remembered that the passing vehicles are not self-selected at a SVB, and may not have higher desired speeds than the vehicles they were following. They may just simply become new platoon leaders at the downstream of the SVB, with little change in bunching.

5. Analysis of Results

5.1 Vehicle Types Using SVBs

SVBs are designed to provide space for typically slow moving vehicles, such as trucks and recreation vehicles. Although quite a few car drivers are likely to use SVBs too, it begs the question of whether SVBs are more effective where proportions of slower moving vehicles are greater.

Guidelines like Transit New Zealand's *Geometric Design Manual* (TNZ 2000) suggest that SVBs are rarely used by trucks and they are more suited to recreational vehicles and/or tourist routes where drivers of slow vehicles are usually more willing to let faster vehicles pass. Table 4 summarises the breakdown of vehicle types among SVB users at the surveyed sites.

Table 4 Vehicle types of SVB users recorded at the survey sites

Site Name	Recorded SVB Users	Proportion of SVB Users (%)			%SVB Users Not Followed
		Cars	HCV	Rec. Vehs	
Towai	38	28.9	71.1*		5.3
Waikoau Hill	26	26.9	73.1*		15.4
Kilmog	92	53.3	46.7*		39.1
Rahu Saddle	24	50.0	50.0*		83.3
Palmers Mill South	108	38.8	26.9	34.3	43.5
Kaimai Deer Farm	65	9.2	87.7	3.1	23.1
Old Kaimai Road	57	14.0	86.0	0.0	19.3
Cannonball Deer Farm	50	10.0	82.0	8.0	2.0

* Rec. Vehs (Recreational Vehicles) were not recorded separately.
HCV – Heavy Commercial Vehicles.

From the sites surveyed, most of the SVB users were trucks, and in most cases they were a relatively high proportion of the total truck numbers surveyed (30%-50%). Comparison with Table

3 shows that the sites with the highest rates of car usage in the SVBs also had the lowest proportion of HCVs in the traffic stream (but still the highest proportions of HCVs also using the SVB).

Table 4 also summarises the proportion of vehicles observed using SVBs even when no vehicles were following them. No significant difference in the incidence of this behaviour was observed between vehicle types. This suggests that the road alignment may be causing this and in some cases drivers may be mistaking it for a passing lane. Certainly the long SVBs at Kilmog and Palmers Mill have high rates of SVB users not followed. In other cases, drivers may be taking advantage of the extra road width to ease the effective curvature and travel the curve at higher speeds.

SVBs are designed to encourage slow platoon leaders (i.e. vehicles at the front of queues) to move over and let others pass. Table 5 shows the proportions of platoon leaders using SVBs at the surveyed sites (Rahu Saddle had only one platoon). These figures do not include those SVB users who were not followed (Table 4 gives more details of these).

Table 5 Use of SVBs by platoon leaders related to length of queues

Site	No.Platoon Leaders	%Queues with >1veh	Proportion of Leaders Using SVB			
			Overall	Queue of 1	Queue of 2	Queue of 3+
Towai	116	43.1	27.6	30.3	23.5	23.3
Waikoau Hill	46	34.8	39.1	30.0	46.6	42.9
Kilmog	95	36.8	48.4	46.7	57.2	55.6
Palmers Mill South	75	30.7	74.7	73.1	97.0	87.5
Kaimai Deer Farm	82	42.7	57.3	46.8	86.0	82.4
Old Kaimai Road	90	55.6	40.0	32.5	60.9	60.0
Cannonball Deer Farm	116	48.3	40.5	35.0	62.1	60.9
OVERALL	**621**	**42.7**	**45.4**	**42.4**	**55.1**	**54.9**

Platoon – refers to all bunched vehicles including the lead vehicle.
Queue – refers to the vehicles behind the lead vehicle.

The overall rates are significantly higher than those found by either Harwood & St John (1985) or Rooney (1976). These may be a consequence of better designed SVBs here, or a more prevalent habit in New Zealand of using SVBs. The figures in Table 5 also show that drivers with more than one vehicle following them are more likely to use a SVB, but no distinction between queues of two and queues of three or more is apparent.

5.2 Vehicle Bunching Near SVBs

The Borel-Tanner Distribution (BTD) provides a reasonable model for describing the distribution of bunch (or platoon) sizes in traffic on two-lane, two-way rural roads. The probability of a bunch size b is given by

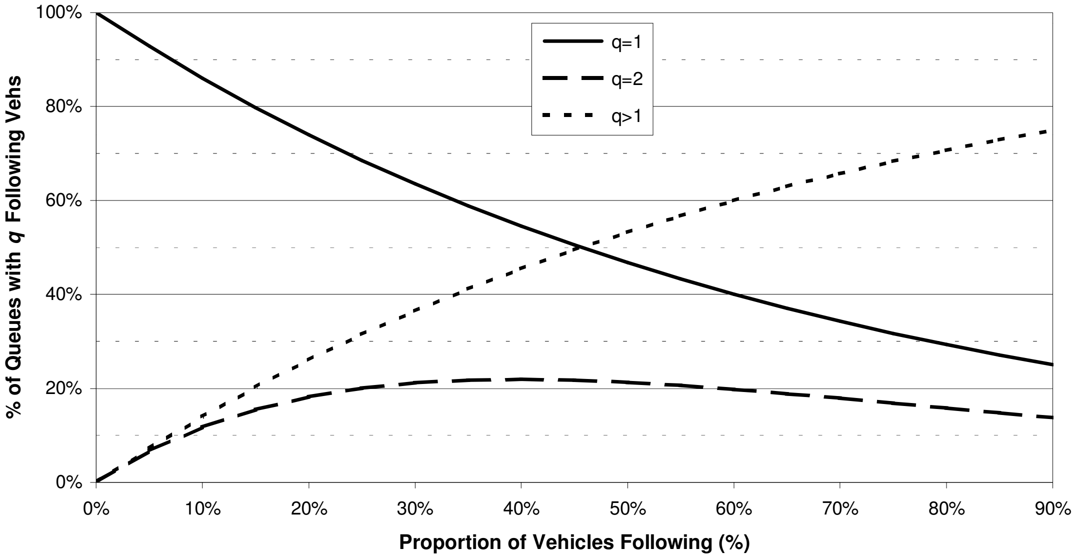
$$P(b) = [bf \exp(-f)]^{b-1} \frac{\exp(-f)}{b!} \quad (1)$$

for $b = 1,2,3, \ldots$ and where f is the proportion of vehicles following. This is also related to the mean bunch size $b_m = 1/(1-f)$, or alternatively, $f = (b_m - 1)/ b_m$.

Analyses of the Towai, Waikoau Hill and Kilmog sites found correlations of better than $r^2 = 99\%$ between the observed distribution of bunch sizes (both before and after the SVB) and that predicted by the BTD. On this basis, further analysis has been done using the BTD to model SVB bunching.

The expected proportion of various bunch sizes for different vehicle-following rates can be derived using the BTD. Single (lone) vehicles are shown to comprise the greatest proportion of ‘bunches’, although they only make up the majority of vehicles up to about 32% following. For SVB analyses, only vehicles with following queues are of interest, so single vehicles can be ignored. Figure 2 shows the proportion of queues with one or two vehicles following respectively, and the proportion for all queues of more than one vehicle. For comparison, from the previous data presented, the typical vehicle-following proportions observed at the surveyed sites were between 20%-40%.

Figure 2 Distribution of vehicle queue sizes to proportion of vehicles following



The results highlight that queues of only one following vehicle are the majority only when less than 45% following overall is observed. Note that the plot shows the relative proportions of queues, not vehicles. In terms of vehicle numbers, drivers are in fact more likely to find themselves in a multi-vehicle queue from about 23% following. Therefore queues of two or more vehicles-following play a significant part when considering the operation of SVBs.

5.3 Minimum Length for Slow Vehicle Bays

In current New Zealand guidelines (Transit NZ 2000), the minimum length for SVBs is based on the assumption that the vehicles entering the bay can stop safely if necessary. It is evident however that many drivers do not want to slow down significantly in SVBs, given the number of potential conflicts observed at the merge taper. This may partly be related to some drivers who feel that, as they have conceded to other traffic sufficiently, it is now their "right" to be able to re-enter the traffic stream without delay. Still others may be under the impression that the merge at the end of the SVB is similar to a passing lane in that no lane has priority over the other.

The use of SVBs may also be affected if drivers do not feel that they can maintain their momentum in the length available while allowing following vehicles to pass safely. This has implications for assessing travel-time benefits of SVBs. Drivers may not want to enter a SVB that slows them down inordinately. Conversely, those who do use the SVB may lose significant time that will cancel out the time savings achieved by the overtaking vehicles.

If we change the length assumption so that vehicles entering the bay can still travel at their own speed with little delay, then we can calculate the new minimum length required. Table 5 above showed that about 30%-50% of platoon leaders were followed by at least two vehicles. Therefore it is pertinent to examine the lengths required to pass at least one or two vehicles.

Consider a slow vehicle, travelling at u km/h, being followed by a vehicle that would like to travel at v km/h. The relative distance required to overtake the lead vehicle is d m (from a point behind the lead vehicle where overtaking begins to a point in front when completed). While this gain is being made on the overtaken vehicle (at a relative speed of v-u), the overtaking vehicle will be travelling forward at its desired speed (v). Therefore the required road distance, L, to complete this manoeuvre is:

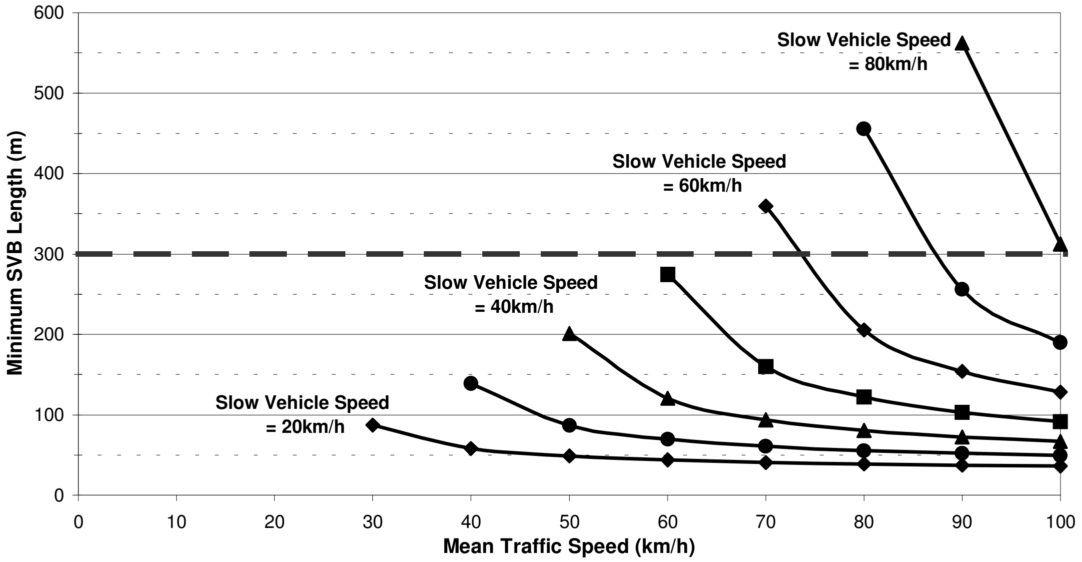
$$L = v.d / (v-u) \quad (2)$$

A reasonable distance *d* might be to allow a one-second clear gap either side of the overtaken vehicle, plus the length of the vehicles concerned. From the survey data above it is reasonable to assume, say, a 6m car overtaking a 12m truck, will require a distance of:

$$d = u/3.6 \times 2 + (6 + 12) \quad (3)$$

So, for example, a vehicle wanting to travel at 70 km/h to overtake a vehicle travelling at 50 km/h would require L = (50/3.6×2+18)×70/(70-50) = 160.2m to overtake without impeding the progress of the slower vehicle. Figure 3 plots the required distances for various combinations of desired mean traffic speeds and slow vehicle speeds.

Figure 3 Minimum length of SVB, for one vehicle to overtake



For high-speed situations (mean traffic speed >60 km/h), with <20 km/h difference in vehicle speeds, the minimum required length is greater than the recommended maximum of 300m. If two following vehicles wanted to overtake the lead vehicle safely, then a longer distance *d* would be required, to allow for the extra vehicle length and clear gap. An even greater minimum length is then required, with even more situations requiring lengths greater than 300m. Table 6 summarises the above findings in a form similar to the existing lengths in Table 1.

Table 6 Recommended minimum SVB lengths

Mean Traffic Speed (km/h)	Minimum Length of Slow Vehicle Bay (m)*	
	followed by 1 veh	followed by 2 veh
30	90	120
40	140	195
50	200	285
60	275	395
70	360	520
80	455	660
90	560	815

*Assumes that a vehicle will enter a SVB travelling at about 10 km/h slower than the mean speed of traffic on the section of road and it will **not** be delayed.

Application of these values would require estimation of the likelihood of queues of more than one vehicle being present in the traffic stream, as determined from field surveys on-site and compared with Figure 2. On steeper gradients it may be possible to use a greater speed differential to reflect the two conflicting traffic streams, in which case the minimum lengths from Figure 3 could be used.

To maintain a 300m maximum length, the above findings suggest that SVBs should only be located where the mean traffic speed is less than about 60km/h. Where traffic volumes are greater and longer queues are more likely, even lower mean speeds are preferable before considering a SVB.

6. Project Evaluation of SVBs

In the current *Project Evaluation Manual* (Transfund 2001), the benefits of SVBs are evaluated by the same simplified procedure used for passing lanes. However, a SVB generally cannot provide as many passes as a passing lane and neither can it provide as much reduction in the proportion of platooned vehicles. SVB users will also be delayed when they have to give way to the following vehicles at the exit of the SVB. Therefore, using the simplified procedure for passing lanes will probably over-estimate the benefits provided by SVBs.

With low traffic volumes, SVB users have little chance to be delayed but, with few users, the SVB does not provide many travel-time savings at all. With high traffic volumes, SVB users are likely to be caught up by following vehicles and delayed at the SVB exit, offsetting the travel-time savings of overtaking vehicles. Hence we cannot expect much overall travel-time benefits by the SVB.

Therefore, claiming only the frustration benefits, as measured by the reduction in the percentage of bunching vehicles (PEM), and possibly some safety benefits, may be more realistic and reasonable. Either TRARR modelling or simplified procedures are ways of analysing these effects.

6.1 TRARR Models

An option for handling SVBs is incorporated into TRARR (known as "passing bays" in TRARR terminology). Though TRARR does not consider the length of a SVB and treats it as a stop, it may still provide reasonable output because most SVBs are generally very short. To test the validity of TRARR modelling of SVBs, two models were built to simulate the Waikoau Hill and Kilmog SVBs (being the two SVBs that most effectively reduced the platooned vehicles). The site models were calibrated and validated with the data from field surveys.

State highway road geometry data were used to create a TRARR road file surrounding each site. TRARR was then run using the same volumes, %HCVs and initial %Following as observed in the field. The downstream %Following was then compared with the observed field data.

TRARR uses a PBAYS file to specify the location of and parameters associated with SVBs. Modelling with the default parameters provided by ARRB gave a poor fit with the observed data. Inspection of the PBAYS file revealed that few vehicle classes were specified to use the SVB. In particular some heavy vehicles would never use SVBs, while other vehicles would only use them when they had many vehicles queued behind them. Based on the field surveys, some adjustments were made to the PBAYS parameters, resulting in a far better fit. Interested practitioners are welcome to contact the author of this paper for an electronic copy of the updated PBAYS file.

TRARR models SVBs as a point where slow vehicles can pull aside and stop while being overtaken. They join the traffic again only when there is no vehicle behind. Hence the travel-time savings for overtaking vehicles are greatly offset by the delays experienced by those SVB users. In reality, some of those vehicles should be able to travel at their own speed in the bay without delay while being undertaken. Therefore, TRARR under-estimates the actual travel-time savings.

One solution to assess travel-time savings may be to model the SVB as a short passing lane. However, this is likely to over-estimate travel-time savings. The true answer is probably somewhere between these two values and will be dependent on the likelihood of overtaken vehicles having to slow down or stop. The previous discussions on SVB use and minimum SVB lengths should be applied to assess this likelihood and to derive a realistic time saving. For example, a fairly short SVB with high volumes is likely to be more realistically modelled using PBAYS, while a longer or lower volume site may be more accurately modelled as a passing lane.

6.2 Simplified Modelling of Frustration Benefits

As seen above, this change in vehicles following can be reasonably assessed by TRARR. However the effort required to do this may not be justified for many small SVB projects. The simple nature of SVB interactions allows a theoretical approach to be developed instead.

At a SVB, where the queuing proportion at the entry is a (as measured in the field), the remaining proportion must either be leading a bunch or be on their own. The number of bunches, including isolated single vehicles, is therefore equal to

$$(1\text{-}a) \times Volume \qquad (4)$$

Assuming that vehicle bunching can be modelled using BTD as discussed in Section 5.2, the probability of a 'bunch" of size 1 (i.e. single vehicle) is given by:

$$P(1) = e^{-a} \qquad (5)$$

Therefore we can estimate that the number of bunches, excluding those of size 1, is

$$(1\text{-}a) \times Volume \times (1\text{-}e^{-a}) \qquad (6)$$

Assume the proportion of platoon leaders who would use a SVB is s, and that the next vehicles following them would no longer be bunched. Therefore the number of vehicles freed up are:

$$(1\text{-}a) \times Volume \times (1\text{-}e^{-a}) \times s \qquad (7)$$

The effect on the overall bunching proportion can be seen by dividing by the volume. Therefore the bunching proportion, b, at the end of the bay can be estimated by:

$$b = a - [(1\text{-}a) \times (1\text{-}e^{-a}) \times s] \qquad (8)$$

This formula relies on the overtaken vehicle not continuing to be part of the following queue. This may not be the case if some following vehicles had similar desired speeds and were quite content to follow. However it should provide a reasonable approximation of bunching reduction.

From the field survey, we know that on the average 45.4% of platoon leaders would move to the SVB and let the following vehicles pass (see Table 5). By applying this figure to the formula above, the bunching rates at the end of the Waikoau Hill and Kilmog SVBs can be calculated.

6.3 Assessment of Methods

The outputs from both the TRARR models and the simplified bunching formula are compared with the survey results in Table 7.

Table 7 Comparison of SVB Field data with TRARR Models and Simplified Bunching Formula

Site	%Following at Start	%Following at End			*Difference*	
		Field	TRARR	Formula	*TRARR*	*Formula*
Waikoau Hill	29.8	20.1	22.5	21.6	*+2.4%*	*+1.5%*
Kilmog	32.2	24.8	26.1	23.7	*+2.0%*	*-1.1%*

The differences are acceptable, and hence we can say that either method is adequate for predicting the bunching rates after a SVB. Therefore, they can be applied to the calculation of the frustration benefits from a proposed SVB. The parameter s (the proportion of those platoon leaders who would use a SVB) cannot be obtained directly since the SVB is not built yet. However, a value can be estimated either from other similar existing SVBs or based on the findings from this research.

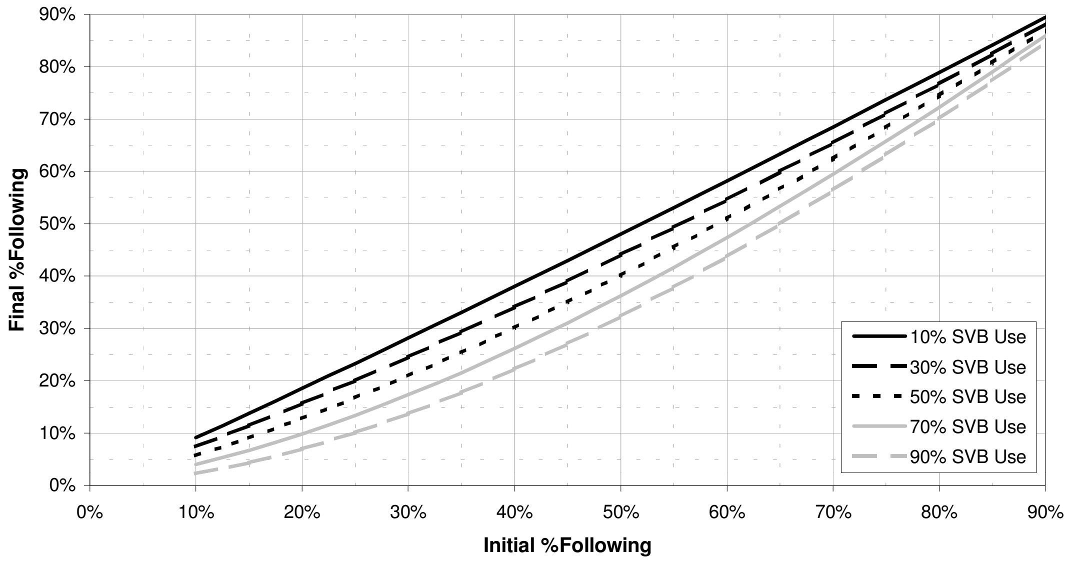
To assist in determining the likely improvement, a range of SVB use rates have been applied to various initial bunching rates to determine the likely reduction in bunching. Figure 4 shows the results, allowing easy interpolation.

7. Conclusions

Field surveys and subsequent desktop analysis of eight slow vehicle bay (SVB) sites in New Zealand, together with literature review, revealed:

- Unlike passing lanes, SVB use appears to be very dependent on the location and design of each site; a poorly placed or insufficiently long SVB can suffer low usage and provide little benefit.

Figure 4 Theoretical improvements in %Following at SVBs



- Generally 30%-60% of platoon leaders use SVBs, a higher rate than that found in overseas studies. Use increased by >10% on average for platoons with more than one vehicle following.
- SVBs do not greatly reduce the proportion of bunched vehicles, particularly in winding alignments, with less than 10% (absolute) reductions observed at all sites (and some increased). The short-term benefits however probably do provide some reduction in driver frustration.
- Trucks and recreational vehicles typically made up 70%-90% of all vehicles using SVBs, with trucks in particular being high users (30%-50% of all trucks). Some sites that looked more like passing lanes had higher car use.
- Evidently confusion by drivers exists over the use of some SVBs. This is seen in their relatively high use by vehicles when no one is following and in conflicts at SVB merges.
- The Borel-Tanner Distribution provided an excellent model for bunch sizes observed at SVBs. Using this model, it is clear that queues of two or more vehicles following play a significant part when considering the operation of SVBs, particularly where vehicle following is >20%.
- The current New Zealand guidelines for SVB lengths may be inappropriate, given the number of merge area conflicts and multi-vehicle queues. An analysis of minimum required lengths to allow one or two vehicles to safely pass another vehicle without greatly impeding it showed that many high-speed situations require longer than the recommended 300m maximum length.
- For a short SVB with sufficient queuing, any travel-time benefits gained by the passing vehicles may be negated by the delay placed on the overtaken vehicle.
- SVBs modelled by TRARR, using a modified PBAYS file, provide a realistic reduction in the proportion of platooned vehicles. However TRARR under-estimates SVB travel-time savings, while re-modelling the SVB as a short passing lane is likely to over-estimate. The true answer will be dependent on the likelihood of overtaken vehicles having to slow down or stop.
- A simplified formula has been developed that appears adequate for predicting bunching rates after a SVB, given initial on-site field surveys, and can be applied to the calculation of the frustration benefits from a proposed SVB.
- The safety benefits of SVBs are not entirely clear. A poorly designed merge area or unacceptably short SVB may cause a high level of serious conflicts. Downstream crash savings beyond the site may be very limited, but at the site savings are likely if the new SVB provides a safer alternative to previous overtaking attempts at that site.

8. Recommendations

The following items are recommended for further investigation or action.

- SVBs should be clearly marked distinctly from passing lanes, to prevent confusion of the two by drivers. The length of each site should also be considered when deciding what they qualify as.
- Driver education should be carried out on the purpose and correct use of SVBs.
- To maintain a 300m maximum recommended length, SVBs should be located only where the mean traffic speed is less than about 60km/h. Where traffic volumes are greater, even lower mean traffic speeds are preferable before a SVB is considered.
- An updated version of TRARR's PBAYS file, developed in this research, should be used for TRARR SVB modelling in New Zealand. For assessing travel-time savings, a comparison should also be made against modelling the site as a short passing lane instead.
- Travel-time savings from SVBs should only be considered where the site does not cause undue delay to those vehicles being overtaken that are waiting to re-enter the traffic stream.
- An alternative simplified evaluation procedure should be used for SVBs based on these research findings, instead of the existing simplified passing lane procedures.

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