MANUSCRIPT NO. TE/2005/023375

PASSING OPPORTUNITIES AT SLOW VEHICLE BAYS

By Glen Koorey[1]

Abstract

Recent research in New Zealand has investigated ways of assessing the need and providing for improved passing opportunities on rural two-lane (single-carriageway) highways. This paper focuses on studies of the performance of slow vehicle bays (SVBs), also known as "turnouts". Field surveys at eight sites identified the effect of different features on usage and reduction in following. The surveys observed higher levels of SVB use than reported overseas, however this use also appears to be very dependent on the location and design of each site. The effect of SVBs on vehicle following was generally not substantial, although the short-term benefits probably do provide some reduction in driver frustration. Minimum desirable lengths for SVBs were also reviewed and it was found that the current New Zealand guidelines for SVB lengths may be inappropriate, given the number of merge area conflicts and multi-vehicle queues. From these findings, project evaluation methods were developed using simplified analytical procedures and a simulation modelling package such as TRARR.

CE Database subject headings: passing opportunities, rural highways, highway improvements, traffic delays, two-lane roads, slow vehicle bays, turnouts, project evaluation, simulation models.

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[1] *BE(Hons)(Civil), ME(Civil), BSc(CompSci), MIPENZ*
Lecturer in Transportation Engineering
Dept of Civil Engineering
University of Canterbury
Private Bag 4800, Christchurch, New Zealand
Phone: +64-3-364 2951
Fax: +64-3-364 2758
Email: Glen.Koorey@canterbury.ac.nz

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 (single-carriageway) 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 (described below and also sometimes known as "turnouts"), provide a means to relieve these pressures and their construction is greatly encouraged by the general public.

Some overseas national or state jurisdictions justify passing opportunity construction by means of warrant requirements (e.g. WSDOT 2005). However New Zealand's project evaluation requirements (Transfund NZ 2004) mean that specific benefits must be calculated, usually by means of a rural road simulation model, such as the TRARR ("**TRA**ffic on **R**ural **R**oads") computer package (Shepherd 1994).

Research Outline

This research was undertaken to investigate ways of analyzing and providing for improved passing opportunities on rural highways in New Zealand. One of the research objectives was to investigate the use and performance of slow vehicle bays using field surveys, and to compare the results with those from TRARR and theoretical models. This paper focuses on these investigations and subsequent analysis. Further details on this and the other research objectives can be found in Koorey & Gu (2001).

Slow Vehicle Bays

Slow vehicle bays (SVBs) are the formalized use of very short lengths of widened, unobstructed and 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 passing opportunities (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 passing lanes (i.e. treated like a short passing lane), until research to assess the performance and appropriateness of these alternative passing measures was done.

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

- Recent overseas and local studies were reviewed to assess the likely benefits from SVBs.
- Field data at a number of SVB sites were collected and analyzed, and then compared with the results of simplified analytical models of the sites.
- TRARR models of the surveyed sites were used to confirm field data findings.

It should be noted that, at the time of this research, there was no legal obligation in New Zealand to use a SVB even when a motorist was impeding a number of following vehicles. Such legislation is common in a number of U.S. states (albeit pertaining to any pull-over area); in California for example, the Vehicle Code requires *"a slow-moving vehicle that is being followed by five or more motor vehicles to turn out at the first safe place"* (State of California 1965). More recently, new road user rules (New Zealand Government 2004) have spelt out obligations in this situation more explicitly by specifying that *"A driver who is driving at a slow speed that* *would impede the normal and reasonable movement of any other vehicle… must move into the slow vehicle bay as soon as the movement may be made with safety and… continue there until the driver reaches the end of the slow vehicle bay or is able to proceed without impeding the normal and reasonable movement of vehicles using the road.*”

Literature Review

The geometric design manual for New Zealand State Highways (Transit NZ 2000) recommends some minimum lengths for SVBs, in relation to mean traffic speed on the road in the vicinity of the bay (see **Table 1**). Note that the minimum SVB 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 decelerating at a rate not exceeding $3m/s^2$.

Transit NZ also recommends that SVBs should not be longer than 300 m, because drivers may then treat them as a conventional passing lane (which Transit NZ suggests should ideally be at least 800 m in length). Harwood & Hoban (1987) recommends that SVBs should be no longer than 600 ft (190 m). The implications of these length restrictions in terms of performance are discussed later. Another Transit NZ recommendation is that SVBs should not be mixed with passing lanes along a route, again to minimize driver confusion. The lane markings for SVBs and passing lanes are different at the start and end tapers, and there is a difference in legal priority when merging at the end. There are several instances in New Zealand where existing SVBs have been converted to exceptionally short passing lanes to meet this policy.

Operational Effectiveness

Passing opportunities generate economic benefits by reducing travel times, as they release impeded vehicles from “platoons” (also known as a “bunches”). 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 a lack of passing opportunities they are likely to become frustrated. This can lead to an increase in unsafe passing maneuvers that can in turn lead to crashes.

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 following per passing maneuver as a passing lane.

A safety review of ten SVBs on State Highway 29 over the Kaimai Ranges in New Zealand (Nicholson & Brough 2000) 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 centerline to pass a slow vehicle. However, as the forward sight distance was good in most cases with a passing lane present for opposing traffic and low traffic volume, this maneuver was not considered a major safety problem.

During their surveys, 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. are more suited to lower speeds. This may indicate a driver education issue that needs to be addressed in New Zealand.

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 percentage of following 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 and are listed in **Table 2**, together with site details such as the Annual Average Daily Traffic (AADT) and the proportion of Heavy Commercial Vehicles (%HCVs). The last three sites listed (SH29 “Kaimai” sites) are within a 5 km section and were surveyed together to assess the effect of a series of SVBs.

Study Method

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 percentage of following vehicles immediately before the SVB, and the level of use of the SVB, i.e. which vehicle types were using it. Another surveyor collected percentage following information at some distance after the end of the SVB, typically about 100 m past the merge taper. 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 about 100 m before each SVB and about 500 m after the last one. These measured the individual vehicle classes, speeds and headways (i.e. vehicle spacings). Survey periods lasted for 2-4 hours, with half-hour recording intervals.

Results

Survey results from the eight sites are summarized 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.

Rather disappointingly, only four of the surveyed SVBs appeared to reduce the percentage of following vehicles downstream (although only Palmers Mill showed a notable 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, presumably mostly because of following vehicles, suggests that the true percentage of following vehicles likely to benefit is probably greater.

Harwood & St John (1985) had also found only a 2% reduction in following (on average) immediately downstream of a SVB, and possibly up to another 4% in the subsequent 450 m. However if the alignment is fairly steep or winding downstream, vehicle following 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). Four classifier locations provided before and after data for the three SVBs investigated, over a distance of about 5 km. For each site, the level of following was related to the traffic volume in hourly increments. **Figure 1** shows how the following rate varies at those four locations with changing traffic volumes.

If these three SVBs performed in a similar manner to passing lanes, the percentage of following vehicles should decrease from survey location 1, through locations 2 and 3, to location 4. However, there is no discernible trend between the latter three locations. Only location 1 (located before all of the SVBs) is considerably different, and in fact displays vehicle following levels about 20% lower than the subsequent survey locations.

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 following levels. The remaining SVBs have only succeeded in keeping the status quo in terms of vehicle following.

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 end of the SVB, with little change in following percentages.

Analysis of Results

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 the proportions of slower moving vehicles are greater.

Transit NZ (2000) suggests 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** summarizes the breakdown of vehicle types among SVB users at the surveyed sites.

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%-60% on examining individual site data). 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 summarizes the proportion of vehicles observed using SVBs even when no vehicles were following them. No notable difference in the incidence of this behavior was observed between vehicle types. The sometimes high proportions suggest 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 the Kilmog and Palmers Mill locations 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 should ideally be designed to encourage slow platoon leaders (i.e. vehicles at the front of platoons) to move over and let others pass. **Table 5** shows the proportions of platoon leaders using SVBs at the surveyed sites; note that Rahu Saddle had only one platoon. These figures do not include those SVB users who were not followed; see **Table 4** for more details. Note that "platoon" refers to all bunched vehicles including the lead vehicle, while "queue" refers to the following vehicles behind the lead vehicle.

Overall, the proportions of platoon leaders using SVBs are considerably higher than those found by either Harwood & St John (1985) or Rooney (1976). This 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.

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 (Austroads 1988). The probability of a bunch size *b* is given by

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

for b = 1,2,3, … and where f is the percentage 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 $r^2 > 0.99$ between the observed distribution of bunch sizes (both before and after the SVB) and that predicted by the BTD. The absolute difference between observed and estimated bunching proportions was never more than 0.03, although in some cases this difference was proportionately quite large when applied to small values and few observed cases, e.g. probability that bunch size>4. 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 calculations show that they only make up the majority of vehicles for up to about 32% following. For SVB analyses, only vehicles with following queues are of interest, so single vehicles can be ignored (except for the purposes of calculating % following). **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 **Table 3**, the typical vehicle-following percentages observed at the surveyed sites were between 20%-45%.

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. Calculations of vehicle numbers in various queue groups reveal that drivers are in fact more likely to find themselves in a multi-vehicle queue from about 23% following upwards. Therefore queues of two or more vehicles-following play a significant part when considering the operation of SVBs.

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 considerably in SVBs, given the number of potential conflicts observed at the merge taper. This may be partly 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 may 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** shows that about 30%-55% 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 maneuver is:

$$L = \frac{v.d}{(v-u)} \tag{2}$$

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

$$d = u/3.6 \times 2 + (6 + 12) \tag{3}$$

So, for example, a vehicle with desired mean speed of 70 km/h wanting to overtake a slow vehicle travelling at 50 km/h would require L = (50/3.6×2+18)×70/(70-50) = 160.2 m 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 (all assuming a 6 m car overtaking a 12 m truck). Similar plots could be derived for different vehicle lengths. Note that the figures are conservative in not allowing for following vehicle acceleration; for speed differences less than 40 km/h however, this is typically <50m extra distance.

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 300 m. 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 300 m. **Table 6** summarizes the above findings in a form similar to the existing lengths in **Table 1**. These minimum lengths assume 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 300 m maximum length, the above findings suggest that SVBs should only be located where the mean traffic speed is less than about 60 km/h, or where the speed differential is expected to be large, e.g. on steep grades. Where traffic volumes are greater and longer queues are more likely, even lower mean speeds are preferable before considering a SVB.

Project Evaluation of SVBs

In the current New Zealand *Project Evaluation Manual* (Transfund NZ 2004), the benefits of SVBs are evaluated by the same procedure used for passing lanes. This involves determining any savings in travel time (due to passing slower vehicles), quantifying “driver frustration” benefits (as measured by the reduction in the percentage of following vehicles), and possibly ascribing some crash saving benefits. However, a SVB generally cannot provide as many passes as a passing lane and neither can it provide as much reduction in the percentage of following 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 same 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 held up by following vehicles and delayed at the SVB exit, offsetting the travel-time savings of overtaking vehicles. Hence we cannot expect major overall travel-time benefits from the SVB.

Therefore, claiming only the driver frustration benefits, and possibly some safety benefits, may be more realistic and reasonable. Either TRARR modelling or simplified procedures are ways of analyzing these effects.

TRARR Models

An option for handling SVBs is incorporated into TRARR (known as “passing bays” in TRARR terminology). Although 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 following vehicles.

The site models were calibrated with the data from field surveys and then compared against the observed changes in vehicle following. 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 an optional file (“PBAYS”) to specify the location and parameters of SVBs. Modelling with the default parameters provided with TRARR 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 between the observed and modeled SVB usage. Interested practitioners are welcome to contact the author for an electronic copy of the updated 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 overtaken. Therefore, TRARR under-estimates the actual travel-time savings.

One option for assessing 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.

Simplified Modelling of Frustration Benefits

The computational and resource effort required to model using TRARR 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 percentage following at the entry is q (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

$$(1-q) \times Volume \tag{4}$$

Assuming that vehicle bunching can be modelled using the BTD as discussed previously, the probability of a “bunch” of size 1 (i.e. single vehicle) is given by:

$$P(1) = e^{-q} \tag{5}$$

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

$$(1\text{-}q) \times Volume \times (1\text{-}e^{-q}) \tag{6}$$

Assuming that the proportion of platoon leaders who would use a SVB is *p*, and that the next vehicle immediately following each of them would be released, the number of vehicles freed up are:

$$(1\text{-}q) \times Volume \times (1\text{-}e^{-q}) \times p \tag{7}$$

The effect on the overall percentage following can be seen by dividing by the volume. Therefore the percentage following, *r*, at the end of the bay can be estimated by:

$$r = q - [(1\text{-}q) \times (1\text{-}e^{-q}) \times p] \tag{8}$$

This formula relies on the overtaking vehicle not continuing to be part of the following bunch. 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 reduction in percentage following.

From the field survey, it was found that on 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 SVBs can be calculated.

Assessment of Methods

For the Waikoau Hill and Kilmog SVBs, the outputs from both the TRARR models and the simplified bunching formula are compared with the survey results in **Table 7**. It should be noted that comparison at some other sites would not be appropriate because no or little reduction in vehicle following was observed, partly for other reasons identified previously.

The differences between techniques appear acceptable, in terms of their small impact on predicted benefits, and hence we can say that either method is adequate for predicting vehicle following percentages after a SVB. Therefore, they can be applied to the calculation of the frustration benefits from a proposed SVB. The parameter *p* (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 following rates to determine the likely reduction in following. **Figure 4** shows the results, allowing easy interpolation.

Conclusions

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

- 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.

- Generally 30%-60% of platoon leaders in New Zealand use SVBs, a higher rate than that found in overseas studies, and this use increased by >10% on average for platoons with more than one vehicle following.

- SVBs do not greatly reduce the percentage of following 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%-60% of all trucks). Some sites that looked more like passing lanes had higher car use.
- Confusion by drivers exists over the use of some SVBs, particularly in comparison with passing lanes, and this is seen in their relatively high use by vehicles when no one is following and in conflicts at SVB merges. More distinct marking of SVBs and passing lanes may prevent confusion of the two by drivers.
- The Borel-Tanner Distribution provided an excellent model for bunch sizes observed at SVBs. Using this model, it is clear that bunches with two or more following vehicles play a significant part when considering the operation of SVBs, particularly where the percentage of following vehicles is >20%.
- Current 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 recommended maximum lengths to allow slow vehicles to use them without being impeded.
- For a short SVB with sufficient queued vehicles, any travel-time benefits gained by the passing vehicles may be offset by the delay placed on the overtaken vehicle.
- SVBs modelled by TRARR provide a realistic reduction in the percentage of following vehicles. However TRARR under-estimates SVB travel-time savings. Re-modelling the SVB as a short passing lane is likely to give an over-estimation, and 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 vehicle following percentages after a SVB, given initial on-site field surveys, and can be applied to the calculation of the frustration benefits from a proposed SVB.

These findings have implications worthy of further investigation or action by state roading jurisdictions, including appropriate evaluation methods and SVB design standards.

Acknowledgements

In presenting this paper, the author would like to thank Opus International Consultants Ltd and Transfund New Zealand for their support of the research described here.

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Notation

The following symbols are used in this paper:

b = bunch size;

b_m = mean bunch size;

d = relative distance required to overtake a lead vehicle;

f = percentage of vehicles following;

L = required road distance to complete an overtaking maneuver;

n = number of following vehicles

p = proportion of platoon leaders who would use a SVB

q = percentage of vehicles following at the start of a SVB

r = percentage of vehicles following at the end of a SVB

u = speed of a lead slow vehicle;

v = speed that a following vehicle desires to travel at;

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

Table 2. Slow vehicle bay sites monitored in the field surveys

Site Name	State Highway & Location	Length	Grade	AADT	%HCVs
Towai	SH1N, south of Kawakawa	90 m	+2%	5200	17
Waikoau Hill	SH2, north of Whirinaki	100 m	–7%	1600	18
Kilmog	SH1S, north of Dunedin	450 m	–10%	3900	11
Rahu Saddle	SH7, east of Reefton	90 m	+7%	1900	20
Palmers Mill South	SH5, north of Wairakei	250 m	+5%	3200	12
Kaimai Deer Farm	SH29, west of Tauranga	200 m	–8%	5900	15
Old Kaimai Road	SH29, west of Tauranga	200 m	–5%	5900	15
Cannonball Deer Farm	SH29, west of Tauranga	150 m	–9%	5900	15

Table 3. Summary of survey results from slow vehicle bay sites

Site Name	No. of Vehicles (one-way)	% of Trucks, Recreation Vehicles	% Following Before (q)	% Following After (r)	% Vehs 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

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	HCVs	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.

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

Site	No. of Platoon Leaders	% Queues with >1veh	Proportion of Leaders Using SVB			
			Overall (p)	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

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

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

Site	%Following at Start of SVB	%Following at End of SVB			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	+1.3%	-1.1%

Figure Captions

Figure 1. Vehicle Following levels at Kaimai SVB sites

Figure 2. Distribution of vehicle queue sizes vs percentage of vehicles following

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

Figure 4. Theoretical improvements in %Following at SVBs

Figure 1. Vehicle Following levels at Kaimai SVB sites

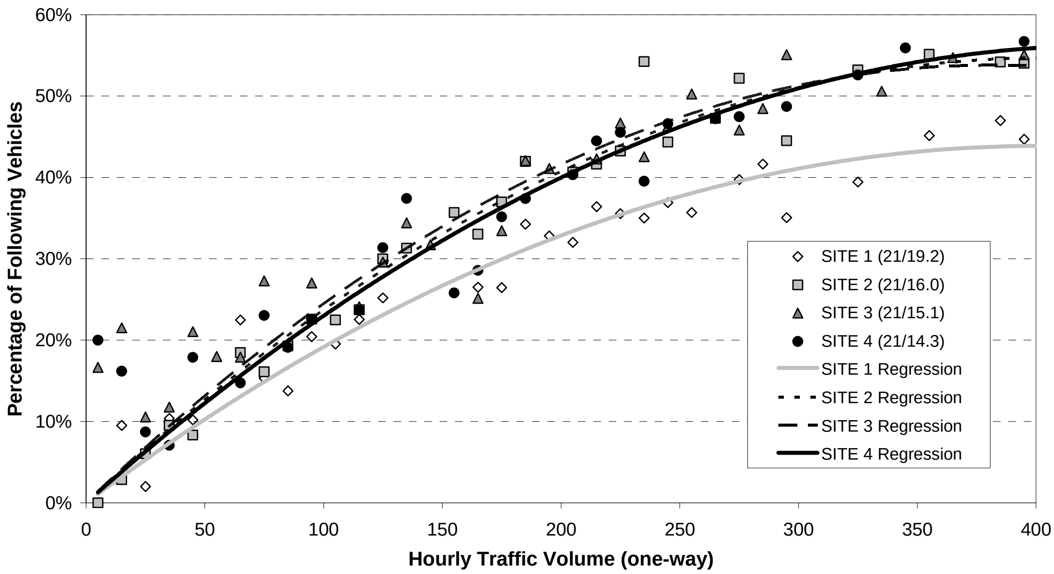

Figure 2. Distribution of vehicle queue sizes vs percentage of vehicles following

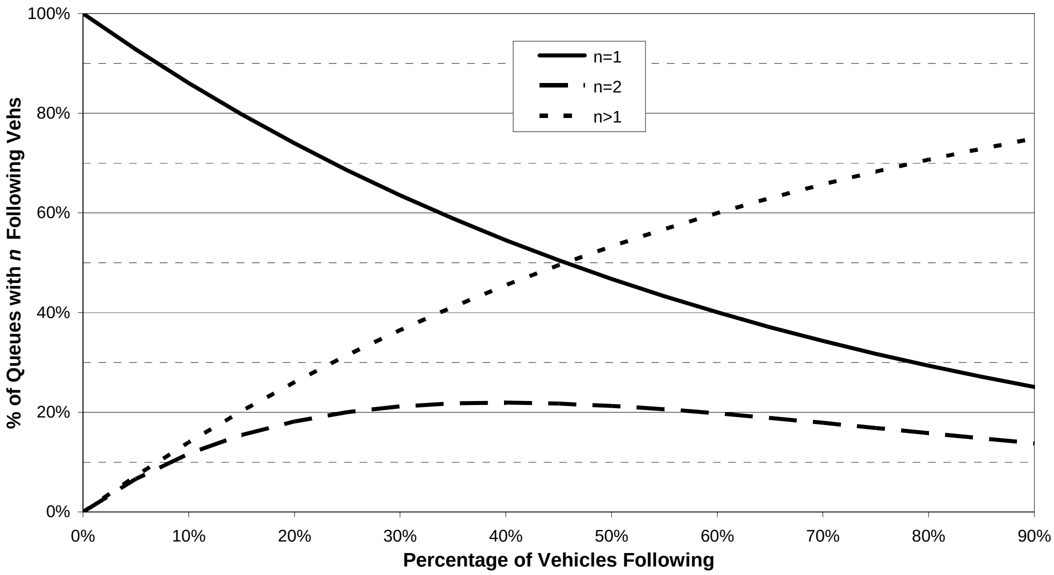

Figure 3. Minimum length of SVB, for one vehicle to overtake

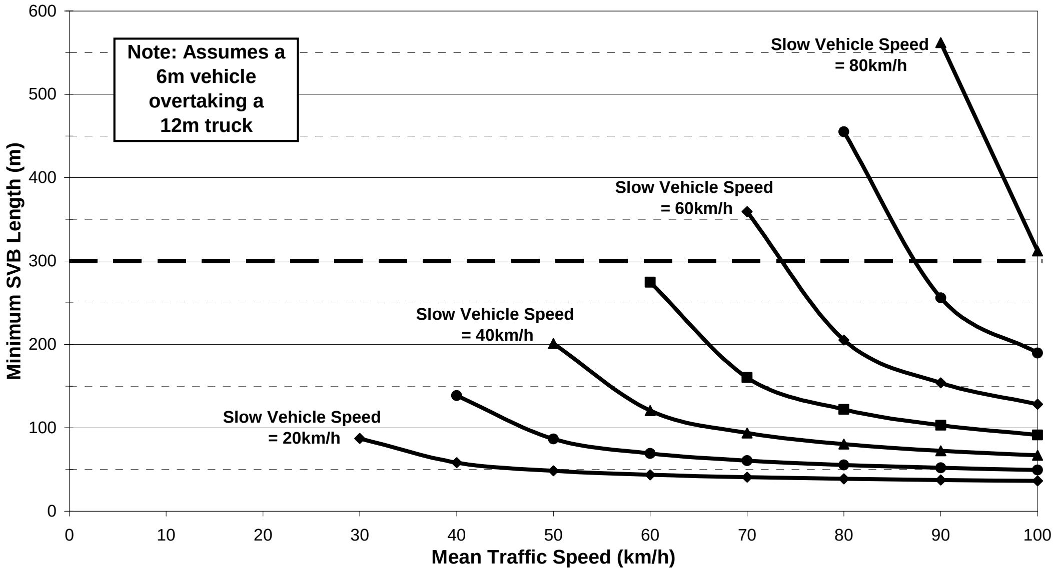

Figure 4. Theoretical improvements in %Following at SVBs