The Transition between the Divided and Undivided Road on Australia's Highways

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1 Introduction

The highway network in Australia provides vital links between cities and major towns around the country. The highway travel demand surrounding major cities is higher at a closer distance to the city, so typically the road is of a divided motorway standard. This standard of road cannot be maintained for Australia's entire highway network, due mostly to economic limitations. It is therefore inevitable that a lesser standard of road will eventuate on any route at some distance from a major centre.

In most cases, the distinct point of change from one road type to another is where two separate carriageways become a single carriageway. At this point, the divided road is often a four-lane motorway, and the undivided road a two-lane highway.

It is well established that two-lane highways are less safe than divided motorways, but it is not economical to provide this level of infrastructure countrywide. Where it may appear to cause a problem in terms of safety and crash history does not necessarily suggest an upgrade to a four-lane motorway should be the solution, as this may simply be relocating the transition point further along the road corridor.

This paper documents an investigation on how the aspects of this scenario are currently addressed in practice, and a subsequent case study of the transition between a four-lane divided motorway and two-lane highway.

The research encapsulated in this paper was sponsored by the RACQ, which each year offers a scholarship to support an engineering student for their final year project. The information and conclusions presented are the product of an undergraduate thesis, and not verified by PB.

2 Rural road reference review

The main documents available for professionals in the highway engineering field in each area of study consist of the following:

- Traffic operations
  - The Transportation Research Board's (TRB) *Highway Capacity Manual 2000* (*HCM 2000*)
  - Austroads' *Guides to Traffic Engineering Practice* (largely based on earlier HCM procedures)
- Road design
  - State road agency guidelines such as the Queensland Department of Main Road's (QDMR) *Road Planning and Design Manual* (*RPDM*)
  - Austroads' *Rural Road Design: A Guide to the Geometric Design of Rural Roads*
  - The American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets 1994* (commonly referred to as the *Green Book*)
- Highway management

- State road agency guidelines such as QDMR's *Manual of Uniform Traffic Control Devices* (*MUTCD*)
- Austroads' *Rural Road Design: A Guide to the Geometric Design of Rural Roads*
- AASHTO *Green Book*

A review of these references sought consistencies between the methodologies for a two-lane highway and a four-lane divided motorway, and for relationships between the engineering areas researched.

2.1 Relationships within the engineering activities

A summary of the relationships between the two road types under each area of research is illustrated in Figure 1. They are discussed below.

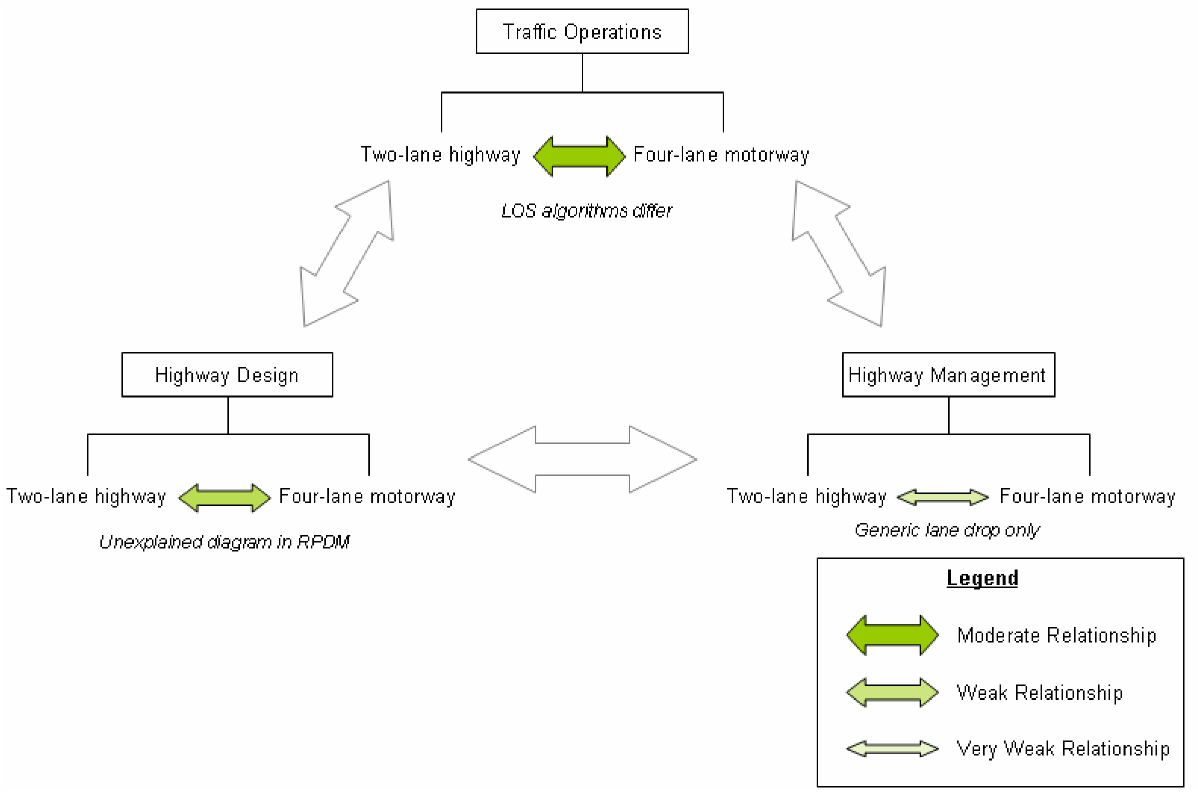


Figure 1: Relationships within engineering activities

2.1.1 Traffic operations

Applying the TRB's *HCM 2000*, the level of service (LOS) analysis of a motorway involves developing a suitable speed-flow curve and then applying the relationship to estimate an average speed for a particular flow rate. A measure of performance for a motorway could be based on this speed, or a translated density, or volume-capacity ratio. A two-lane highway LOS analysis involves either calculating the average travel speed or the percent-time spent following to measure the performance. Therefore, performances are based on different measures.

The only common measure of performance of operation between the two different road types is speed; however, the speed prediction equations are different between the two-lane highway and divided motorway, so it raises the question of whether the LOS analyses are comparable between sections.

2.1.2 Highway design

The transition between a divided motorway and two-lane highway is acknowledged in design references, but only to comment that it should be treated appropriately. The most specific guide to treating the transition found was in QDMR's *RPDM Chapter 4 Applications of Design Principles and Guidelines*, (2005). This featured the figure and cited paragraph below.

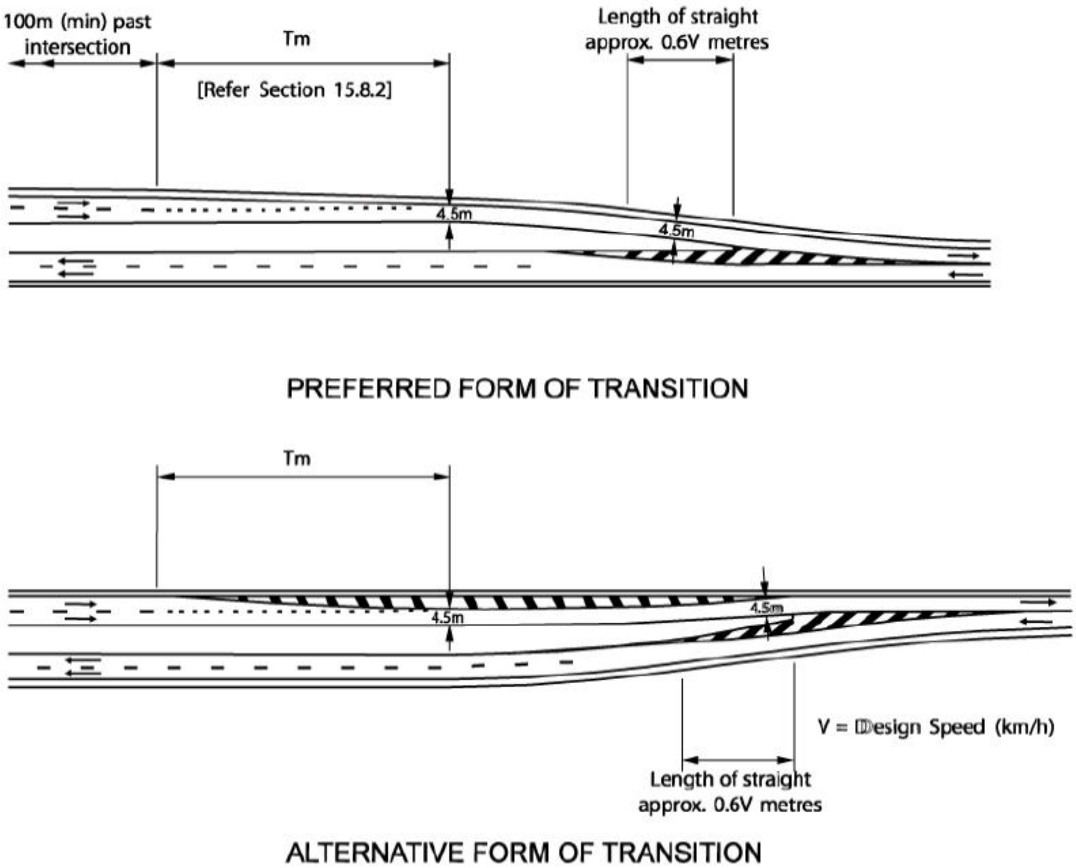


Figure 2: Simple merging manoeuvre, (source: QDMR 2005)

"[The figure] illustrates some simple merging manoeuvres, as in the case of the transition from two lanes to one. Chapter 15 [Auxiliary Lanes] includes details of the calculation of merging lengths for auxiliary lanes. The treatment on acceleration and deceleration lanes is given in Chapter 13 [Intersections at Grade]," (QDMR 2005, pp4-22).

The text accompanying the above diagram does not include any further explanation, but it may be inferred that the length of straight is intended to allow drivers to adjust between reverse curves, which, in the preferred transition arrangement, are located on the side of the lane drop to encourage reduced operating speeds approaching the two-lane highway.

2.1.3 Highway management and hypothesis

Functional classification indicates the need for a different type of facility for a specific trip purpose. This paper considers a situation where two types of facilities serve the same trip purpose, along the same route. The surrounding land use may not change, the trip purpose does not change, and therefore direction of travel may not change, yet the road type and standard change substantially.

It is hypothesised that, due to this, it may be difficult for drivers to adjust their driving behaviour to suit the change in conditions. Consequences of this situation could include:

1. The possibility of driving inattentively within a more demanding undivided road environment immediately after having driven in a less demanding road environment on the divided motorway. This concept has been highlighted in several studies, in particular, one lead by McLean, which found that constrained road geometry succeeding a high design speed road environment would tend to be overdriven (Austroads 2003).
2. Conversely, the possibility of a tendency to over-relax when arriving on the divided motorway after driving the more demanding two-lane roadway for an extended period.

The QDMR's *MUTCD* offers only a suggestion for a generic lane drop (e.g. three to two lanes), not a lane drop that signifies a change in road type. It also does not include any recommendations for speed limit changes on a road unless they are intended as buffer zones approaching and departing a highway town.

2.2 Relationships between the engineering activities

A summary of the relationships between each of the areas of focus is illustrated in Figure 3.

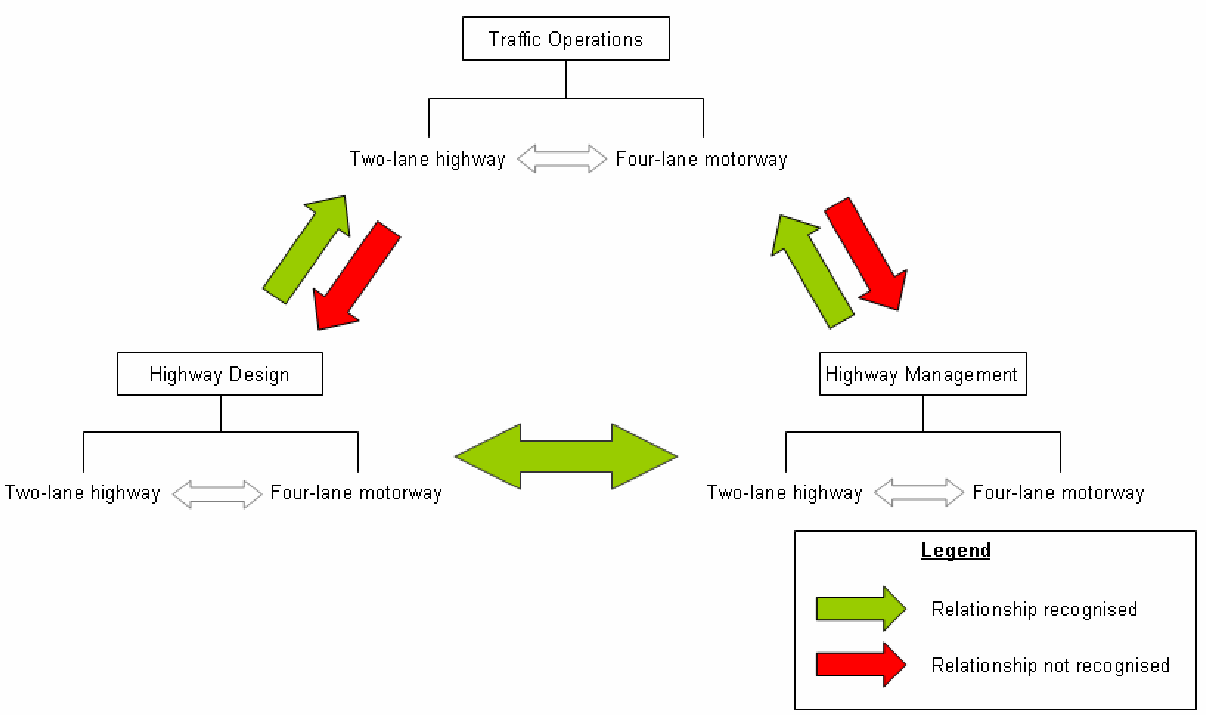


Figure 3: Overall relationships between engineering activities

Traffic operations analyses are treated in quite an isolated fashion. At best, vertical grade is factored into operational analysis methodologies. Otherwise, the effects of horizontal and vertical geometry and access control are not explicitly recognised in the procedures, only attempted to be accounted for in the family of flow relationship curves.

Conversely, highway design and management are closely related, featuring in most of the same resources, and hence tend to overlap. The highway design and management disciplines acknowledge that aspects such as geometry and side friction affect traffic operations, and thus road capacity. Consequently, professionals are reminded to consider this in design and management practice.

2.3 Innovations

The most significant innovative treatment found to address this transition between four-lane divided and two-lane undivided road types was the 2+1 road arrangement, which has existed in Europe since the 1980's. The 2+1 roads provide frequent overtaking opportunities for each direction, and serve the purpose similarly described in Austroads' *Guide to Geometric Design of Rural Roads*, which suggests that overtaking lanes at regular intervals provide an intermediate service between a four-lane road and a two-lane road, (Austroads 2003).

2.3.1 Overview of 2+1 roads

The US National Cooperative Highway Research Program (NCHRP) conducted a site visit of 2+1 roads in Sweden, Germany, and Finland, and summarised the findings in a paper published in 2003. The concept is illustrated in Figure 4.

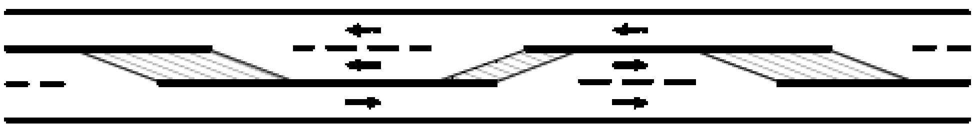


Figure 4: Schematic diagram of a 2+1 road, (source: NCHRP 2003).

General conclusions formed by the NCHRP (2003) are summarised as follows:

- Procedures for capacity estimates are yet to be determined; however effective operation has been observed on roads carrying 15 000 to 25 000 vehicles per day.
- Some average speeds have been observed to be around 100 to 110km/h.
- Cross sections vary, though are typically around 13m.
- Some 2+1 roads visited were previously two-lane highways that had linemarking redone to the 2+1 configuration. The crown being located in the centre of the roadways did not seem to cause a problem on the restriped road.
- 2+1 roads were deemed adaptable to both level and rolling terrain. Conventional climbing lane arrangements were recommended for mountainous terrain.
- Many 2+1 roads were managed as semi-motorways, with limited access and grade separated interchanges, however intersections at grade do exist, and tend to be treated similarly to Austroads' Type C channelised intersections. The intersection is located in the zone between passing lanes.
- Safety records show that since the introduction of the 2+1 roads, crashes have decreased significantly, by at least 22%. Sweden, the only country to have cable barriers for the median at the time, saw a crash number reduction of 55%. It is also believed that crash severities have been greatly reduced by the median barrier.
- One analysis in Finland concluded that the implementation of 2+1 roads has seen a decrease in risky behaviour on two-lane highways. The study found that there was in increase in passing on 2+1 road sections while two-lane highways upstream and downstream saw a decrease in passing manoeuvres undertaken
- Passing lane lengths are typically 1.0 to 1.4km, (NCHRP 2003).

2.3.2 Applicability to Australian roads

The NCHRP (2003) considers the use of 2+1 roads appropriate for the US road network, especially in cases where the traffic volumes are inadequately serviced by a two-lane highway with infrequent passing lanes, but still do not justify a four-lane motorway. This relates to Austroads' aim to provide an intermediary level of service between a four-lane divided motorway and a two-lane highway. The NCHRP (2003) also sees 2+1 roads as a solution to limited funding preventing an upgrade to a four-lane motorway.

Some European 2+1 roads have a continuous crossfall, which may be convenient for the case of future duplication, and eliminates the transitioning required on curves. Access may need to be limited in some cases as European roads are more often managed as semi-motorways, unlike Australian and American two-lane highways where direct access is more common.

As most Australian design standards, including Austroads and QDMR's *RPDM*, are based closely on US guidelines, the NCHRP recommendations ought to be considered for adaptation for Australian roads.

3 Case study of transition between four-lane divided and two-lane road

The case study selected for this research was a 15km segment of the A1 (Bruce Highway) at Cooroy, Queensland (Noosa hinterland), 130km north of Brisbane. The purpose of the case study was to apply the concepts of the three engineering areas reviewed to an existing road and from the outcomes, highlight considerations for treatments of the transition.

The methodology for this review consisted of dividing the road into three different road types that exist throughout the study length. A schematic diagram and photographs of the typical road environments are shown in Figure 5. A black line in Figure 5 represents a lane on the road. The branches off the mainline illustrate the types of accesses that exist along the study length.

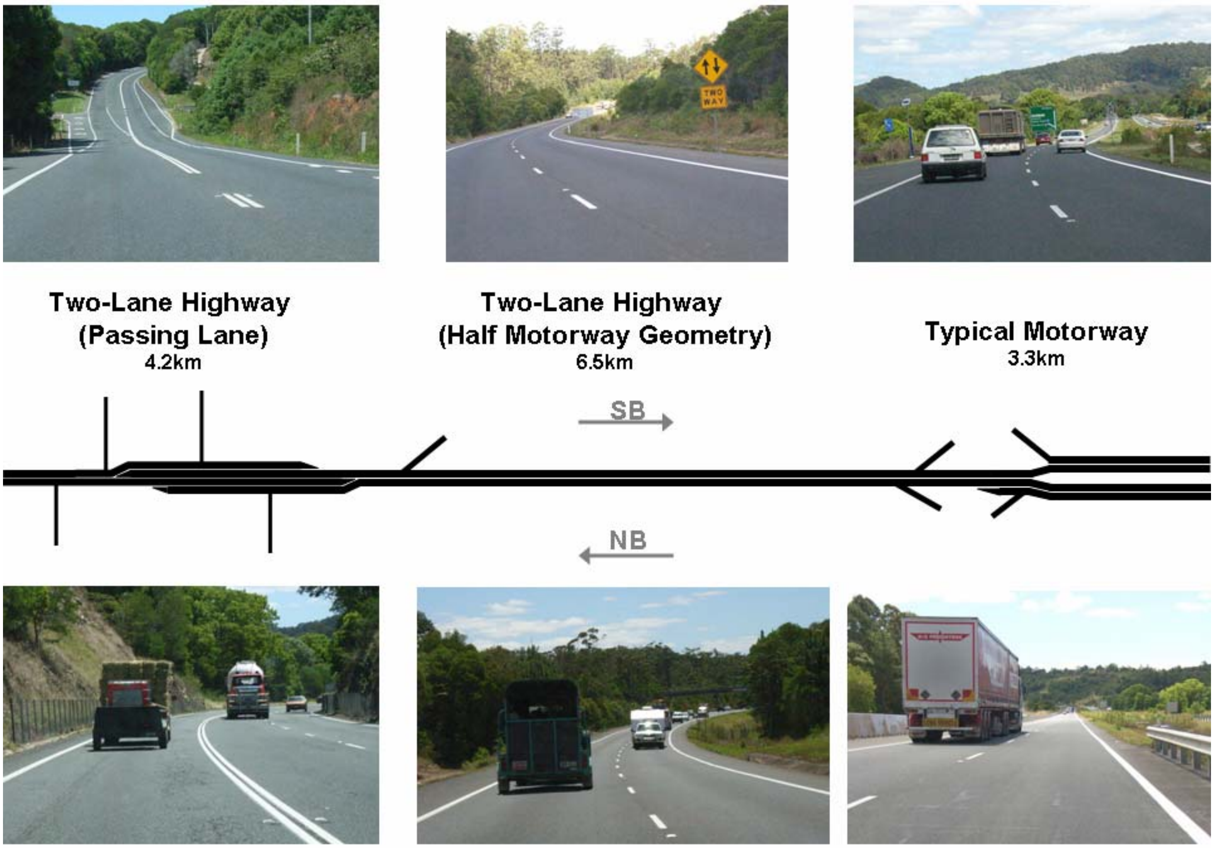


Figure 5: Bruce Highway study length

All following analyses and reviews were conducted and classified by the three different road environments - a typical four-lane divided motorway, a two-lane highway with half-motorway geometry (intended for future duplication), and a typical two-lane highway which includes climbing lanes - illustrated in the diagram above.

3.1 Background

The Australian Automobile Association (AAA) has developed the *Australian Road Assessment Program* (*AusRAP*) to assess risk and identify safety deficiencies on the AusLink National Network. The AusRAP report looks at two measures of risk:

- Collective risk – the annual average casualty crashes per kilometre
- Individual risk – the annual average casualty crashes per 100 million vehicle-kilometres travelled

The worst performing link in the AusRAP report for 2005 and again in 2006 was the 40km of the Bruce Highway from Cooroy to Gympie. This section of road recorded 27 fatalities between 1999 and 2003, the highest number on any link analysed in the AusRAP reports, (AAA 2005). The study area for this project is contained within part of the AAA's 'worst performing link'.

Pertinent 2005 traffic characteristics of the 15km study length are summarised as follows:

- 15 000 – 17 500 AADT
- 17% commercial vehicles
- 6% annual growth in traffic

3.2 Traffic operations analysis

The operational analyses were carried out according to procedures in the *HCM 2000*. Level of service (LOS) analyses were conducted for both northbound and southbound directions, and where procedures allow, average speeds were predicted, as they are the only common measure of performance between the different road types.

It should be noted that where motorway-style interchanges existed on a two-lane highway environment, speed prediction algorithms could not be applied. The *HCM 2000* does not include procedures for ramp analyses for merge or diverge arrangements with a single lane of through traffic.

Traffic data was supplied by QDMR in the information package, and factored and balanced across the study area to obtain volumes for a 2005 peak hour analysis. The employed traffic volumes were arrived at based on permanent and manual counts and historic data reflecting traffic growth over 5 years.

3.2.1 Results

The LOS analysis results for each road type are shown in Figure 6.

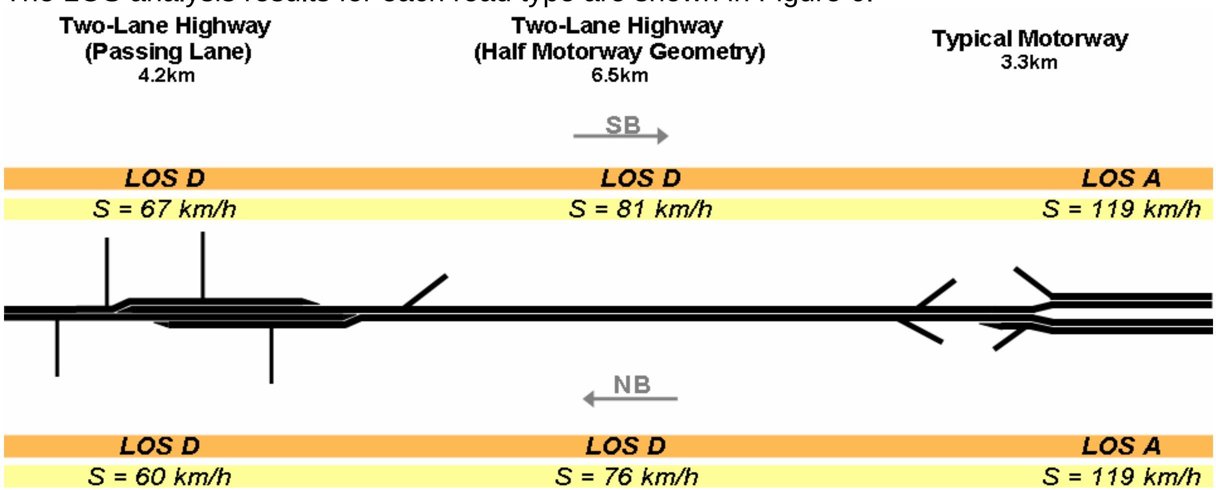


Figure 6: Results of HCM 2000 traffic operations analyses for the estimated peak hour

The significant reduction in the northbound average travel speed was experienced during several test drives using a GPS device, as was estimated in the LOS analysis. However, the further reduction in speed over the two-lane highway section estimated using the procedure was not found to be experienced in practice. This estimate is questionable not only because test drives reported a higher average speed, but also because this section includes a passing lane, so it would normally follow that average travel speed should increase. The calculated results may be due to the steep grade (up to 7%) and high proportion of heavy vehicles (17%).

The analyses show a definite trend in the level of service across the three different road types; the change in operation between the divided and undivided roads being particularly abrupt, with a speed reduction of approximately 40km/h over a very short distance, within 1 to 1.5km. The LOS values are based on speed prediction algorithms for the relevant road type.

3.3 Highway design overview

The study length was reviewed from a highway design perspective by commenting on horizontal geometry, vertical geometry, cross section and sight distance for each of the three road types.

3.3.1 Results

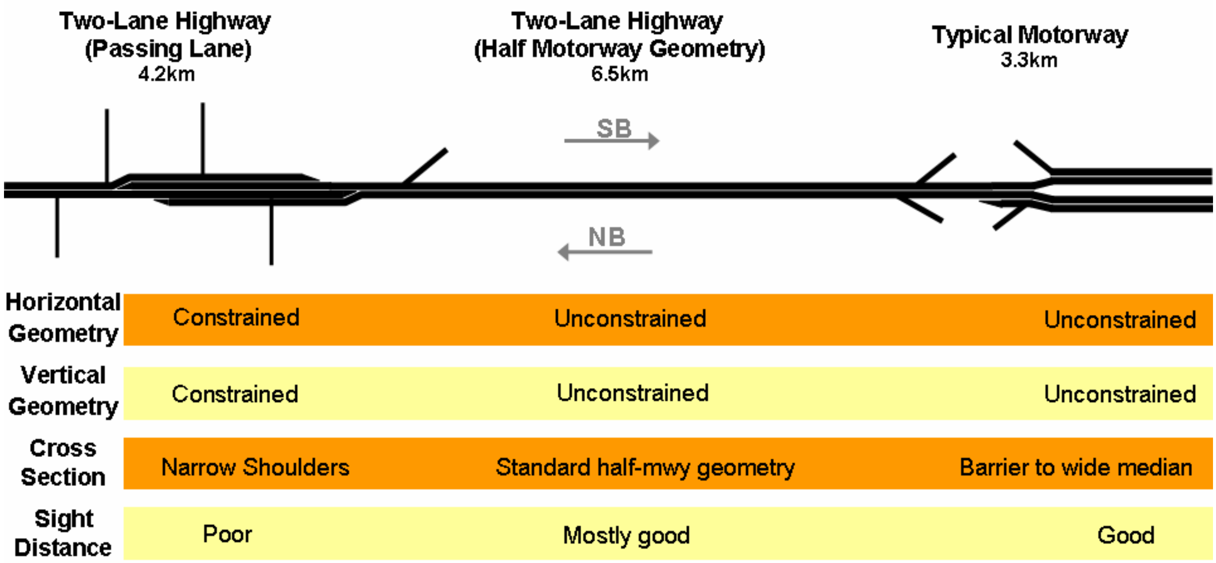


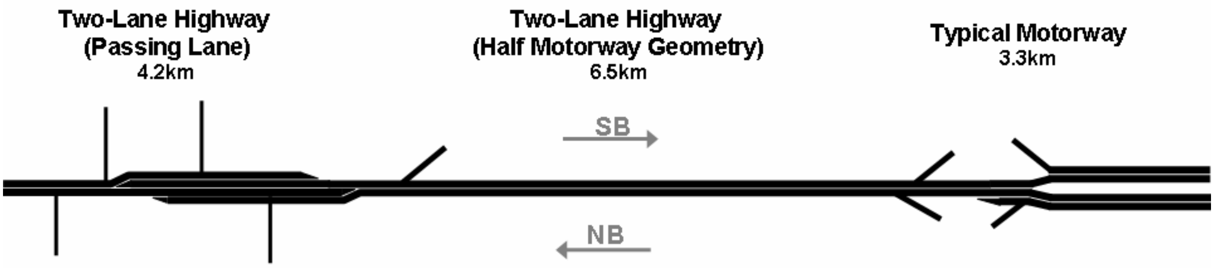
Figure 7: Highway design overview

Similar to the trend in the operational analyses, the design elements become more restricted with a lower standard of road type (from the typical motorway through to the two-lane highway with passing lanes).

3.4 Highway management overview

The highway management techniques commented on in this part of the review included access density, land use, speed limits, signage and linemarking, again for each road type across the study length.

3.4.1 Results



Access	2.5/km: T junctions	0.4/km: Ramps only	Ramps only
Land Use	Rural Residential	State Forest	Rural Residential
Speed Limit	100km/h	100km/h	100km/h to 110km/h
Signage	Crash & merge warnings	Two-way warnings	Speed limit change warning
Linemarking	Standard	Standard	Speed limit change warning

Figure 8: Highway management overview

There is a notable increase in access density as the road standard decreases in the northbound direction. The standard of the accesses themselves also declines accordingly, from ramps to T-junctions and concealed driveways.

There is no obvious change in land use from the road across the study length, as the highway goes through a heavily treed rural area, and residential access is only allowed on the two-lane highway passing section.

Regarding signage and linemarking, there is warning of the speed limit drop in the northbound direction. On the half motorway segment, there are 14 two-way warning signs in both directions. An example is included in Figure 5, top centre.

On the typical two-lane highway section there are non-standard signs warning drivers in passing lanes not to overtake merging traffic. An example is included in Figure 9. The standard linemarking in these sections requires vehicles in the kerb lane to give way to vehicles in the passing lane. While the signage and linemarking conflict, generally driver behaviour in this environment does not strictly abide by the 'give way' rule at a merge as the typical linemarking does suggest.

Figure 9: Non-standard sign for merge instructions

3.5 Crash summary

A five-year crash history was investigated, however it is recognised that work may have been done on part of the motorway segment during this period.

The total number of crashes and crash densities were summarised in each direction for each road type.

3.5.1 Results

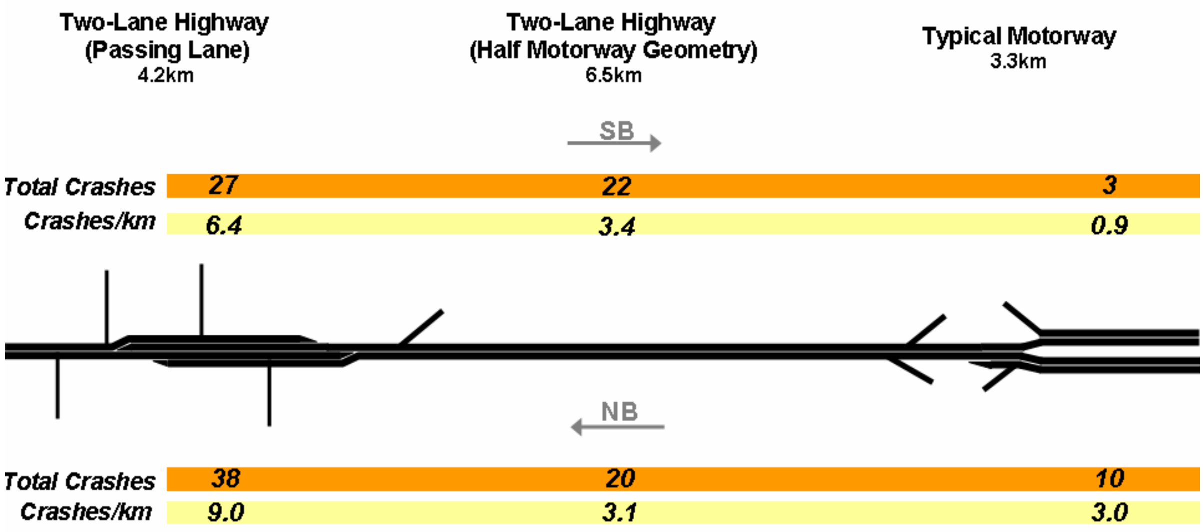


Figure 10: Summary of crashes over five years by road type and direction

It is well understood that two-lane highways typically have a poorer safety record than divided motorways. However, what is significant in this crash summary is the magnitude of the increase in crashes between the road types. More specifically, there are generally more crashes on the northbound side of the road, and a larger increase in crashes from the motorway to the two-lane highway with passing lanes.

On any of the three road sections, the road environment is not notably different between directions, so from a broad perspective, the main environmental difference between directions of travel is the approach experienced by the driver. To the south of the study length is at least 100km of four-lane divided motorway type road environment. To the north of the study length is approximately 40km of two-lane highway type road environment.

The greater increase in crashes in the northbound direction may reflect a tendency to 'overdrive' the section. This is consistent with the hypothesis 1 presented in Section 2.1.3 and hence McLean's work (Austroads 2003).

However, there is no evidence from the crash data in Figure 10 to suggest that hypothesis 2 is the case.

3.6 Discussion

Based on the above summaries, the standards of operation, design, management and safety generally decline from the divided motorway, across the half-motorway to the two-lane highway.

The half-motorway section assists in transitioning drivers into a new road environment by offering a length of design and management treatments that are an intermediate standard.

This is particularly noticeable in the geometry and access management. In turn, crash occurrence follows these trends.

However, the same cannot be said for operation. The change in the operational characteristics from the divided motorway to half-motorway is quite abrupt. This would largely be attributed to the platooning effect from a high proportion of commercial vehicles and lack of overtaking opportunities.

3.7 Case study conclusions and recommendations

3.7.1 Crashes

The main finding of this case study is that the standard of operation, design and management decline from the four-lane motorway to the typical two-lane highway, however this is as expected. The significance of this finding is that the number of crashes does not follow the transition of the road types consistently between directions. The increase in crashes in the northbound direction is markedly higher than the numbers in the southbound direction, indicating that more attention needs to given to the case where the road standard reduces from the driver's perspective.

3.7.2 Highway design

In the northbound direction, the lane drop is located within an interchange, which creates a high-density area of conflict points.

The ramp interchange arrangement on a two-lane highway is unusual. It was not found in any design guidelines or references, and no operational analysis procedure has been published in the main guidelines for this treatment. Common driver behaviour at a merge is often that a vehicle approaching on the motorway is able to change to the offside (right) lane to allow a merging vehicle to enter the motorway. A merge on a two-lane highway does not allow this, and could create confusion between entering and through traffic. This was observed during several site visits. Behaviour observed may be likened more to that of a move-in-turn lane drop, which commonly occurs on the departure of a signalised intersection in an urban environment.

In the study area the 3km of typical motorway includes a steep grade (up in the northbound direction, as steep as 5%) towards the lane drop. Currently, the speed limit change (from 110km/h to 100km/h) is located in the area of level terrain at the top of the grade approximately 500m before the lane drop (illustrated in Figure 11).

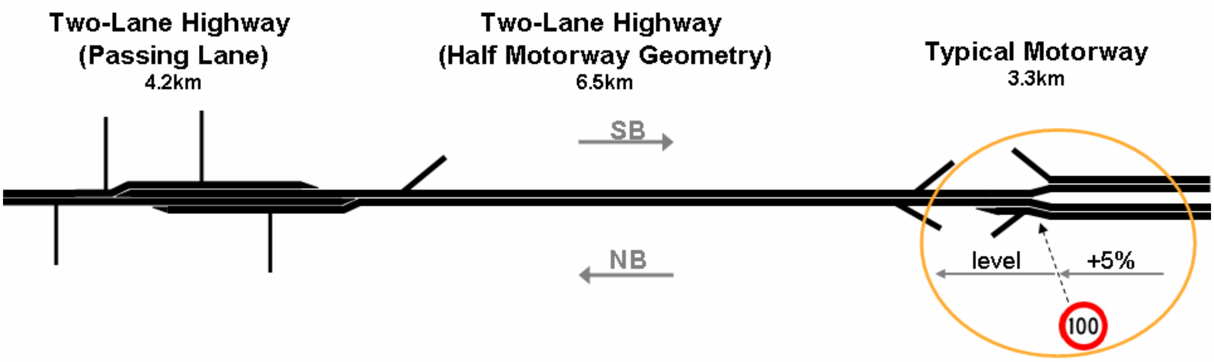


Figure 11: Existing 100km/h speed limit location, northbound

A suggestion that may assist in effective use of the speed limit and road type change is to relocate the 100km/h zone to the commencement of the grade increase. Taking advantage of the natural terrain in this fashion may encourage drivers to better adjust their speed to the different road type when it is then approached on level terrain at the end of the upgrade.

3.7.3 Highway management

It was also observed that along the half-motorway section drivers are well informed of the different road type, with 14 two-way warning signs in each direction (an example can be seen in Figure 5, top centre). This ensures that, despite the ramp interchange and the geometry that are typical of a divided motorway, drivers are reminded that it is in fact a two-lane highway.

A further suggestion is to continue to inform drivers of the road change over the typical two-lane highway segment, particularly about private and local road accesses. Further, the channelised intersections with side roads are located either side of a crest, on passing lane sections (see and example in Figure 12). This can create conflict between overtaking and turning traffic, which may be unexpected, particularly at nighttime, during wet weather or for unfamiliar drivers.

Figure 12: Example of channelised intersection in passing lane segment

3.7.4 Traffic operations

In acknowledgement of the transition between the divided and undivided road, Austroads advises that regular overtaking lanes can offer an intermediate level of service between the two road types, (2003). The 2+1 roads as they currently exist in Europe (and illustrated in Figure 4) can serve as one example of this concept. The half-motorway section of road in the case study area is approximately 6.5km long (refer to Figure 5), which would allow for several overtaking lanes to serve each direction under a 2+1 concept treatment.

4 Conclusion

Upon completion of this project, several areas have been highlighted for more detailed research to be carried out.

Overall, the guidelines and manuals consulted by highway practitioners need to be updated to offer more assistance for the situation of the transition between a four-lane divided and two-lane undivided road. Research to develop specified design guidelines is a priority, because this transition is not uncommon on Australia's National Network.

In particular, detailed crash studies and driver behaviour assessments may produce the most influential results. This information could assist in deciding where best to locate such a lane drop, particularly whether within an interchange is the most suitable point.

In addition, further investigating the application of a 2+1 road cross section, or similar, as an intermediate level of service between a typical four-lane motorway and two-lane highway may be worthwhile. At first, the extra cost for a wider pavement may seem unjustifiable when the half-motorway is intended to be duplicated in the future. However, the cost of crashes in the interim must be taken into account. In addition, to reason that the road will be duplicated also raises the question of how the transition will be treated at the end of the future upgraded segment.

To avoid continually relocating the transition between the four-lane divided motorway and two-lane undivided highway, a safe solution needs to be established through further investigation of these issues and concepts.

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