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An assessment of conspicuous traffic signals: mast arms

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ABSTRACT

Traffic signal conspicuity is likely to be a factor behind difficulties in detecting traffic signals. There is increasing interest in South Australia in providing mast arm mounted traffic signals at intersections to increase traffic signal conspicuity and reduce specific crash types. This report aims to review best practice principles in the conspicuity of traffic signals and determine the extent to which poor conspicuity of traffic signals contributes to crashes at signalised intersections. Without any recent Australian studies, it is difficult to determine the extent to which crashes result from a failure to detect traffic signals. According to best practice principles, the installation of additional traffic signals on mast arms at intersections has potential to improve traffic signal conspicuity. The second aim of this report is to attempt to quantify any road safety benefits in terms of crash reductions for installing additional signals, specifically traffic signals on mast arms at intersections. Research evidence from a number of evaluations shows that the installation of mast arms at intersections is associated with effects ranging from an estimated 89 per cent reduction in the total number of crashes to a 21 per cent increase in crashes. The greatest crash reductions were reported for right angle crashes (15-100%) while left turn crashes (equivalent to right turn in Australia) were associated with small crash reductions. Although this review shows that mast arms were associated with some crash reductions, it is important to note that these findings are not conclusive as many of the evaluations suffered from poor methodological design.

KEYWORDS

Traffic signal, Signalised intersection, Mast arm, Driver information.

Summary

Traffic signal conspicuity is likely to be a factor behind difficulties in detecting traffic signals. In recent years, there has been increasing interest in South Australia in providing overhead or mast arm traffic signals at intersections to increase traffic signal conspicuity and reduce specific crash types. Mast arms are designed for use where the stopping sight distance to the post-mounted signal face is inadequate and where the roadway is too wide for kerb-mounted signal faces to fall within the driver's line of sight (Akcelik, 2003). This report reviews best practice principles in the conspicuity of traffic signals and investigates the extent to which poor conspicuity of traffic signals contributes to crashes at signalised intersections. This report also attempts to quantify any road safety benefits in terms of crash reductions for installing additional signals, specifically traffic signals on mast arms at intersections.

According to best practice principles, the conspicuity of a traffic signal, and a driver's response to the traffic signal, is enhanced by fewer competing information sources (i.e., visual clutter), strong signal to background contrast, the position of a signal in the driver's field of vision, and placing signals in uniform and consistent locations where people are looking for visual clues. Considering these principles, the installation of additional traffic signals on mast arms at intersections might improve traffic signal conspicuity.

To determine the safety benefits associated with the installation of mast arm signals, a review of the international research evidence was undertaken. However, findings from this review are not conclusive as many of the evaluations suffered from a number of methodological limitations such as, but not limited to, using simple before and after crash analyses without control sites and failure to account for traffic flow. In particular, many of the studies failed to account for regression to the mean effects. In some cases, mast arms were installed at intersections with high crash frequencies and crashes were measured over a short follow up period. Consequently, findings from these studies are likely to exaggerate the positive effects of mast arms. In addition, a lack of information about the intersections and the placement of mast arms in these evaluations means it is not possible to determine whether a certain approach to mast arm treatments is more effective than others. Another limitation was that most of these studies were conducted in North America where they take a different approach to traffic signal configuration and mast arm use.

Acknowledging these problems, evidence from a variety of mast arm evaluations shows that mast arms at intersections were associated with effects ranging from an 89 per cent reduction in the total number of crashes to a 21 per cent increase in crashes. With respect to crash type, mast arm treatments have demonstrated the greatest crash reductions for right angle crashes (15-100%). This is consistent with the argument that engineering measures are likely to reduce unintentional red light running, evident in the reduction of right angle crashes. Left turn crashes (equivalent to right turn crashes in Australia) recorded the lowest crash reductions of all crash types. Enforcement measures such as red light cameras might reduce left turn crashes, which are markers for intentional red light running. The only available research evidence from Australia found mast arms did not reduce casualty crash frequency but reduced the severity of casualty crashes. Further methodologically sound research is needed to determine the effectiveness of mast arms in the Australian context.

There is some concern with respect to the use of excessive traffic signals and mast arms at intersections asserting that an excessive number of signals may add to the visual clutter in the urban environment and cost more to install. Mast arms may be confused with adjacent upstream signalised intersections, and may lead to an incorrect perception of the stop line position when located at the secondary or tertiary position (on the departure side) if not installed according to standards and guidelines. Further research into these issues is recommended.

Contents

1 Background

This report is concerned with drivers' failure to detect traffic signals. Traffic signal conspicuity is likely to be a factor behind difficulties in detecting traffic signals. Among other measures that might improve traffic signal conspicuity, potential safety benefits might be expected from the installation of additional traffic signals at signalised intersections and pedestrian crossings.

In recent years, there has been increasing interest in providing overhead or mast arm traffic signals at signalised intersections in South Australia (under Black Spot funding) to increase traffic signal conspicuity and reduce specific crash types such as rear-end and right angle crashes. However, there is little available evidence from other States and Territories to support the safety benefits of such installations. Consequently, the Department of Transport, Energy and Infrastructure (DTEI) has questioned the appropriate benefit/cost values to be used in assessing the installation of traffic signals on mast arms in South Australia.

This report aims to review best practice principles in the conspicuity of traffic signals and determine the extent to which poor conspicuity of traffic signals contributes to crashes at signalised intersections. Based on DTEI's concerns, this report will also attempt to quantify any road safety benefits, in terms of crash reductions, for installing additional signals, specifically traffic signals on mast arms, at intersections.

To address these aims, this report begins with an international literature review of best practice principles in the conspicuity of traffic signals, briefly covering any literature on the extent to which crashes result from failure to detect traffic signals. Next, means of enhancing traffic signal conspicuity are discussed with specific reference to the provision of mast arm mounted traffic signals. Finally, studies evaluating the installation of mast arms at intersections are reviewed to quantify whether the installation of mast arms might be beneficial in South Australia.

2 Conspicuity of traffic signals: a brief literature review

The purpose of a traffic signal is to direct and regulate traffic flow and this can be achieved through two fundamental principles: conspicuity and clarity (Kell & Fullerton, 1991). Conspicuity means that the traffic signal must not only be visible, but also attract a driver's attention. Clarity means that the message or direction given can be easily understood. This report will primarily focus on conspicuity.

The conspicuity of a particular set of traffic signals can be difficult to measure objectively due to many competing information sources in the traffic environment such as background light and visual clutter. Better conspicuity of traffic signals assists in earlier recognition and detection by the driver. This is particularly important for older drivers; drivers over the age of 70 require an additional 1.5 seconds of time for signal display recognition (Allen *et al.*, 1980).

In the following section, a brief international review of research evidence concerned with best practice principles in the conspicuity of traffic signals is undertaken. Firstly, the extent to which crashes result from the failure to detect traffic signals is investigated.

2.1 Failure to detect traffic signals in crash causation

Studies examining the causes of crashes at signalised intersections provide an indication of the extent to which crashes result from the failure to detect traffic signals. An early study in the 1970s involved researchers attending and conducting an in-depth analysis of crashes in the Adelaide metropolitan area to which an ambulance was called (McLean et al., 1979). The crash sample was representative of the crash population by time of day and day of week. Of the 304 crashes investigated, 45 occurred at signalised intersections. The conspicuity of traffic signals was not identified as a factor in any of these crashes.

Tijerina et al. (1994) conducted a detailed analysis of the causes of 50 police-reported crashes at signalised intersections in the United States. Drivers who were unaware of the traffic signal and its status caused around 41 per cent of the crashes. In contrast, drivers deliberately disobeying traffic signals caused 39 per cent of these crashes. The precise percentage breakdown by principal cause and driver intention are provided in Table 2.1. Note that these percentages are weighted based on crash severity.

Table 2.1
Causes of crashes at signalised intersections (Tijerina et al, 1994)

Principal cause of crash	Number of crashes	Weighted %
Unintentional		
Inattentive driver ("did not see" signal)	17	36.4
Vision obstruction (i.e., vehicle or roadway)	2	4.3
Intentional		
Ran red light	12	23.2
Tried to beat signal change	8	16.2
Other		
Driver intoxicated	7	12.6
Other (e.g., vehicle defect, collision with ambulance)	3	7.5

An unpublished Federal Highways Administration study reported traffic signal violation was a contributing factor in crashes at 31 signalised intersections located in three US states (McGee, 2003, p. 15). The definition of a "contributing factor" was not specified. A reason for the violation was provided in 139 out of the 306 crashes, based on self-report. At least 55 per cent of crashes were considered to be unintentional, attributed to poor signal visibility and confusing traffic signals. Table 2.2 shows the predominant causes of these crashes, grouped by driver intention.

Table 2.2
Self-reported causes of crashes at signalised intersections
(Federal Highways Administration, cited in McGee, 2003)

Self-reported cause of crash	%
Unintentional	
Did not see the signal	40
Mistook the signal to be green	12
Confused by another signal at the intersection or at a closely spaced intersection	3
Intentional	
Tried to beat the yellow signal	25
Intentionally violated the red signal	8
Unable to bring vehicle to a stop (due to vehicle defects or environmental conditions)	6
Other	
Followed another vehicle into the intersection	4
Varied	2

Note that care should be taken in interpreting this information because it is self-reported, it cannot be independently verified, and is based on a small sample. When causes of crashes are based on statements from the driver, it is possible that few drivers will admit that they intentionally violated the signal. Nonetheless, given the limitations of self-reported information, findings from these two studies suggest that inconspicuous traffic signals can lead to a significant number of crashes at signalised intersections.

In an effort to match the causes of red-light crashes with appropriate countermeasures, Bonneson and Zimmerman (2004) conducted a review of the literature and examined red light-related crash data, including time into red (number of seconds after red light when crash occurs) and crash types. The examination of crash reports revealed that the causes of red light-related crashes could be grouped into four categories of which three were deemed intentional and one unintentional. The unintentional crashes were caused by inattention whereby the driver did not see the signal or saw it too late to respond appropriately, suggesting traffic signal visibility or conspicuity was a problem.

Investigation of red-light violation characteristics (Bonneson *et al.*, 2002) revealed that the time of the violation was correlated with crash type. Around 98 per cent of red light violations occurred within the first four seconds of the start of the red period (i.e. end of yellow). With respect to red light-related crash types, the two most common are right angle crashes and right turn crashes (Milazzo *et al.*, 2001). Right turn crashes occur when a driver turns in front of an opposing through vehicle (usually when an unprotected right turn is allowed at an intersection). These crashes predominantly occur within the first four seconds after the onset of the red signal (Bonneson & Zimmerman, 2004). In this situation, it is generally the right turning driver attempting to clear the intersection at the end of the through phase and an opposing driver runs the red light. These crashes during the first few seconds after the start of the red signal are suggestive of driver frustration, possibly due to excessive delay, inadequate yellow interval or excessive speed (Bonneson & Zimmerman, 2004). Right angle crashes typically occur throughout the red phase. When a driver enters an intersection late into the red, this may be an indication of deficiencies in signal conspicuity or sight distance along the intersection approach (Bonneson & Zimmerman, 2004).

In contrast to red light violations, Milazzo et al. (2001) found that of 34 red light-related crashes investigated, 80 per cent were right angle crashes. Moreover, all of these crashes occurred after the first three seconds of red. Other research investigating red light camera crash data from several jurisdictions (mainly from the United States but also includes Australia) reported that 65 per cent of crashes were right angle (Bonneson & Zimmerman, 2004). The median time after red for right angle crashes was 8.9 second compared to 0.9 seconds for right turn crashes. With one exception, all of the right angle crashes occurred after five or more seconds of red.

Based on these findings concerning crash types and time into red, Bonneson and Zimmerman (2004) concluded that enforcement efforts such as red light cameras are likely to reduce intentional red light running during the first few seconds of the red phase and reduce the frequency of left turn crashes (equivalent to right turn in Australia). Most relevant to this report, engineering measures designed to improve signal visibility are likely to reduce unintentional red light running throughout the red phase and reduce the frequency of right angle crashes. Bonneson and Zimmerman also note that while increasing the all-red interval is likely to reduce right angle crashes that occur during the first few seconds of red, these crashes are relatively uncommon so this measure would have little effect in reducing the total number of crashes.

Evidence from crash records and self-reported crash data in the United States reviewed here indicate that engineering measures designed to improve traffic signal conspicuity can potentially reduce crashes at signalised intersections. Estimates of crash reductions range from 40 to 55 per cent of crashes at signalised intersections (McGee, 2003; Tijerina et al., 1994) although the true proportion is likely to be at the lower end, due to limitations associated with self-reported data. The author is not aware of any evidence from Australia concerning the extent to which crashes result from the failure to detect traffic signals since the 1970s. It is possible that Americans may be more or less law abiding than Australians, and different enforcement methods may have an effect (e.g., red light cameras might be more prevalent in Australia). The Australian approach to traffic signal display and location also differs considerably from that in the United States. For example, the minimum number of signal faces for a given approach is three in Australia and two in the United States (see Section 3.2). Without any such recent Australian studies, it is difficult to determine the extent to which crashes result from failure to detect traffic signals in Australia.

2.2 Conspicuity of traffic signals: human factors

Any discussion of best practice principles in traffic signal conspicuity should consider the human factors involved in the detection and response to traffic signals. Considerable literature on the decision-making process shows that drivers can only comprehend a limited amount of information in the driving context at any given time (e.g., Hanscom & Dewar, 2001). Consequently, traffic signals are competing with other information sources in the driving environment for a driver's attention. For a traffic signal display to be conspicuous, the driver must be able to distinguish the traffic signal from other irrelevant information sources, light and visual clutter. Complex background lighting or a bright sky, particularly for traffic signals orientated in an east-west direction, may decrease traffic signal conspicuity. Backplates or black target boards are useful for increasing traffic signal conspicuity against such backgrounds.

There is little research investigating the effects of visual clutter on driver behaviour. Although, the experimental study design is not strongly representative of real driving, Ho et al. (2001) found that images of driving scenes classified as high clutter required longer latencies and more eye fixations to acquire target signs, were associated with more errors, and had longer eye fixation durations than low clutter scenes. Contrary to Schieber and Goodspeed's (1997) findings, older adults were no more likely to be affected by increased visual clutter in driving scenes than young adults.

Traffic signals also need to be placed where the driver will see them. A study of signalised intersections showed that signal heads should be placed as close to the driver's line of sight as possible and one signal should appear in a consistent location expected by the driver (King, 1977). With respect to detecting and responding to a traffic signal, the most important factors are the sight distance at which the signal first becomes visible and the offset of the signal position from the line of sight. In Australia, the stopping sight distance is determined by the 85th percentile approach speed. For example, an approach speed of 55-64 km/h requires a stopping distance of 55 metres, based on a reaction time of 1.5 seconds (see Standards-Australia, 1996).

Human factors studies have found that generally, a driver's lateral vision is excellent up to 5 degrees on either side of the line of sight (a cone of vision of 10 degrees). For example, Engel (1977) found that the conspicuity of targets decreased when objects were more than 5 degrees off the line of sight while Cole and Jenkins (1979) found object detection decreased when moved 6 to 12 degrees off the line of sight. Driver's vision is judged as 'adequate' at 20 degrees on either side (cone of 40 degrees), although visual acuity used for reading decreases after 10 to 12 degrees (Hanscom & Dewar, 2001). The Manual for Uniform Traffic Control Devices (MUTCD) in the United States requires that at least one traffic signal head (and preferably two) are located within 20 degrees to the left and right of the centre of the approach lanes, measured at the point 3 metres before the stop line (Kell & Fullerton, 1991). Where a roadway is too wide for kerb-mounted traffic signals to be placed within a driver's line of sight, traffic signal conspicuity can be improved by mounting additional signals on overhead mast arms or, in the United States, suspended from catenary cables. A traffic signal positioned over the middle of a traffic lane is in the driver's cone of vision, increasing visibility.

Although much is known about a driver's field of vision, there is little agreement as to how drivers visually scan for traffic signal information and where the optimal position is to display this information. The problem with visual target searches is that they are not consistent or dominated by internally driven scan strategies (Noyce, 1999). For example, some studies suggest searches for visual targets start in the upper left of the display while others found search patterns began in the centre of the display, avoiding outer edges (Megaw & Richardson, 1979; Parasuraman, 1986). However, note that these studies were not conducted in a driving context. Response time and driver errors also increase with the number of display and action choices within the search pattern (Noyce, 1999). Inexperienced drivers have a limited visual scan pattern and will obtain less additional information from cues located further down the roadway than experienced drivers (Mourant & Rockwell, 1972).

An increased mental workload has been found to reduce the effectiveness of searches for visual targets (e.g., lower variability in spatial gaze direction) while driving (Recarte & Nunes, 2003). Earlier research has also shown that clearly visible signs were not easily detected by drivers in locations where the driver was kept busy by the driving task or where there were other competing sources of relevant visual information (Cole & Hughes, 1984). Therefore, the conspicuity of a traffic signal might be improved when the driving task is made easier, either through familiarity with the intersection or good signing. For example, if a driver is approaching an unfamiliar intersection and trying to determine which lane to be in, good signing may prevent their attention from being directed away from the task of detection and recognition of traffic signals.

Target searches are driven in part by cognitive factors related to expectancy of where the target, or most useful information, will be in the visual field. For example, Shinoda et al. (2001) examined driver's ability to detect stop signs, visible for restricted periods, in a virtual environment. They found that the frequency of the search was influenced by learnt knowledge of the probable structure of the environment. Participants were more likely to search for stop signs in the region of intersections. Consequently, variability in traffic signal displays and locations (e.g. pedestrian crossings) can conflict with driver expectations and lead to increased response times, inappropriate responses, informational demand, and driver errors (Benioff & Rorabaugh, 1980; Noyce & Kacir, 2001). For example, in the United States, driver expectancy might be violated when a vertically mounted signal display is observed at one location followed by a horizontal mounting arrangement at a different location. It is conceivable that the use of vertical post mounted and mast arm mounted traffic signals might conflict with driver expectations, although it is only likely to be a problem if mast arm mounted signals replaced post mounted signals, not if they were supplementary. One study reported no significant differences in correct responses to traffic signals between median post mounted and mast arm mounted signal displays for protected and permitted left turns (equivalent to right turn in Australia), based on responses to photographs of intersections (Noyce & Kacir, 2002).

Australian guides to traffic signal installation argue that driver expectancy is maximised when traffic signals are placed in a uniform and consistent manner at signalised intersections (Akcelik, 2003). Drivers must know where to look to find the appropriate information. Uniform and consistent placement of traffic signals ensures that visual search requirements are minimised, the amount of complex information placed on the driver is reduced, and driver comprehension of the signals improved. Reinforcing expectancies through uniform presentation of traffic signals assists a driver in responding quickly and correctly to the intended message. Consequently, traffic signal displays are not mounted horizontally in Australia.

To summarise, the conspicuity of a traffic signal and a driver's response to the traffic signal is enhanced by fewer competing information sources (i.e., visual clutter), strong signal to background contrast, the position of a signal in the driver's field of vision, and placing signals in uniform and consistent locations.

3 Mast arms: a solution for traffic signal conspicuity?

Few studies have examined the potential safety benefits of improving traffic signal visibility and conspicuity. A simple before and after analysis conducted by Kassan and Crowder (1969) indicated that enhanced signal visibility reduced right angle crashes by 32 to 57 per cent and rear end crashes by 44 to 86 per cent. However, significant increases between 33 and 98 per cent were found for other crash types. More recent studies, using methods ranging from simple before and after analyses to empirical Bayes techniques, estimated that improved signal visibility at signalised intersections could reduce crashes by 20 to 30 per cent and rear end crashes by 30 to 40 per cent (Felipe *et al.*, 1998; Hamilton Consulting Ltd, 1997; Navin *et al.*, 2000; Ogden, 1996).

These studies indicate that substantial road safety benefits may be obtained from improving traffic signal visibility and conspicuity. A recent US publication suggests a number of engineering measures to improve traffic signal visibility and conspicuity (McGee, 2003). Recommendations include: placing signals overhead on mast arms, increasing the number of traffic signal heads, increasing signal size, improving the line of sight, increasing signal redundancy, increasing signal brightness using LED signal lenses, installing backplates, and installing supplementary strobe lights. The focus of the present report is on the safety benefits of the installation of additional traffic signals on mast arms.

This Section begins by stating the function of mast arms. Following this, the configuration of traffic signals and placement of mast arms is discussed in terms of enhancing traffic signal conspicuity. Studies attempting to quantify the safety benefits of mast arm treatments are reviewed in Section 4.

3.1 What are mast arms?

A mast arm is a cantilevered structure that allows the installation of traffic signal heads above traffic lanes. Mast arms can also support traffic signal heads mounted on the vertical pole and accommodate a street light as seen in Figure 3.1. The combination mast arm shown in Figure 3.1 is used mainly in the Adelaide CBD. Note that in the United States, overhead traffic signals may be suspended from span wire strung across the road. In this report, only the literature referring to traffic signals on the rigid mast arm structures are discussed.

According to the Traffic Engineering Manual (1999) produced by Vic Roads, mast arms are designed to fulfil two objectives: "to support a lantern over or to the side of an obstruction which is inhibiting the visibility of the primary lantern and to reduce the offset of the primary lantern from the drivers line of sight (desirable maximum offset 7.5m)" (p. 3-20). Essentially, the purpose of mast arm mounted signals is to provide adequate warning of the approach of an intersection and provide an early indication of the signal aspect (Ogden & Newstead, 1994).

Figure 3.1
Combination mast arm at a signalised intersection, Adelaide CBD

3.2 Configuration of traffic signals and placement of mast arms

An early study from the United States concluded that mixed configurations of overhead (i.e., mast arm mounted) and post mounted signal heads were generally better than either all post or all overhead displays (King, 1977). Extensive research from the Insurance Corporation of British Columbia (ICBC) concluded that there was a significant safety benefit to traffic signal configurations at signalised intersections that included primary overhead signals for each lane and pole mounted secondary (left side in Canada) and tertiary (right side in Canada) traffic signals. Felipe et al. (1998) reported that the installation of additional overhead primary signal heads mounted directly over each traffic lane (e.g., two overhead signal heads replaced by three) resulted in estimated crash reductions between 30 and 40 per cent. Slightly greater reductions were estimated for property damage only crashes (30-35%) than injury/fatal crashes (10-25%). Right angle crashes were reduced by between 15 and 45 per cent while rear end crashes were reduced by 30 to 45 per cent (see Table 4.1).

The national standard for traffic signals in the United States is provided in the Federal Highway Administration's Manual on Uniform Traffic Control Devices (2003), first published in 1935. Noyce (1999) notes that the lack of specific mandates in the manual concerning the selection and use of some traffic signals has led to different applications in different jurisdictions.

In the United States, a minimum of two signal faces is required for the major movement on the approach of an intersection (*Manual on uniform traffic control devices*, 2003). Based on these findings mentioned above, the preferred signal configuration to improve visibility in the United States is to provide an overhead signal display centred over the middle of each approach lane (but two overhead signals for a one lane approach), and if the sight distance is restricted, supplemental post-mounted signals (McGee, 2003). For very wide approaches (i.e., four lanes or more), it is suggested that overhead signals are placed directly over each lane line of the approach.

In Australia, the display, location and operation of traffic signals must be in accordance with specifications in the Australian Standard 1742.14, Manual of uniform traffic control devices Part 14: Traffic signals (Standards-Australia, 1996). An Austroads publication (Akcelik, 2003) also provides traffic engineers with guidelines for traffic signals to supplement the standard. Some Australian states also produce their own guidelines: Victoria, New South Wales, Queensland, and Western Australia (currently in the process of developing guidelines). Each of these states dedicates a brief section to mast arms in the guidelines.

The Australian approach to traffic signal display and location differs considerably from that in the United States. To begin, the minimum number of signal faces for a given approach in Australia is three. The United States Manual on Uniform Traffic Control Devices (2003) requires at least one traffic signal within 20 degrees on either side of the drivers' line of vision (see Section 2.2). While the Australian Standard does not have any explicit requirements, it refers to the Austroads guidelines for determining whether traffic signals are sufficiently close to the drivers' line of sight (Akcelik, 2003, see p.54-55). Two signal face visibility templates are given, based from the driver position at the point where the driver is required to detect the traffic signal so that they may stop the vehicle before the stop line (i.e., stopping distance). The first template, applied to roads where the speed limit is 60 km/h or less and the lantern size is 200 mm, is based on a 12-degree angle on either side of the driver's line of sight. The second template, used for speed zones greater than 60 km/h and 300 mm sized lanterns, is based on a 21-degree angle on either side.

With respect to mast arms, the Australian Standard AS1742.14 states that overhead signals or mast arms are required "where the stopping sight distance to the post-mounted signal face is inadequate, e.g., because of vertical or horizontal alignment, awnings, poles, trees or similar sight obstructions, and where the roadway is too wide for kerb-mounted signal faces to fall within the driver's line of sight" (p. 20). Nevertheless, it is recommended that mast arm signals be omitted if it is likely that they could be confused with an adjacent upstream signalised intersection. Presumably, the concern is that the green light on a mast arm may cause danger when thought to apply to an upstream intersection that actually has a red light. No reference to this concern has been found in North American literature. The Austroads guidelines (Akcelik, 2003) add to the Standard acknowledging that traffic signals on mast arms are expensive to install and to maintain, and on this basis suggest that their use is minimised (p.53).

Concerning the location of mast arm mounted signals, the Australian Standard requires that at least one overhead signal face is provided on an undivided road approach with more than three lanes (Standards-Australia, 1996). The provision of at least one mast arm on approaches with three lanes is suggested. The primary signal face location (adjacent to the stop line or point where traffic is required to stop) is preferred for mast arms because it provides the greatest sight distance from the stop line and alerts drivers to the approaching traffic signal when dual primary signal faces cannot be provided (Akcelik, 2003). Figure 3.2 shows the Austroads designated locations for traffic signals on undivided and divided roads (note that in Figure 3.2, overhead refers to a mast arm). Where two overhead signals are required for each approach, Austroads suggest primary and secondary signal faces for opposite approaches are mounted on the same mast arm to reduce costs.

Some concern has been expressed regarding the placement of mast arms at either the secondary or tertiary position (located on right and left of departure side, not approach), particularly at large intersections (Duarte & Corben, 1998). It is thought that departure side mast arms might lead to incorrect perception that the stop line is further away than it actually is. A photograph of a signalised intersection with a mast arm at both the approach and departure is depicted in Figure 3.3.

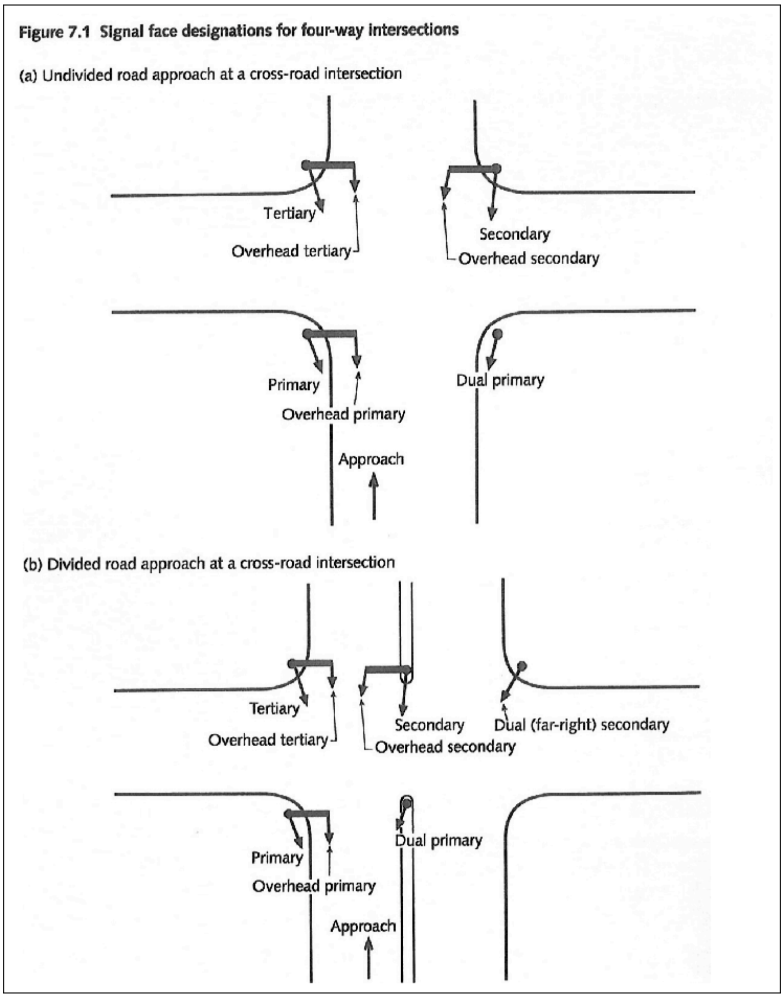

Figure 3.2
Designation of signal faces for four-way intersections (Source: Akcelik, R. (2003). *Guide to traffic engineering practice Part 7: Traffic signals*. Sydney: Austroads. p. 50)

Austroads recommend the mast arm outreach should locate the signal face above the second lane from the kerb unless obstructions such as powerlines are present. The bottom of the target board on the mast arm should provide a minimum clearance of 5.4m from the road pavement (Standards-Australia, 1996).

The maintenance of mast arms is an important factor for the lateral positioning of the traffic signal on the mast arm. The New South Wales traffic signal design guidelines, developed by the Road Traffic Authority (2006), prefer the signal face to be located above the centre of a lane, but no less than one metre from the lane line, to meet maintenance OH&S requirements. Signal maintenance is executed from an elevated platform vehicle (i.e., cherry picker).

VicRoads state that mast arms should be installed in the median strip of divided roads (i.e., with three lanes or more) to provide clearance between the mast arm and overhead electricity cables (*Traffic engineering manual vol 1*, 1999). This location also ensures that the overhead traffic signal is closest to the fastest moving vehicles and, if there is an indented right turn lane, provides a signal display clearly visible above the through lane.

Austroads (Akcelik, 2003) mention several other considerations when determining the location of mast arms. Firstly, the poles supporting mast arms are rigid structures (to support the mast arm) and they should only be positioned where the likelihood of impact by vehicles is low. The concern is that poles located at the intersection of major roads have the highest risk of crash involvement (Fox *et al*., 1979). Secondly, it is thought that "excessive numbers of signal faces add to the visual clutter at the intersection and add to intersection operating costs" (Akcelik 2003, p.52). While financial costs might be a practical consideration for road authorities, there is no research evidence, of which the author is aware, suggesting that the addition of extra signal faces (using a consistent display) is confusing for road users.

In addition to concern about the amount of rigid structures on the roadside, the Road Traffic Authority (2006) list possible delays in replacing burnt-out lamps/signals as a reason for keeping mast arm use minimal.

Figure 3.3
Mast arms on approach and departure of a signalised intersection, Adelaide

3.3 The South Australian approach to traffic signal conspicuity

The South Australian Department of Transport, Energy and Infrastructure (DTEI) provides its own Operational Instruction document to enable consistency in the application of traffic signals on DTEI roads. The Traffic Signal Faces Operational Instruction 14.2 (2006) should be read in conjunction with the Austroads Guide to Traffic Engineering Practice Part 7 Traffic Signals (Akcelik, 2003), and Australian Standard 1742 Part 14 for traffic signals and Part 7 for railway level crossings (Standards Australia, 1996).

At present, a number of measures are used to increase traffic signal conspicuity on South Australia roads (refer to Operational Instruction 14.2). They include:

- The installation of visors and louvres to reduce the potential for lanterns to be seen from adjacent conflicting approaches. Special visors (tilt or vertical louvered) are used where the adjacent traffic signals are less than 200m apart. New designs must be checked using vision cone templates. In addition, closed visors are used on secondary and tertiary lanterns so that the lantern is hidden from the view of drivers on other approaches.

- Improving the line of sight to traffic signals. This might involve clearing roadside vegetation and relocating roadside signs obscuring site distance to signals. DTEI also reviews all applications for proposed illuminated signs near traffic signals to limit visual clutter and distractions. Generally, the height and location of primary, secondary and tertiary signals is not altered except in special circumstances where standard mounting is not possible.

- The installation of target boards on all lanterns to increase signal contrast with the background.

- The use of LEDs to increase signal brightness. In addition, LED signals significantly outlast incandescent globes and therefore require less maintenance.

- Extended range lanterns (300mm) for roads with higher speed zones (80km/h and over) to provide adequate warning for the driver to stop at the approach. The design site distance for 300mm aspects is 240m. For speed zones less than 80 km/h, 200mm signal faces are used with a sight distance of 100m.

- For any approach, the installation of a minimum of three signal faces for any through movement and a minimum of two signal faces for any turning movement.

- The installation of traffic signals on mast arms to provide adequate stopping sight distance. Consistent with the Australian Standard 1742.14 and Austroads guidelines (2003), the operational instruction 14.2 (2006) states that where a primary signal face is obscured by an obstruction (e.g. trees, verandas) and cannot therefore be provided, an overhead primary signal face should be installed. Where the overhead primary signal is used as an alternative location for otherwise obscured signals the lanterns size is 200mm. If the overhead signal is for the purpose of providing an extended range for sight distance, lantern size is 300mm. Overhead signals in speed zones of 80km/h or greater must have 300mm signals. In South Australia, the mast arm outreach is typically 2m, 3.5m or 5.5m. The configuration and placement of mast arms in South Australia is consistent with the Australian Standard. For economic and operational reasons, it is common practice to install back-to-back signals on the same mast arm pole at locations where there are no median signals and overhead powerlines prevent the installation of a separate mast arm for the approach in the opposite direction.

4 Evaluations of mast arm treatments

A review of the international literature found a number of studies that have attempted to quantify the road safety benefits of the installation of traffic signals on mast arms. The majority of these studies were conducted in North America. A summary of these studies and estimated crash reductions are provided in Table 4.1. Note that a "left turn" crash refers to the equivalent of a right turn crash in Australia.

In the following two Sections (4.1 and 4.2), each of the evaluations listed in Table 4.1 are discussed briefly. A summary of the methodological issues associated with these studies is given in Section 4.3. Note that these issues limit the conclusiveness of findings. Based on the evaluations, potential estimated crash reductions for mast arm treatments are summarised in Section 4.4.

4.1 North American research

An early report by Malo (1967) described a very simple before and after crash analysis evaluating the installation of mast arm signals to supplement far side corner signals at two wide one-way street intersections in Phoenix, Arizona. The number of crashes decreased by 75 per cent, from eight crashes in the previous year to two crashes in the following year. In the year prior to mast arm installation, all crashes were right angle but in the year after installation, there were no crashes of this type. Lalani (1991) conducted before and after crash analysis (one year of data before and one year after) for various treatments aimed to increase the visibility of traffic signals. The installation of mast arm signals at one intersection reduced crashes by 60 per cent. No analysis is included and it is unclear what type of intersection was involved. The results from these two studies should be interpreted with caution because of the small number of intersections examined and the small number of crashes reported at each intersection.

Felipe et al. (1998) reported on an economic evaluation analysis for the installation of an additional primary signal head at 34 intersections in the City of Vancouver. Intersections with one primary signal head per approach and two lanes per approach were selected. The evaluation was conducted based on two scenarios: costs for the installation of signal heads only, and costs for the installation of new mast arms and signal heads. The analysis suggested that providing two primary signal heads per approach would result in a reduction of 190 crashes and a saving between $1,310,000 and $2,570,000 per year, with a minimum project life of 2 years. Further analysis suggested a 2:1 return on investment over two years with 100 per cent reliability, regardless of the cost scenario.

A paper by Craven (1985) examined the effectiveness of a number of projects to improve intersections with a high crash record in Illinois under the Federal Hazard Elimination Safety Program. These programs included signal installation, signal upgrading, and geometric changes to intersections. The evaluation was undertaken in terms of a simple before and after analysis using two years of data before and after the treatment. Of the 52 projects in the program, two projects incorporating the installation of mast arms, among other treatments, are discussed in the paper. Note that the following results should be interpreted with caution because no control sites were used in the analysis to determine whether crash reductions were due to regression to the mean. Also, potential changes in traffic volume were not considered.

Table 4.1
Reported effectiveness of mast arm treatments at signalised intersections

				Percentage reduction in crashes [a]					
Study	Treatment	Location	No. of intersections	Total	Right angle	Rear end	Left / right turn	Other	Benefit cost ratio
Malo (1967)	Installation of mast arm signals	Phoenix, Arizona, USA	2	75	100	-	-	-	-
Craven (1985)	Installation of mast arm signals, road geometry improvement and altered traffic control phasing (Project B)	Illinois, USA	1	47	-	-	-	-	-
	Installation of mast arm signals, new detection equipment, addition of signal backplates and modified channelization (Project C)	Illinois, USA	1	+24	-	-	-	-	-
Lalani (1991)	Installation of mast arm signals	California, USA	1	60	-	-	-	-	-
Bhesania (1991)	Replacing post-mounted signals with mast arms and addition of one second all-red interval	Kansas City, USA	5	25	63	19	+35	27	10.5:1
Parsonson (1993)	Installation of mast arm signals to supplement far-side corner signals	Atlanta, USA	?	89	93	-	-	-	-
Voss (1997)	Replacing post-mounted signals with mast arm signals	Kansas City, USA	24	49	74	41	12	-	26:1
Felipe et al. (1998)	Installation of additional primary mast arm signal heads	British Columbia, Canada	8	20-30	15-45	30-45	-	-	-
	Installation of additional primary mast arm signal heads (economic evaluation)	British Columbia, Canada	34	-	-	-	-	-	2:1
Newstead & Corben (2001)	Installation of mast arm signals	Victoria, Australia	8	+21	-	-	-	-	12.4:1
Thomas & Smith (2001)	Replacing post-mounted signals with mast arm signals	Iowa, USA	33	36	72	+20	+2	27	11.2:1

[a] + denotes an increase in crashes

Crash records for the intersection in the first project indicated that sideswipe and rear end crashes were over-represented due to poor signal visibility and vehicles turning left in the through lanes. Improvements to this intersection involved the installation of mast arm mounted signals, improved road geometry and altered traffic control phasing. A total crash reduction of 47 per cent was reported (19 crashes before, 10 crashes after) with a 60 per cent reduction (15 crashes before, 6 after) in the crash types addressed by the treatment, sideswipe and rear end crashes. Prior to the treatment, the majority of crashes at the intersection in the second project were identified as rear end and left turning crashes. Improvements to the intersection incorporated the installation of mast arm signals, new detection equipment, 12-inch signals with backplates and the modification of channelization at an intersection. Left-turn phasing was also planned for the intersection but was omitted due to cost. Subsequent crash data showed that crashes increased by 24 per cent and left turn crashes continued to be over-represented. Given the number of treatments applied to the intersections in both projects, it is not possible to determine the separate effect of mast arms. However, these finding highlight the fact that treatments must be tailored to address specific problems at intersections.

Far-side-corner traffic signals were supplemented with traffic signals on mast arms at some signalised intersections in Atlanta, United States. Parsonson (1993) reported that right-angle crashes were reduced by 93 per cent and total crashes reduced by 89 per cent at these intersections. However, specific details about the treatment, analysis, and the type or number of intersections investigated are not provided in the report. It is also not known whether other treatments were given to these sites.

Several traffic studies have concluded that the *replacement* of post mounted with mast arm signals results in a reduction in the number of crashes. In the first of these studies, post-mounted signals were replaced with mast arm signals at the same time a one second all-red interval was added to both through phases at five intersections (Bhesania, 1991). The intersections were wide multi-lane roads in Kansas City (a minimum of two lanes, and in most cases three or more lanes in each direction). A before and after analysis was conducted using 12 months of crash data before and after installation of the treatment. The author noted that the intersection traffic volumes were “fairly constant” during the before and after periods and no other treatments were implemented. The total number of crashes was reduced at three intersections, showed no change at a fourth intersection, and increased at a fifth intersection. Overall, a statistically significant reduction of 25 per cent was reported for total crashes and 63 per cent for right angle crashes. The number of rear-end crashes also decreased by 19 per cent and other types of crashes by 27 per cent. Left-turn crashes increased by 35 per cent. Bhesania (1991) also reported that it was a cost effective treatment with an estimated benefit-cost ratio of 10.5:1 (assumed 30 year life of project and 8 per cent interest rate). However, this study was not able to determine the separate effects of the mast arm and the all-red interval treatments. In addition, control sites were not used in the analysis to determine whether crash reductions were due to regression to the mean.

A subsequent study in Kansas City evaluated a number of projects to improve safety at intersections, including the removal of pole mounted traffic signals and replacement with mast arm signals (Voss, 1997). A simple before and after crash analysis was conducted, using three years of crash data before and after the project. Based on data from 24 intersections, a total crash reduction of 49 per cent was reported. Analysis by crash severity indicated that injury/fatal crashes were reduced by 44 per cent and property damage only crashes reduced by 51 per cent. By crash type, a reduction of 74 per cent was reported for right angle crashes and 41 per cent for rear end crashes. The smallest crash reductions were recorded for left turn crashes, a 12 per cent reduction. A benefit cost ratio of 26:1 was estimated based on the assumption of a 15 year service life and an annualised cost for the 24 intersections of $71,833. However, control sites were not included in the study and changes in traffic volume were not considered.

The most comprehensive study of the impact of replacing post-mounted signals with mast arm signals was conducted by Thomas and Smith (2001). They examined the effects of seven types of traffic safety improvements for intersections in Iowa, including replacing pole-mounted signals with mast arm signals. Two types of analysis were conducted for each type of improvement; the first method was an estimation of the mean crash reduction and confidence interval, and the second method was calculation of the benefit-cost ratio. The second method required the authors to assign monetary values to crashes by crash severity (i.e., fatal, major injury, minor injury, possible injury, and property damage only) to compare the cost benefits using net present worth analysis. Crash data was obtained for three years before and after the treatment.

The authors claimed the most important outcome to be the significance of traffic signal visibility. After removing outliers, the analysis showed that the mast arm treatment, used at 33 intersections, resulted in a large reduction in crashes (36%) and the highest benefit-cost ratio for all intersection improvements. Analysis by crash type showed a 72 per cent reduction in right angle crashes and a 27 per cent reduction in 'other' crashes. However, like Bhesania (1991), increases in some crash types were observed; rear end crashes increased by 20 per cent and left turn crashes increased by two per cent. A benefit-cost ratio of 11.2:1 was calculated, assuming a 15-year service life and inflation rate of three per cent. Note that this study did not take into account traffic volumes (reliable data was not available for all locations) or regression to the mean phenomena.

4.2 Australian research

Within Australia, very little research evaluating the road safety benefits of mast arm mounted signals could be found. While not an evaluation as such, one study examined the characteristics of selected signalised intersections with a high, normal and low crash frequency during a five-year period in Melbourne (Ogden *et al.*, 1994). Traffic volumes were taken into account. Mast arms were more likely to be present at approaches of intersections in the 'high' crash group. This was interpreted as indicating that the least safe intersections had mast arms fitted, probably in response to problems, but the sites continued to have a poor crash record: "…while mast arms have been shown elsewhere to contribute to safety, they nevertheless cannot prevail if other conditions contributing to hazard are present. Conversely, many intersections, depending on their traffic flow, sight distance etc, function safely without overhead mast arms" (p. 19). Even though this study did not find mast arms enhanced the safety of signalised intersections, the authors endorsed the continued use of mast arms to provide an advance warning of signalised intersections based on positive findings from previous studies.

Traffic signals on mast arms were one of five treatments used in Victoria's 1994/96 accident 'black spot' program that did not achieve the intended effect, that is, a reduction in casualty crash frequency (Duarte & Corben, 1998). In Victoria, mast arm treatments were applied to mainly signalised intersection approaches but also included the departures of a large roundabout. Corben et al. (1996) evaluated seven sites receiving mast arm treatment in a 1992/94 TAC program and found a 10.2 per cent increase in casualty crashes, although not statistically reliable.

A second study of the same seven sites with 1996 crash data found that the treatment resulted in an overall 27.5 per cent increase in casualty crash occurrence (Duarte & Corben, 1998). However, a more detailed analysis of target crashes (i.e., rear-end and pedestrian crashes), showed that the target crashes, as a percentage of the total crashes, reduced from 41 per cent to 27 per cent.

Further analysis of five black spot sites deemed "unsuccessful", that is, sites that did not experience reductions in crash frequency (see sites 1, 2, 3, 5 and 7 in Table 4.2), showed that target crashes, expressed as crashes per year, decreased at three sites after the mast arm treatment. Note that the total numbers of target crashes at these sites both before and after the treatment were very low. At the other two sites, target crash frequency remained relatively unchanged at one (site 5), but increased substantially at the other site during the six month follow up period (site 7).

Table 4.2
Casualty crash details for sites receiving mast arm treatments in Victoria (Duarte & Corben, 1998)

Site no	Yrs before data	Years after data	Total crash before	Total crash after	Est. crash change[a] (%)	Target crash type	Total target crash before	Target crash per yr before	Total target crash after	Target crash per yr after
1*	5	4	7	6	99	Rear end	3	0.6	1	0.25
2*	5	2	23	11	81	Ped.	2	0.4	0	0
3*	5	3	11	5	16	Ped. visibility	2	0.4	0	0
4	5	3	0	1	N/A	N /A	0	0.0	0	0
5*	5	2	24	10	0	Rear end	12	2.4	5	2.5
6	5	0.5	12	0	-100	Rear end Ped.	10	2.0	0	0
7*	5	0.58	16	4	149	Rear end	9	1.8	4	6.9

* 'Unsuccessful' black spot sites

[a] Takes into account change in crashes at control sites. A negative number indicates a reduction in crashes.

A third evaluation of the Victorian accident "black spot" program was completed using crash data up to the end of 1998 so that all treated sites had a minimum of 2.5 years of post–treatment data (Newstead & Corben, 2001). The analysis also used control sites, improving on the methodology of the previous evaluation. As this study had the longest follow up period for the sites receiving the treatment, this study, but not the two previous studies, is reported in Table 4.1. Crash data for each individual site and information about target crash frequencies was not provided. An estimated 21 per cent increase in casualty crashes was reported for the eight sites where mast arms were installed although this increase was not statistically significant. Note that the number of crashes at the treatment sites decreased (29%) but greater crash reductions were reported at control sites (41%).

The mast arm program, with an eight per cent discount rate (typically used in the evaluation of public expenditure capital works treatment), cost a total of $285,583 for the eight sites. Taking into consideration crash severity and treatment costs, an economic analysis calculated a benefit cost ratio of 12.4:1 for the mast arm treatment. This was based on an estimated casualty crash cost savings of 26 per cent. These findings indicate that mast arms did not reduce casualty crash frequency but reduced the severity of casualty crashes.

A draft report evaluating the effectiveness of mast arms in metropolitan Adelaide (DTEI, Internal report) was recently completed after the writing of this report. For a brief summary of the findings, see Appendix A.

4.3 Methodological issues

Although there is a number of studies that have attempted to evaluate the installation of mast arm mounted traffic signals, it is difficult to conclusively estimate their relative cost effectiveness or potential crash reductions. This is because findings from such studies are predominantly site specific; mast arm treatments might be more appropriate for certain signalised intersections and not others. In addition, many of these studies were conducted in the United States where the use of mast arms differs to Australia. Moreover, the majority of the evaluations are constrained by at least one or more of the following methodological issues:

- Only a very small number of intersections are given the treatment (mast arms).
- Little information is provided concerning the type of intersection receiving the treatment. It is possible that the treatment may be more effective for certain type of intersections (e.g., wide streets, higher speed zones, curved or undulating alignments).

- Other treatments are given to the intersection(s) of interest.

- A short follow-up period for crash data (e.g., 12 months) is used resulting in few recorded crashes.

- Simple before and after crash analyses are undertaken without including control sites. This means that other factors that may have accounted for crash frequency were not controlled for in the analysis.

- Regression to the mean effects for crash frequency are not accounted for. Regression to the mean is likely to occur when sites with high crash frequencies are selected for treatment and crash frequency is measured over a short period. Consequently, the likelihood of reductions in crash frequency at these sites is high, merely due to chance. Findings are then likely to exaggerate the positive effects of the treatment.

- Changes in traffic flow at the intersections are not considered (e.g., an increase in traffic is likely to result in an increase in crashes).

4.4 Summary of estimated crash reductions for mast arm treatments

Acknowledging the methodological problems associated with the studies evaluating the safety benefits of mast arm treatments, a rough estimate of the percentage of crash reductions for mast arms are shown in Table 4.3 by crash type. These percentages are based on the crash reductions reported by the studies listed in Table 4.1, however, two studies (Bhesania, 1991; Craven, 1985) were omitted because it was known that other treatments were introduced at the same time as the mast arms. Note that the crash reduction figures for left turn crashes (equivalent to right turn in Australia) refer to the replacement of pole mounted signals with mast arm signals.

Table 4.3
Summary of estimated crash reductions associated with mast arm treatments

Crash type	% reduction in crashes [a]
Total	89 to +21
Right angle	15 to 100
Rear-end	45 to +20
Left turn (right turn in Australia)	12 to +2
Other	27

[a] + denotes an increase in crashes

The available research suggests the provision of mast arms is associated with effects ranging from an estimated 89 per cent reduction in the total number of crashes to a 21 per cent increase in crashes. With respect to crash reductions by specific crash type, the installation of mast arms was associated with the greatest reductions for right angle crashes (15-100%). This is consistent with Bonneson and Zimmerman's (2004) conclusion that engineering measures are likely to reduce unintentional red light running, evident in the reduction of right angle crashes. Conversely, it might initially appear disconcerting that the number of left turn crashes increased (Thomas & Smith, 2001) or resulted in only small crash reductions (Voss, 1997) after the replacement of pole mounted signals with mast arm signals. However, Bonneson and Zimmerman (2004) argue that enforcement countermeasures such as red light cameras will be more beneficial in reducing intentional red light running and so, left turn crashes (right turn in Australia). These observations suggest that mast arms are not necessarily a solution for all signalised intersections with a high crash rate.

While mast arms might provide a means of improving traffic signal conspicuity, they are not the only possible solution for this problem. Other treatments that provide extra information about the traffic signal to the driver have shown some success in improving traffic signal conspicuity. Some examples are: increasing the traffic signal lens size to 12 inches / 300 mm (Polanis, 2002), improving visibility using LEDs (Bonneson *et al.*, 2002), adding signal backplates (Bonneson & Zimmerman, 2004; Polanis, 2002), putting retroreflective tape on backplates (Sayed *et al.*, 1998), displaying dual red signals (Polanis, 2002), and providing advance warning signs with flashers (Farraher *et al.*, 1999) and without (Polanis, 2002). In addition, changing the road geometry or reducing approach speeds at intersections may also increase traffic signal conspicuity (i.e., greater time to detect and respond to traffic signals).

5 Discussion

Traffic signal conspicuity is likely to be a causal factor behind difficulties in detecting traffic signals. This report began with a review of best practice principles in the conspicuity of traffic signals and examined the extent to which poor conspicuity of traffic signals contributes to crashes at signalised intersections. Research from the United States reports that approximately 40 to 55 per cent of drivers involved in crashes at signalised intersections claim that they "did not see" the traffic signals (McGee, 2003; Tijerina et al., 1994), although it is highly likely that the true proportion is lower due to the unreliable nature of self-reported data. Without any such recent Australian studies, it is not possible to determine the extent to which crashes might result from a failure to detect traffic signals.

According to the literature, the conspicuity of a traffic signal, and a driver's response to the traffic signal, is enhanced by fewer competing information sources (i.e., visual clutter), strong signal to background contrast, the position of a signal in the driver's field of vision, and placing signals in uniform and consistent locations (e.g., Kell & Fullerton, 1991). Considering these principles, the installation of additional traffic signals on mast arms at intersections might improve traffic signal conspicuity. Mast arms are designed to reduce the offset of traffic signals from a driver's line of sight and provide adequate warning of an approaching intersection and the traffic signal display.

To determine the safety benefits associated with the installation of mast arm signals, a review of the international research evidence was undertaken. However, findings from this review are not conclusive as many of the evaluations suffered from a number of methodological limitations such as, but not limited to, using simple before and after crash analyses without control sites, failure to account for traffic flow, and short crash follow up periods. In particular, many of the studies failed to account for regression to the mean effects. Mast arm treatments were installed at sites with high crash frequencies and crash frequency was measured over a short period. As a result, the probability of crash reductions at these sites was high simply due to chance. Consequently, findings from these studies are likely to exaggerate the positive effects of mast arms. In addition, a lack of information about the intersections and the placement of mast arms in these evaluations means it is not possible to determine whether a certain approach to mast arm treatments is more effective than others.

Another consideration is that most of these studies were conducted in North America where they take a different approach to traffic signal configuration and mast arm use. For example, the United States requires a minimum of only two traffic signal faces at each approach to an intersection while Australia requires three. In addition, the United States uses mast arms in the primary position and supplement these with post mounted traffic signals.

Acknowledging these problems, evidence from a variety of mast arm evaluations shows that mast arms at intersections were associated with effects ranging from an 89 per cent reduction in the total number of crashes to a 21 per cent increase in crashes. Of interest, the study reporting an increase in casualty crashes was one of the more methodologically sound evaluations and was conducted in Australia (Newstead and Corben, 2001). It is possible that their findings differ from others due to the Australian context or the inclusion of a site where mast arms were located at the departures from a large roundabout. Nevertheless, a cost benefit analysis indicated that mast arms were a worthwhile intersection improvement with every dollar invested returning a casualty crash savings 12 times that of the original investment. Thus, mast arms did not reduce casualty crash frequency but reduced the severity of casualty crashes.

With respect to crash type, mast arm treatments have been associated with the greatest crash reductions for right angle crashes (15-100%). This is consistent with the argument that engineering measures are likely to reduce unintentional red light running, evident in the reduction of right angle crashes (Bonneson & Zimmerman, 2004). Left turn crashes (equivalent to right turn crashes in Australia) recorded the lowest crash reductions of all crash types. Enforcement measures such as red light cameras are likely to reduce left turn crashes, crashes that are markers for intentional red light running (Bonneson & Zimmerman, 2004).

In the literature, there is some concern with respect to the use of excessive traffic signals and mast arms at intersections. An excessive number of signals may add to the visual clutter in the urban environment and be expensive to install (Akcelik, 2003). With respect to mast arms, it is thought that they may be confused with adjacent upstream signalised intersections (Akcelik, 2003) and may lead to an incorrect perception of the stop line position when located at the secondary or tertiary position (on the departure side) (Duarte & Corben, 1998). There is no evidence, of which the author is aware, that additional traffic signals add to the visual clutter at intersections and a number of studies have shown that the benefits of mast arm treatments, in terms of crash reductions, considerably outweigh the costs (Bhesania, 1991; Felipe et al., 1998; Newstead & Corben, 2001; Thomas & Smith, 2001; Voss, 1997). To address the other issues, further research is recommended.

6 Conclusions

Is traffic signal conspicuity a problem at signalised intersections?

Evidence from crash records and self-reported crash data in the United States suggest that engineering measures designed to improve traffic signal conspicuity can potentially reduce crashes at signalised intersections although there are limitations associated with self-reported data. Nevertheless, the Australian approach to traffic signal display and location differs considerably from that in the United States.

The author is not aware of any evidence from Australia concerning the extent to which crashes result from a failure to detect traffic signals since the 1970s. Without any recent Australian studies, it is difficult to determine the extent to which crashes result from poor traffic signal conspicuity. Further research is recommended.

Do mast arms provide a solution for traffic signal conspicuity?

Although this review of the international research evidence found a number of studies that have attempted to evaluate the effectiveness of mast arm mounted traffic signals, it is difficult to conclusively estimate their relative cost effectiveness or potential crash reductions. This is because many of the evaluations suffered from a number of methodological limitations. In addition, many of these studies were conducted in the United States where they take a different approach to traffic signal configuration and mast arm use. The only available research evidence from Australia found mast arms did not reduce casualty crash frequency but reduced the severity of casualty crashes. Further methodologically sound research is needed to determine the effectiveness of mast arms in the Australian context.

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Appendix A - Effectiveness of mast arms in Metropolitan Adelaide

An evaluation of the effectiveness of mast arms at nine sites in metropolitan Adelaide was recently completed (DTEI, Internal report). A before-after analysis was performed using three years of casualty crash data before and after mast arm installation. At each site, the change in the number of crashes for the treated approach was compared to the change in the number of crashes on all other approaches. The resulting reductions in casualty crashes are shown in Table A1. While there were crash reductions on the treated approaches, these generally reflected decreases found on all approaches. Only right angle crashes appeared to have a greater decrease on the treated approach. However, there are some limitations associated with this evaluation. Firstly, it is not known whether there were any changes in traffic volume or the signal phasing during the before and after period. Secondly, it is not known whether any other treatments were applied to the intersections.

Table A1
Casualty crash reductions by crash type for selected sites where mast arm were installed in South Australia

Crash type	All approaches	Treated approach
Rear end	-14	-8
Right angle	-14	-43
Right turn	-48	-34