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Our Ref: NA80813070 / 002
Contact: Richard Thomas

20 December 2013

Attention: Peter Waugh

Cardno (NSW/ACT) Pty Ltd
ABN 95 001 145 035

Level 9
The Forum
203 Pacific Highway
St Leonards NSW 2065
Australia

Phone: 61 2 9496 7700
Fax: 61 2 9499 3902

www.cardno.com.au

Wollongong Hospital Queuing Study
Traffic and Transport Technical Note – Revision 2

Introduction

This technical note has been prepared to document the methodology, results and conclusions of a queuing study undertaken for the proposed boom gate access control to the Wollongong Hospital Car Park.

In the Traffic Impact Assessment prepared by Cardno in May 2013, the queuing storage required to comply with the minimum requirements of the Australian Standard AS2890.1 was assessed. Specifically, the report presented the requirements as specified by Table 3.3 of AS2890.1. This table determined that the queuing space required was:

> 33 Car Lengths at the New Dapto Road access; and
> 11 Car Lengths at the Dudley Street access.

However, Table 3.3 of AS2890.1 is intended to provide guidance in the absence of more reliable analysis or data regarding the anticipated queuing. Furthermore, Clause 3.4 also specifies that Table 3.3 should be used in the absence of more specific guidance. In this regard, the specifications for minimum queuing space in AS2890.1 are intended to be conservative estimates for the requirements of queuing space in the absence of more detailed analysis. These conservative estimates are provided in AS2890.1 to ensure that any queuing does not impact upon the adjacent road network when the data available is limited.

The "specific guidance" referred to in Clause 3.4 includes considering the impact of "anticipated entry / exit flow (and) hourly parking accumulation and turnover". Based upon this, it is possible to undertake a first principles study based upon Queuing Theory. Queuing Theory presents a statistical context for analysing the development of queues in general using the ratio of the amount of vehicles arriving to the amount of vehicles being served. In the context of this study, it will consider the amount of vehicles seeking to use the car park, versus the amount of vehicles which can be physically served by the boom gates. In this regard, Queuing Theory is applicable in fulfilling the "specific guidance" requirement of AS2890.1 in determining the queuing space required.

Based upon the ratio of the amount of demand to the physical capacity of the system, it is possible to calculate the impact upon queuing in terms of both the queue length and the queuing time. As a result of this, the results from Queuing Theory represent a practical design value based upon the available data, empirical results and the likely operation of the boom gate.

More specifically, this study will combine Queuing Theory with a statistical exceedance probability to determine the resulting minimum queuing space at the entry boom gate required using the maximum surveyed arrival rates of the existing car park.

Scope of Works

This study has following the following scope of works:

> Utilise the parking accumulation survey results and estimates prepared by TTW for the existing hospital car parks to determine the anticipated maximum peak hour arrival rate. These counts provide a 30minute interval, so we would multiply the peak 30minute period to conservatively estimate the peak hourly demand;
> Apportion the arrivals based on the previous traffic splits identified in the Cardno Traffic Impact Assessment report, being 75% to New Dapto Road and 25% to Dudley Street;
> Estimate the boom gate capacity based on assumed method of operation. In this instance and to ensure a robust outcome, we assume that a combination of staff swipe cards and paper ticket dispensing will be utilised;
> Apply empirical formulae derived from Queuing Theory and Little's Formula to estimate the extent of the 95th percentile "back of queue" for the boom gate access controls for the peak period scenario;

Assumptions

The following assumptions have been made is undertaking this assessment:

> The trip distribution for incoming vehicles to the proposed Wollongong Hospital car park is based upon the previously completed Traffic Impact Assessment by Cardno dated May 2013;
  - This was determined in the original reporting by analysing the 2011 mid-block traffic survey data originally collected for the TTW report;
  - This analysis considered the proportions of vehicles entering via Mercury Street, New Dapto Road (north), Crown Street (east) and Crown Street (west).
    This estimated the trip distribution to each access as being:
    > New Dapto Road – 75%;
    > Dudley Street – 25%;
> The data used for the average parking demand is based upon the Parking Accumulation Survey undertaken by Taylor Thomson Whitting (TTW) in their report dated July 2011;
  - These surveys considered the parking demand from on-site parking at Wollongong Hospital as well as the parking demand for on-street parking adjacent to the car park;
    > The analysis by TTW included a conservative assumption that 20% of on-street parking would be for residential land uses. This compared to observations that 25% of on-street parking on nearby streets was used by residents;
> The proposed plans for the car park layout are the 18 December 2013 revision prepared by Cardno;
> The queuing model is based upon a statistical distribution of the vehicle arrival and service times at the boom gate;
  - In technical terms, it is assumed that the queuing model will operate as two (2) x M / M / 1 queues, as defined by Kendall's Notation for describing a queuing system;
> If drivers perceive the queue at the car park entrance to be excessive, drivers will still join the queue and pass through the boom gate;
  - This assumption permits a conservative analysis of the queuing problem;
  - The assumption is critical to the assumed M / M / 1 queuing model;
> Vehicles are unimpeded once they pass through the boom gate control; and
  - As a result, vehicles in the adjacent circulating aisle and adjacent queuing lane do not interfere with the ability for vehicles to pass through the boom gate and into the car park itself;
> Queuing distance per vehicle has been assumed as 6 metres, as per AS2890.1 Clause 3.4.

Documentation of Methodology

Design Arrival Flow

For the purposes of analysis, the busiest 30 minute period as identified in the parking accumulation survey by TTW has been used as the Design Time Period. Based upon the parking accumulation survey, it has been determined that this busiest interval takes place from 8.30am – 9.00am. During this interval, 290 vehicles enter the existing car park facility, or a peak flow of 580 vehicles / hour.

However, on the basis that the new car park will also have a greater car parking capacity, this flow rate has been factored by the ratio of the car parking capacities. This is based upon the existing car park having 591 car parking spaces and the new car park has 754 car parking spaces. Based upon this, the Design Arrival Flow is 740 vehicles / hour.
It is noted that this flow rate is not sustained for the full hour; but in fact only the peak half-hour. As a result, this design arrival flow should not be used to infer the level of parking turnover.

Applying this Overall Design Arrival Flow, the Design Flows for each of the access locations are:

> New Dapto Road – 555 vehicles / hour
> Dudley Street – 185 vehicles / hour

Design Service Flow (Service Capacity)

AS2890.1 Appendix D specifies the lane capacities for access controlled car parks as being:

> Free Flow – 600 vehicles / lane / hour;
> Card Reader – 400 vehicles / lane / hour;
> Automatic Ticket Issue and Boom Gate – 300 vehicles / lane / hour; and
> Manually Controlled – 250 vehicles / lane / hour.

It is proposed that staff and employees will have access to the car park via a card reader, while outpatients and visitors will utilise a paper ticket. As a result, the effective capacity of each lane of the car park entry will be between 300 – 400 vehicles / lane / hour.

The Design Service Capacity was determined by taking a weighted average between these values based upon the proportion of staff to visitors expected to use this new car park. In using this methodology, the staff using the existing car park have been removed from the calculation. Based upon this, the proportions using in the weighted average were:

> Staff – 73%
> Visitors – 27%

Based upon this, the Design Service Capacity is 373 vehicles / lane / hour.

Results – Design Queue Lengths

New Dapto Road

Table 1 documents the results of the Queuing Theory Model developed by Cardno for determining the Design Queue Length for car parks with an access control mechanism for the New Dapto Road access. Based upon this analysis, a **Total Queue Length of 20 vehicles (120 metres)** will be required.

Table 1 Queuing Theory Model Results – New Dapto Road Access

Design Item	Design Value
Approach Volume (Total)	555 vehicles / hour
Design Service Capacity	373 vehicles / lane / hour
Number of Lanes	2
Total Service Capacity	746 vehicles / hour
Approach Volumes (Lane)	277 vehicles / hour
95th Percentile Queue Length	10 vehicles / lane
	60 metres / lane
	TOTAL: 20 vehicles (120 metres)
99th Percentile Queue Length	15 vehicles
	90 metres

Dudley Street

Table 2 documents the results of the Queuing Theory Model developed by Cardno for determining the Design Queue Length for car parks with an access control mechanism for the New Dapto Road access.

Table 2 Queuing Theory Model Results – Dudley Street Access (2 Lanes)

Design Item	Design Value
Approach Volume (Total)	185 vehicles / hour
Design Service Capacity	373 vehicles / lane / hour
Number of Lanes	2
Total Service Capacity	746 vehicles / hour
Approach Volumes (Lane)	93 vehicles / hour
95th Percentile Queue Length	2 vehicles / lane
	12 metres / lane
	TOTAL: 4 vehicles (24 metres)
99th Percentile Queue Length	3 vehicles
	18 metres

As a result of the reduced queuing at the Dudley Street access, the single lane entry configuration has also been tested. The results of this analysis are presented in **Table 3**.

Table 3 Queuing Theory Model Results – Dudley Street Access (1 Lane

Design Item	Design Value
Approach Volume (Total)	185 vehicles / hour
Design Service Capacity	373 vehicles / lane / hour
Number of Lanes	1
Total Service Capacity	746 vehicles / hour
Approach Volumes (Lane)	185 vehicles / hour
95th Percentile Queue Length	4 vehicles
	24 metres
99th Percentile Queue Length	6 vehicles
	36 metres

Automatic Number Plate Recognition

It is recognised that Automatic Number Plate Recognition (ANPR) technology may be proposed for this car park which would result in a more rapid entry, approaching 600 vehicles per hour. It is unclear at this time whether numberplate recognition technology would be used for both staff and public vehicles. Should numberplate technology be used, a sensitivity test assuming staff numberplates are recognised has been undertaken by using a design service capacity of 519 vehicles / lane / hour. This value is based upon ANPR being available to staff only and thus the weighted average of staff (accessing the car park via ANPR at 600 vehicles / lane / hour) and visitors (accessing the car park via automatic tickets at 300 vehicles / lane / hour).

Although the design of the system may be expanded to include both public and staff numberplates, a lower service capacity of 519 vehicles / lane / hour has been used for the purpose of the sensitivity test to ensure a conservative approach.

The results of this analysis are documented in **Table 4**. These results indicate that the minimum queuing space for the 95th percentile queue would be:

> New Dapto Road Access;
  - 4 vehicles / lane, or 8 vehicles total queuing space;
> Dudley Street;
  - 2 vehicles / lane, or 4 vehicles total queuing space.

Table 4 Queuing Theory Model Results – ANPR Access Control

Design Item	2 Entry Lanes		1 Entry Lane
	New Dapto Road	Dudley Street	Dudley Street
Approach Volume (Total)	555 vehicles / hour	185 vehicles / hour	
Design Service Capacity	519 vehicles / lane / hour		
Number of Lanes	2	2	1
Total Service Capacity	1038 vehicles / hour		519 vehicles / hour
Approach Volumes (Lane)	277 vehicles / hour	185 vehicles / hour	185 vehicles / hour
95th Percentile Queue Length	4 vehicles / lane	1 vehicles / lane	2 vehicles
	24 metres / lane	6 metres / lane	12 metres
TOTAL	**8 Vehicles (48 metres)**	**2 Vehicles (12 metres)**	**2 Vehicles (12 metres)**
99th Percentile Queue Length	7 vehicles / lane	2 vehicles / lane	4 vehicles
	42 metres / lane	12 metres / lane	24 metres
TOTAL	**14 Vehicles (84 metres)**	**4 Vehicles (24 metres)**	**4 Vehicles (24 metres)**

Sensitivity Testing – Automatic Number Plate Recognition

Sensitivity testing has been undertaken on the service capacity of the ANPR system for staff at the entry boom gate. The initial assessment utilised an assumption of 600 vehicles / lane / hour for this ANPR operation. However, to ensure the robustness of this analysis, sensitivity testing was also utilised for a service capacity of 550 vehicles / lane / hour. The results of this analysis are presented in **Table 5**.

These results indicate that the overall difference is no more than 1 vehicle / lane of queuing (or up to 2 vehicles for a single lane configuration). Since this additional vehicle is within the margin for rounding, the choice between 550 vehicles / lane / hour or 600 vehicles / lane / hour for the ANPR service capacity will not have a significant impact upon the expected queue lengths.

Table 5 Queuing Theory Model Results – ANPR Access Control

Design Item	2 Entry Lanes		1 Entry Lane
	New Dapto Road	Dudley Street	Dudley Street
Approach Volume (Total)	555 vehicles / hour	185 vehicles / hour	
Design Service Capacity	483 vehicles / lane / hour		
Number of Lanes	2	2	1
Total Service Capacity	966 vehicles / hour		483 vehicles / hour
Approach Volumes (Lane)	277 vehicles / hour	185 vehicles / hour	185 vehicles / hour
95th Percentile Queue Length	5 vehicles / lane	1 vehicles / lane	3 vehicles
	30 metres / lane	6 metres / lane	18 metres
TOTAL	**10 Vehicles (60 metres)**	**2 Vehicles (12 metres)**	**3 Vehicles (18 metres)**
99th Percentile Queue Length	8 vehicles / lane	2 vehicles / lane	4 vehicles
	48 metres / lane	12 metres / lane	24 metres
TOTAL	**16 Vehicles (96 metres)**	**4 Vehicles (24 metres)**	**4 Vehicles (24 metres)**

Discussion

Design Queue Length – 95th Percentile versus 99th Percentile

The queuing analysis undertaken has presented the results for the 95th and 99th percentile queue lengths. As a result, it would be expected that these estimated queue lengths would be exceeded 5% and 1% of the time, respectively.

However, it is noted that the recommendations regarding the minimum queuing space requirement at the boom gate access control is based upon the 95th percentile. This recommendation is on the basis that the 95th percentile queue length is the industry standard used in queuing analysis and the design of vehicle storage lanes at intersections. On this basis, the 99th percentile queue length has been reported purely for presentation and comparison purposes.

Sensitivity Testing

As noted in the Sensitivity Testing section, the difference in queue length between a service capacity of 550 vehicles / lane / hour and 600 vehicles / lane / hour is no more than 1 vehicle / lane. Since this additional vehicle is within the rounding margin in determining the design queue length, the analysis is not considered to be particularly sensitive to this assumption. As a result, it is considered that the analysis is sufficiently robust to support the use of the 95th percentile queue as the design queue length.

Service Capacity Assumption

It is noted that Queuing Theory analysis assumes that there is no impediment to vehicle flow once the vehicle passes through the boom gate. In order for this assumption to be maintained, it is important that the parking aisle downstream of the boom gates be kept clear in order to maintain the design service capacity.

If this aisle is blocked at any stage, particularly during the peak flow period, there exists a high likelihood that the queue will extend longer than estimated in this analysis. This may have potential implications for interfering with traffic flow on New Dapto Road.

Proposed Design

New Dapto Road Access

The design of the car park entry, as supplied on 18 December 2013, shows that the design of the queuing area at the New Dapto Road access is proposed to provide sufficient space for 20 vehicles. As a result, the queuing space provision is in accordance with the queuing analysis undertaken, which also indicated a 95th percentile queue length of 20 vehicles.

The assessment basis was that there was uninterrupted flow on the downstream side of the boom gates. With the provision of parking spaces on the immediate downstream side of the boom gates, there is the potential that parking movements associated with these spaces and associated short delays to traffic flow may restrict other vehicles from passing through the boom gates and hence modify the queue lengths required.

The quantum of potential delay is unclear, however there is a factor of conservativeness built into the assessment methodology as a result of taking peak half hour arrival rate and grossing this up. There also exist traffic management strategies that could be put into place should the car park operator find that queueing is exceeding the available space.

These strategies include associating a timed parking restriction with the spaces immediately adjacent to the entrance which is unfavourable to the predominant type of user arriving during the peak morning arrival period. For example, on the basis that the peak arrival user is a hospital employee, arriving between 8:00-8:30 for a day long shift, a 2 hour timed parking restriction implemented through signposting would make these spaces unattractive and require that this user continue on and find an all day unrestricted parking space. A second type of parking management technique is for the car park operator to physically block the spaces immediately adjacent to the entrance by using chains, bollards, cones of other form of temporary traffic control. A third type of parking management technique is to allocate these spaces to specific car park users who do not enter or are unlikely to regularly enter during the morning peak. Examples may include

specific hospital directors, surgeons, or other senior management staff however specific users would need to be identified by the hospital based on their more specific knowledge,

It is noted that the impact of the availability of these parking spaces is not certain to cause queueing to exceed the proposed available spaces, and that these management techniques would only be implemented should excess queing arise following operation and observation of the car park.

The design requires the two entry lanes to merge on the departure side of the boom gates. Although not an uncommon design within car parks, the operation of the merge has the potential to limit throughput of the boom gates. This applies to the merge associated with both entry lanes, as well as the merge associated with the circulation lane of the car park level.

At the proposed design service rate for the entry using a combination of swipe and tickets, it would appear that the operation of the booms will be the determining limitation rather than the operation of the downstream merge, so this is not expected to result in queueing which exceeds the 20 vehicle capacity. However if automatic numberplate recognition was implemented in the future, then the merge requirement would become the determining factor in assessing capacity of the entry arrangement.

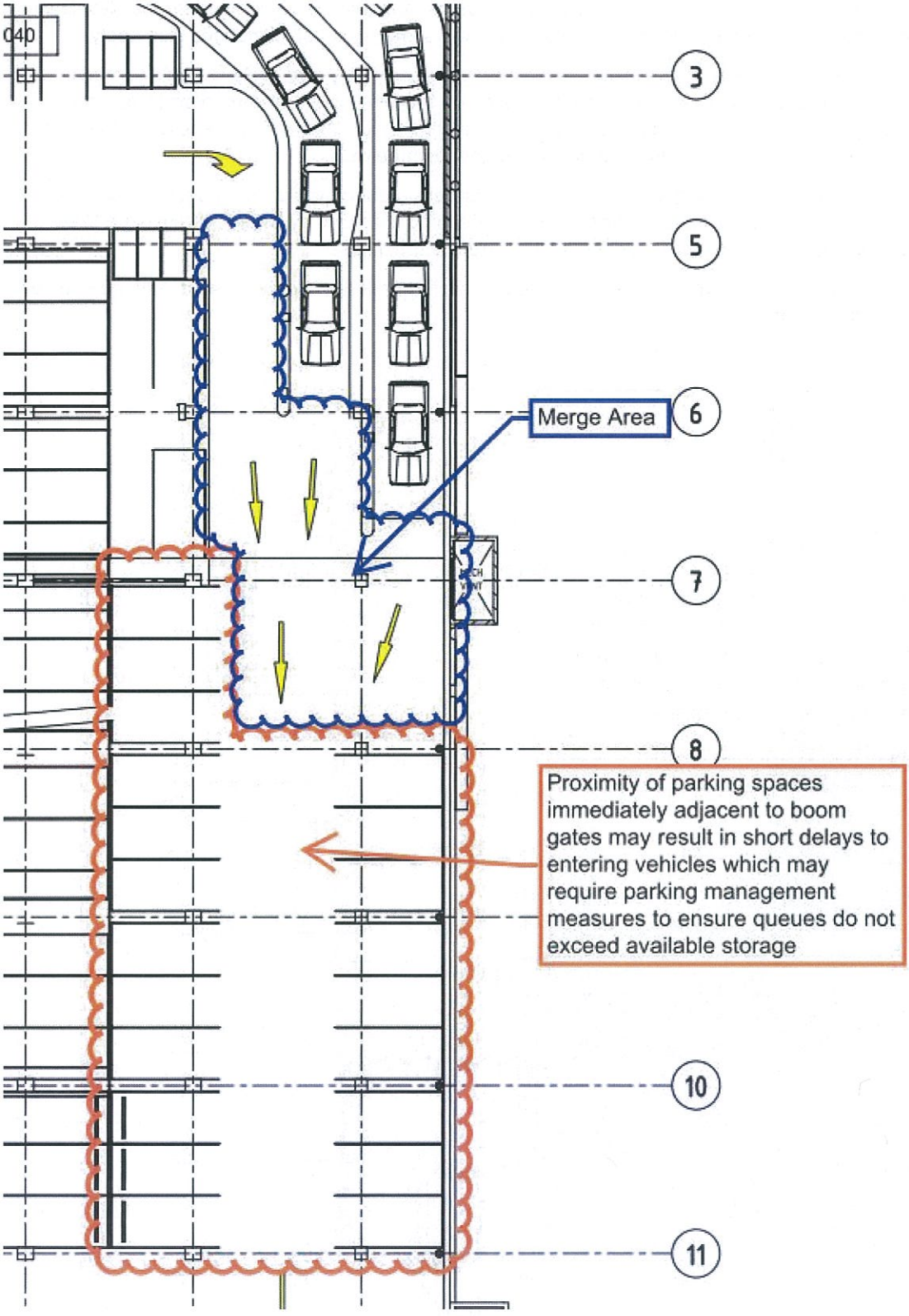
The circulation aisle is not expected to be carrying high volumes of circulating traffic during the morning peak arrival period, which will limit its impact on the operation of the boom gates and queueing.

The staggered arrangement of the merges occurring at the boom gate entry such that only one merge is taking place at a time serves to improve safety over the alternative of having the boom gates line up which would result in a 3 into one merge. Generally drivers have good vision to each other as the driver of the entering vehicle can look out of the driver's window to determine if a merge is required and it is safe to proceed, and all vehicles will be travelling at low speed. Although the merge area is not expected to be an issue, there is the potential to install speed humps in the circulating aisle to reduce the speed of circulating traffic and hence increase the safety of the operation of the merge. Merges such as this occur at many other multi storey car parks and Cardno are not aware of this posing any significant safety risks.

During off peak periods when the arrival rate into the car park is lower than peak, there will be times when only one entry lane is required to comfortably accommodate the queue storage requirements. In these instances, one of the entry lanes to the car park could be closed off. This would remove one of the merge requirements and result in a smoother entry, albeit with a slightly increased delay time to arriving vehicles. The entry lane not in use could be closed by either manual techniques such as positioning of temporary traffic control devices such as cones or trestle board with signage, or via an automated method such as provision of an additional boom gate which monitored the queue length and dynamically allowed operation of the second entry lane or was set to a timer acknowledging regular patterns of peak arrival periods.

It is noted that none of the issues outlined above are considered to likely be severe enough to warrant installation of devices prior to commencement of operation of the car park, and a wait and see approach is recommended with consideration of installation of additional parking management measures only if issues emerge.

Figure 1 New Dapto Road Access – Merge



Dudley Street Access

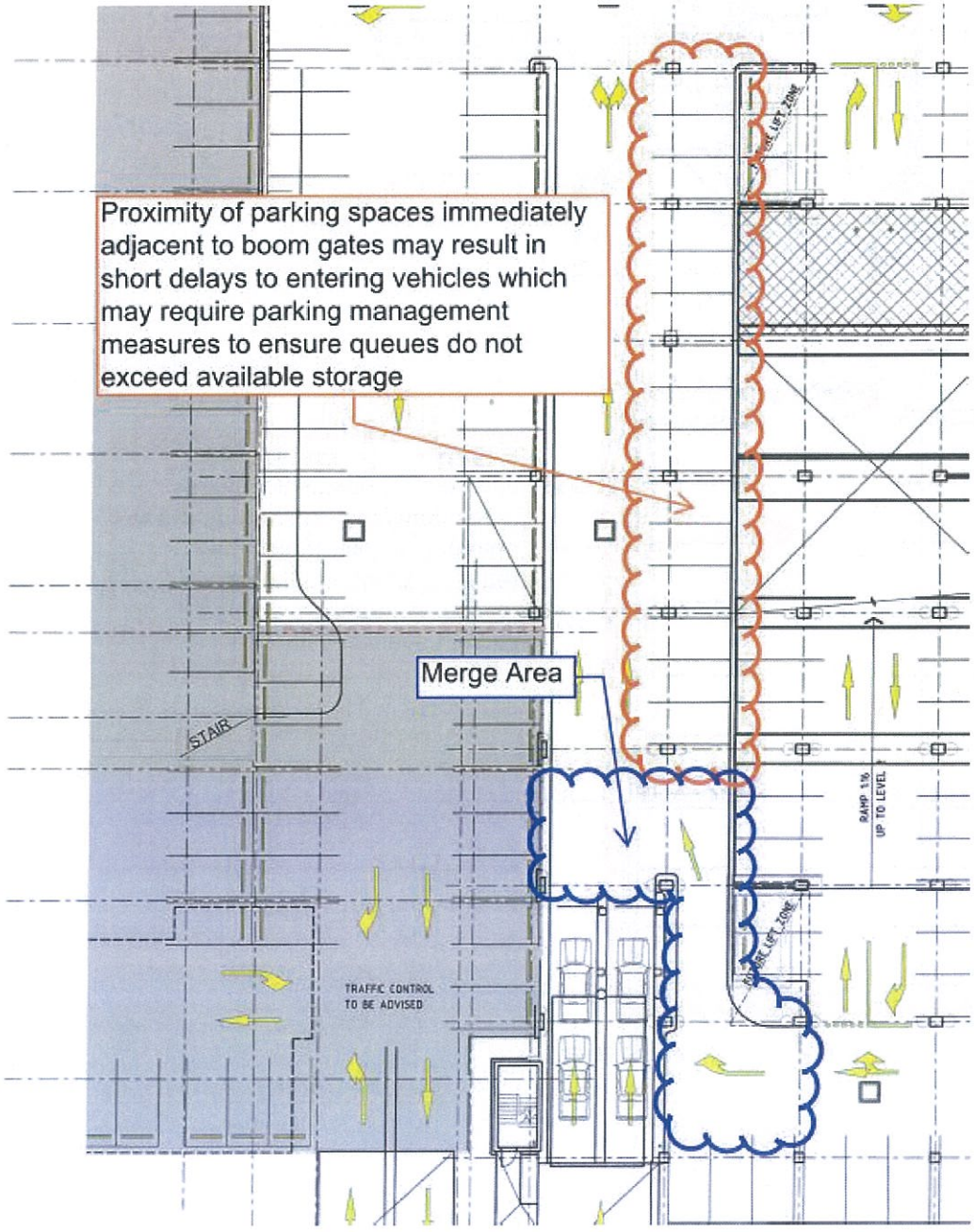
The same issues related to merge and downstream provision of car parking as described for the New Dapto Road entrance also apply to the Dudley Street access, and the same potential mitigations also apply.

It is noted that the circulating aisle in this instance is expected to carry only low levels of traffic and be in use infrequently, with the main exit to the car park being located on the level above. It is recommended that consideration be given to using circulating signage within the car park to direct exiting vehicles to travel to the second level to avoid the need to circulate past the entry boom gates.

It is noted that although the modelling showed that 4 spaces were required to accommodate the expected queues, that up to 6 spaces are available prior to queue extending onto Dudley Street. As such the likely hood of queues being considered excessive for Dudley Street is much less.

Similar to New Dapto Road, and wait and see approach is recommended and only if issues emerge should operational management techniques be put into operation.

Figure 2 Dudley Street Access – Merge



Conclusions

Combined Card Reader / Automatic Ticket Dispenser

Based upon the results presented in **Table 1**, the queuing space at the New Dapto Road access will be required to support at least a total of **20 vehicles** for the 95th percentile queue length. The plans supplied on 18 December 2013 indicate that the New Dapto Road access will provide queuing space for up to 20 vehicles, which is in accordance with the estimated 95th percentile queue length for this access.

Based upon the results presented in **Tables 2 – 3**, the queuing space at the Dudley Street access will be required to support at least a total of **4 vehicles** for the 95th percentile queue length. This result is regardless of whether there are two lanes or one lane provided for access.

Access Design

The design, provided on 18 December 2013, has implications with respect to one of the assumptions of the queuing theory analysis process that vehicles are able to proceed unimpeded after the boom gate. By providing parking close to the boom gates, there exists the potential for vehicle seeking to park their vehicle impeding the flow of traffic past the boom gate. This may cause the queue length to exceed the calculated lengths, however this is not a certain outcome due to factors of conservativeness built into the model. A range of parking management measures could be implemented in order to manage the use of parking adjacent to the boom gate during the peak vehicle arrival period.

The operation of the merge in the vicinity of the boom gate due to the confluence of three lanes at both intersections also has the potential to impact the queue length calculations as well as introduce safety considerations. However these type of merge arrangements are not uncommon in multi storey car parks and appear to work acceptably in practice. In both entrances a similar wait and see approach is recommended with additional parking management measures considered following observation of operation.

It is also noted that swept paths for the merge area to ensure trafficability have not been completed as part of this technical note.

Automatic Number Plate Recognition

Based upon the results presented in **Table 4**, the queuing space can be significantly reduced if Automatic Number Plate Recognition is utilised for staff parking access. The requirement at the 95th percentile queue length reduces to:

> New Dapto Road – 8 Vehicles
> Dudley Street – 2 Vehicles

Richard Thomas

Manager – NSW Traffic and Transport

for **Cardno Traffic & Transport**