Technical Note

Title: **Strand Road Shuttle: Capacity Analysis and Assessment**

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1.0 Introduction

1.1 Background

The 280 metre section of Strand Road leading to the Merrion Gates crossing is characterised by a narrow carriageway of around 6.5 metres (6.2 metres at its narrowest point), narrow footpaths varying from 1.6 metres to around 2.5 metres and houses on both sides of the road. At present there is no protected cycleway provision at all through this narrow section.

The options in the short to medium term to provide protected cycle route through here are:-

1. Convert one of the traffic lanes to a two way cycle track and operate as a one way road in the southbound direction, effectively closing the right turn at Merrion Gates to Strand Road for vehicular traffic. (DCC Proposal).
2. Convert one of the traffic lanes to a two way cycle track and operate the remaining lane in a shuttle running mode i.e. with alternating directions of travel controlled by traffic signals. (STC and SAMRA proposal).

Alternative projects to build a bridge or underpass are considered long term and outside the scope of this analysis.

With option 1 it is clear that existing traffic on Strand Road heading Southbound will operate in a similar manner to that which it does at present and the predicted impact of the dispersion of traffic in the Northbound direction has already been modelled using the ERM, therefore no further analysis of option 1 is required.

Option 2 and its likely effects on traffic and also its safety implications needs to be better understood in terms of how it would operate if implemented, and crucially what capacity or level of service it would offer to road users. The effect of implementing such an alternative proposal is examined in further detail in this technical note.

1.2 Study Objective

The objective of this study was to develop a method of control to describe how a proposed signalised shuttle system would operate on Strand Road with respect to the operation of the Irish Rail signals at the downstream south eastern railway line (Merrion Gates) and the operation of the Dublin City Council traffic signals at the junction of Merrion Road with Strand Road. Furthermore, this study seeks to establish the average hourly capacity of the proposed signalised shuttle operation for a range of possible operating cycle lengths. This analysis is further complemented by a sensitivity analysis to capture the effect on hourly capacity due to likely increases in the number of occurrences of the barrier being down at Merrion Gates due to further future rail capacity expansion, among other things.

1.3 Study Area Description

The study area under consideration, as part of the analysis presented here, is confined to the southern end of Strand Road starting (approximately) from the northernmost junction of Strand Road with Merrion Hall to the Merrion Gates downstream. This is a challenging location to operate a signalised shuttle system considering the length of shuttle working, the number of private residences located along the shuttle route, the somewhat uncertain number of occurrences of barrier lift/drop at the Merrion Gates and the operation of the traffic signals at the junction of Merrion Road @ Strand Road. Figure 1 below depicts the approximate location and length of the signalised shuttle system on Strand Road.

The remainder of this note is structured as follows: Section 2 describes the data collected to undertake the capacity analysis exercise including the development of appropriate hourly northbound and southbound travel demands; Section 3 outlines the method of control for the shuttle, the required intergreens and the likely signal timing intervals for a range of cycle lengths under consideration; Section 4 sets out the approach taken to calculate the average hourly capacity of the shuttle taking account of the impact of disruption to hourly capacity due to the opening/closing of Merrion Gates; Section 5 presents the capacity analysis results for a range of cycle lengths and the results of a sensitivity analysis on the effect of an increasing number of closures of the Merrion Gates to the overall throughput. Finally, Section 6 provides some commentary and concluding remarks on the shuttle operation.

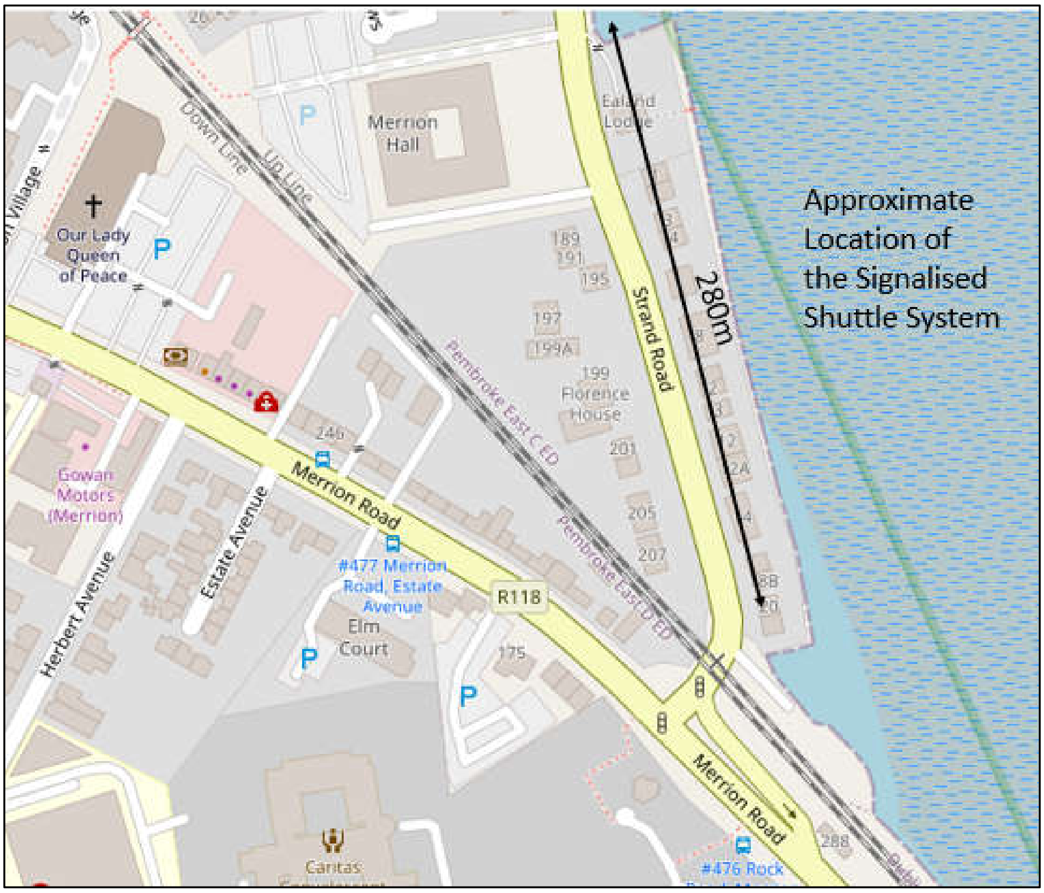


Figure 1: Location of Potential Shuttle System for Strand Road

2.0 Data Collection and Analysis

2.1 Data Collected

Much of the data collected as part of this analysis relied on the Sydney Coordinated Adaptive Traffic System (SCATS) data available for the traffic signals at Site 441: Merrion Road @ Strand Road (Merrion Gates).

Specifically, the following data sources were utilised in the process of developing the capacity analysis for the signalised shuttle proposal:

- SCATS Traffic Reporter detector volume data for Site 441: Merrion Road @ Strand Road/Merrion Gates for four consecutive Thursdays (17/08/20, 24/09/20, 01/10/20 and 08/10/20) representing typical weekday traffic.
- SCATS Log for 08/10/20 and 22/10/20 providing detail on the number of times the level crossing gates open/close per hour (with approximate duration).
- SCATS History for Site 441 to establish traffic phases during which the gates/open close.
- DCC CCTV Camera 53 survey of Merrion Gates in operation (22/10/20).
- Site 441 Controller Operator Sheet (Dublin City Council).

2.2 Traffic Volumes

SCATS detector volume data was extracted using SCATS Traffic Reporter for 4 consecutive weekdays (Thursday 17/08/20, Thursday 24/09/20, Thursday 01/10/20 and Thursday 08/10/20 to represent a typical average weekday traffic profile on Strand Road. The average traffic volumes per hour were calculated for the northbound direction using detector data from Site 441: Merrion Road @ Strand Road (Merrion Gates). Due to the absence of detector data on Strand Road, southbound volumes were conservatively estimated to be the northbound flows scaled up by 15% (this tallies well with legacy, pre-COVID-19 traffic counts). Table 1 below depicts typical 24 hour traffic volumes on Strand Road. It is apparent from Table 1 below that vehicular volumes become significant from 06:00 onwards and stay consistently high in both directions until 21:00. Therefore, in this analysis we will present capacity results for each hour from 06:00 – 21:00 since these are the hours with the highest travel demands. Since SCATS detector data does not provide a classified traffic count we assume that all demand volumes are car vehicles as the percentage of heavy vehicles is likely to be very low and therefore their impact on capacity would be largely negligible.

Table 1: Typical Northbound/Southbound Vehicular Travel Demands on Strand Road

Hour Ending	Northbound veh/hr	Southbound veh/hr
01:00	35	40
02:00	17	19
03:00	10	12
04:00	17	20
05:00	46	53
06:00	93	107
07:00	327	376
08:00	481	553
09:00	465	534
10:00	464	533
11:00	430	495
12:00	412	474
13:00	416	478

14:00	423	486
15:00	398	458
16:00	444	510
17:00	388	446
18:00	384	442
19:00	407	468
20:00	364	418
21:00	270	310
22:00	185	212
23:00	121	139
00:00	60	68

Finally, from examining the data and in the absence of any further information, we assume that the hourly vehicle demand is spread evenly over the hour and that the travel demand maintains itself at these levels notwithstanding the shuttle operation.

2.3 Merrion Gates Train Barrier Data

The operation of the barriers for the signalised level crossing at Merrion Gates is under the control of Irish Rail. However, the City Council's SCATS system collects data regarding the latching/releasing of a detector associated with the barriers at Site 441: Merrion Road @ Strand Road (Merrion Gates). Utilising SCATS Log which records all traffic signal controller events at Site 441 we extracted barrier data for two weekdays and found an overall average number of barrier occurrences of 9 per hour for the hours 06:00 – 21:00 with an average SCATS Log based duration of 3 minutes 30 seconds. Further investigation (see below) reveals that the average actual duration (from a traffic operations perspective) is likely to be approximately 2 minutes 15 seconds.

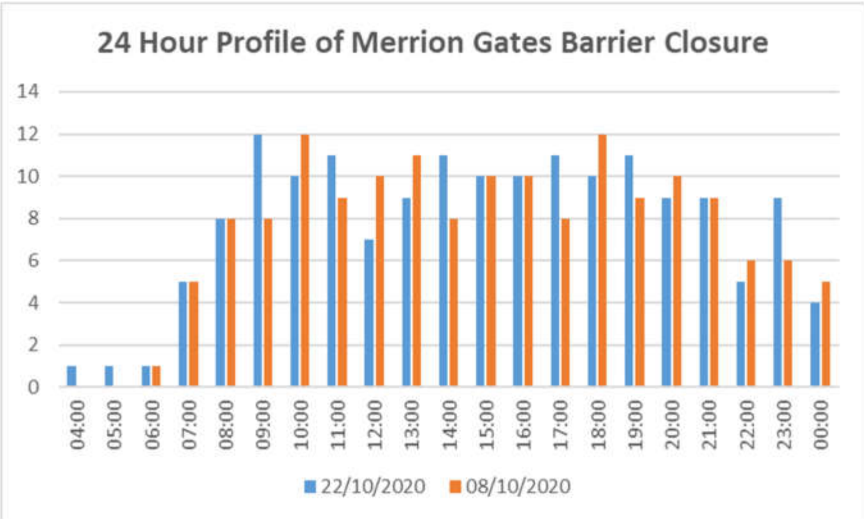


Figure 2: Merrion Gates Barrier Closure

To verify the SCATS Log data, an exercise was undertaken using DCC CCTV to monitor the peak time operation of the Merrion Gates and record the average duration (difference between gates closed and open). The results of this survey are summarised below in Table 2.

Table 2: Summary of Survey Data (DCC CCTV Camera 53) undertaken on 22/10/20

No.	BARRIER DOWN	BARRIER UP	CALCULATED DURATION	No. of Trains
1	09:03:27	09:05:21	00:01:54	2
2	09:07:12	09:08:22	00:01:10	1
3	09:13:12	09:16:40	00:03:28	2
4	09:18:22	09:19:31	00:01:09	1
5	09:24:44	09:26:38	00:01:54	1
6	09:28:53	09:30:34	00:01:41	2
7	09:33:29	09:36:31	00:03:02	2
8	09:42:05	09:45:55	00:03:50	2
9	09:49:10	09:50:46	00:01:36	1
10	09:55:25	09:58:11	00:02:46	2
		Total Duration:	**00:22:30**	**16**
		Average Duration:	**00:02:15**	

It is clear that the number of barrier occurrences recorded in SCATS Log matches perfectly with the survey data meaning we can have confidence that the data for the rest of the day is accurate. The number of trains passing through was also recorded to sense check the data and allow us to better understand the relationship between duration and throughput of trains. The throughputs of DART trains at this time also indicates that the number of related barrier occurrences is very representative a typical busy peak hour.

The average duration of disruption is taken to be that recorded and observed during our CCTV survey since it best relates to the disruption (on average) faced by vehicular traffic whereas the SCATS Log recorded duration of gates being closed and opened again relates more technically to the time pulses/information is received from detectors connected to SCATS and the Irish Rail system.

3.0 Signalised Shuttle Operation for Strand Road: Method of Control

3.1 Overview

Following close consultation with DCC's Traffic Officers the following method of control has been developed to outline how a potential signalised shuttle might operate on Strand Road with reference to the train signals at Merrion Gates and as part of the overall operation of Site 441: Merrion Road @ Strand Road (Merrion Gates).

Note shuttle running refers to the operation of a single carriageway of road under signal control where the direction of travel is alternated from one side to the other and is typically found at roadworks although there are a number of permanent locations which DCC operate (East Road being one).

The main feature of a shuttle is the very long red clearance interval needed after each green to ensure that all vehicles that are travelling in the opposing direction have safely cleared through the single lane section before the green is given to the next direction of travel. For example we need to ensure that a vehicle that leaves in a south bound direction during the last second of green time can safely clear the one lane section before any northbound traffic is signalled to enter the one lane section.

The other issue with a shuttle system is traffic that may turn onto the one way section from either other roads or from peoples drive ways. In this section there are no other roads that will feed into the one lane section but there are multiple driveways and this will be discussed later in the report.

The City Council operate only a small number of traffic signal sites as shuttles. One example is Site 850: East Road Shuttle (entry to East Wall Village) shown in Figure 3 below. This shuttle is about 44 metres in length, has good line of sight and no entrances or exits along its working length. It operates with an intergreen (Amber and All Red) period of 15 seconds between northbound and southbound shuttle phases commencing/terminating.

Figure 3: Shuttle System at East Road, East Wall, D3.

3.2 Method of Control

It is envisaged that the safest and most efficient way to run the new traffic signal site is as part of the overall operation of Site 441. This would allow for easier coordination between the shuttle operation and the existing operation of all phases at the main Merrion Road junction. It also better allows control over how long and when to run the Strand Road phases at the main road junction. For example, it would be important to be able to control exactly when (i.e. after the barrier lifts) to run the Strand Road phase at Site 441 and for the duration necessary. A proposed signal group definition is set out in Figure 4 below.

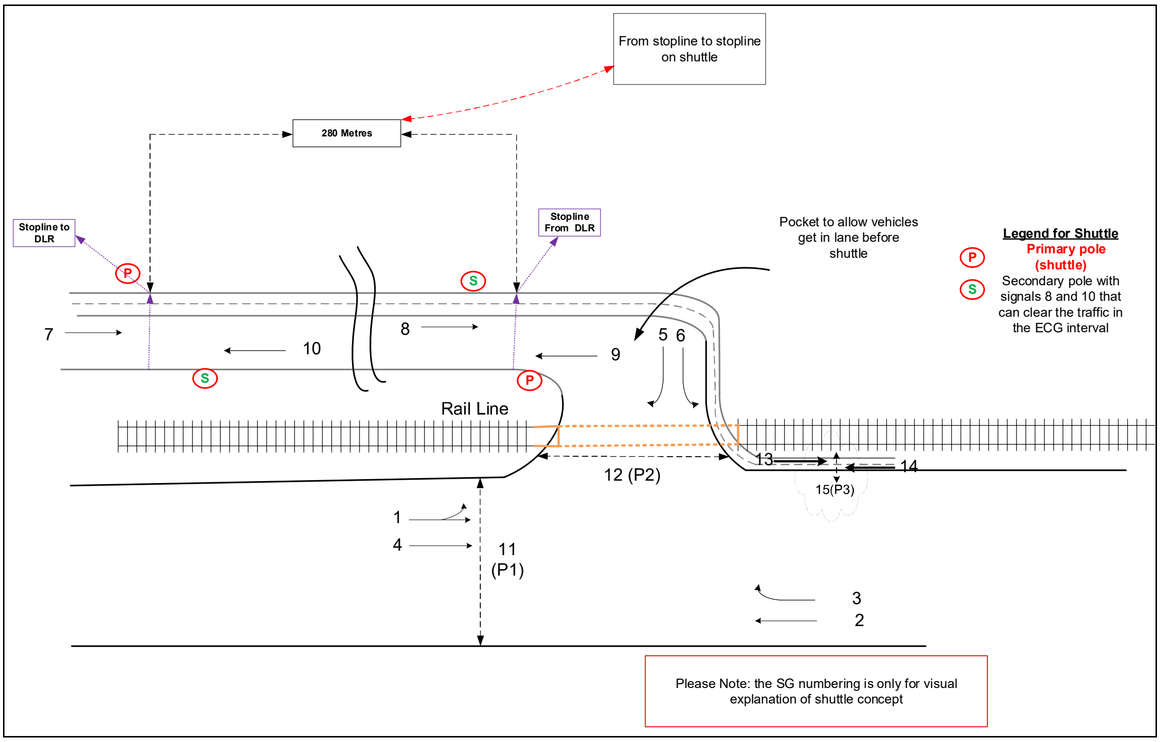
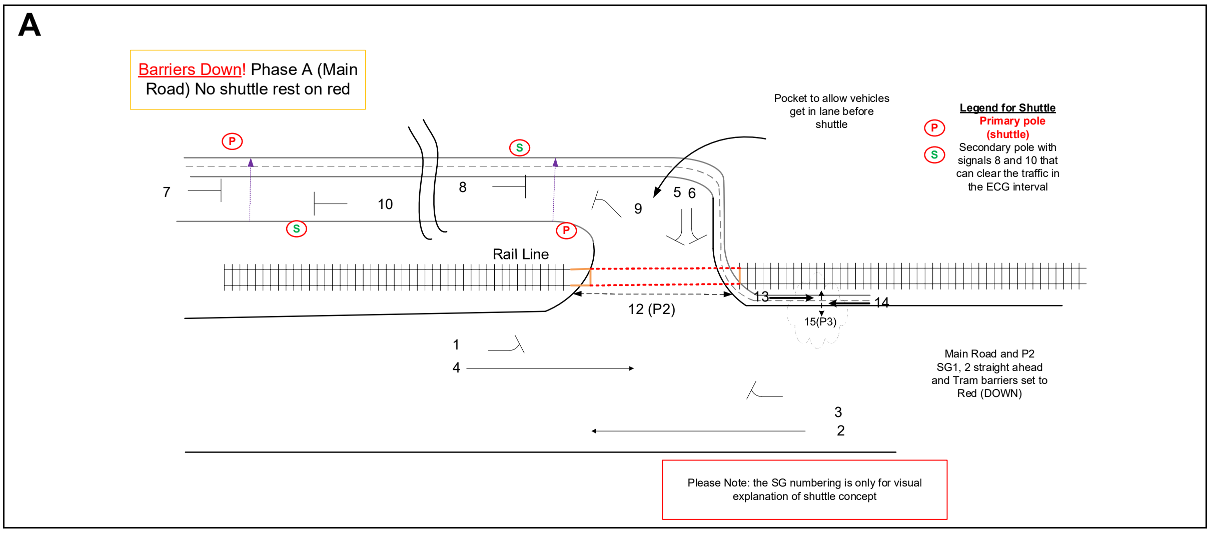
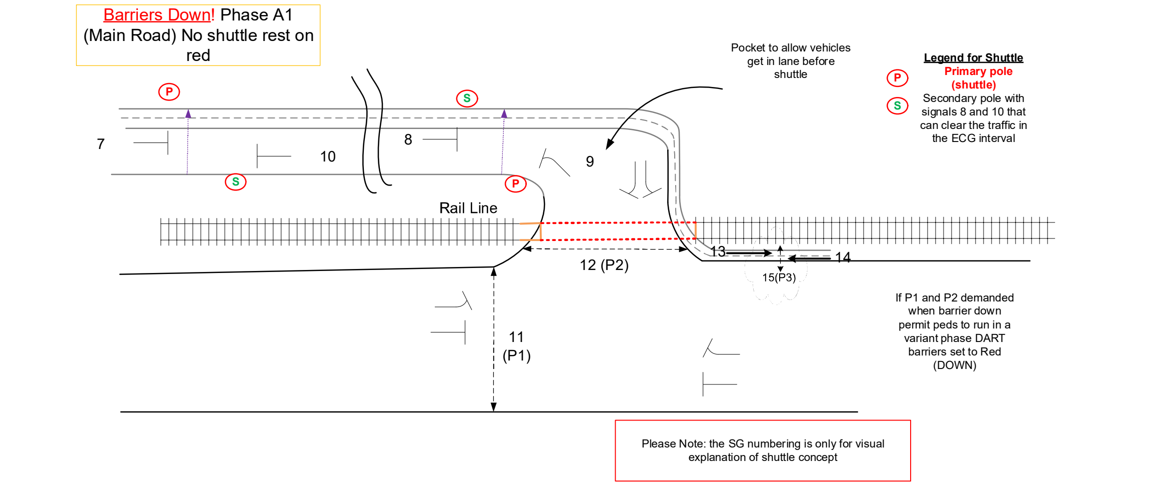


Figure 4: Revised Signal Group Definition for Site 441 Incorporating Strand Road Shuttle

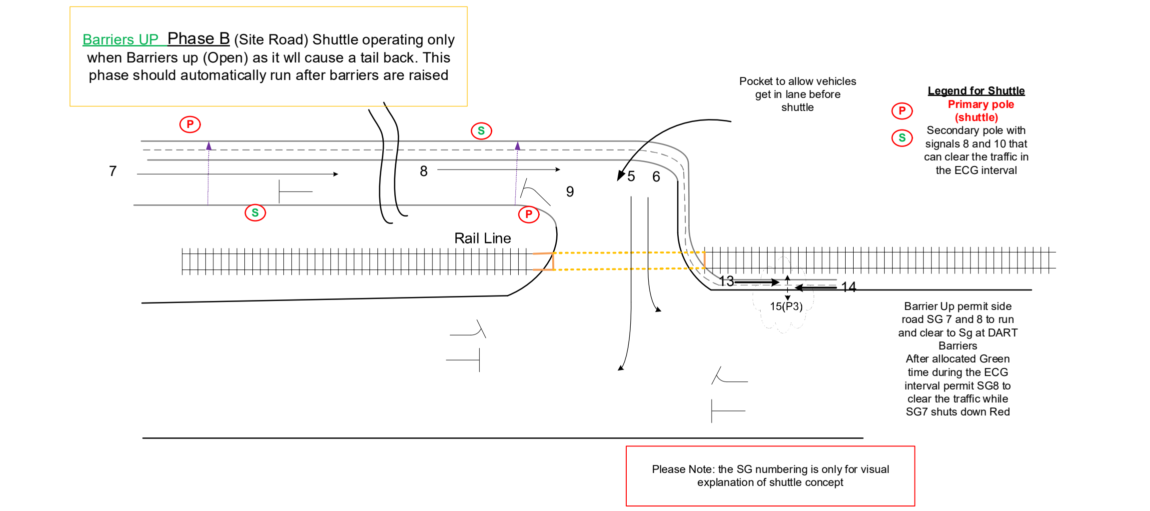
With regards to the shuttle operation - the new traffic signal groups are SG7 and SG8 for the southbound shuttle running and SG9 and SG10 for the northbound shuttle operation. This gives rise to the following potential phase definition (period of the signalling cycle that gives right of way to one or more particular traffic movements) – refer to Figure 5 below.



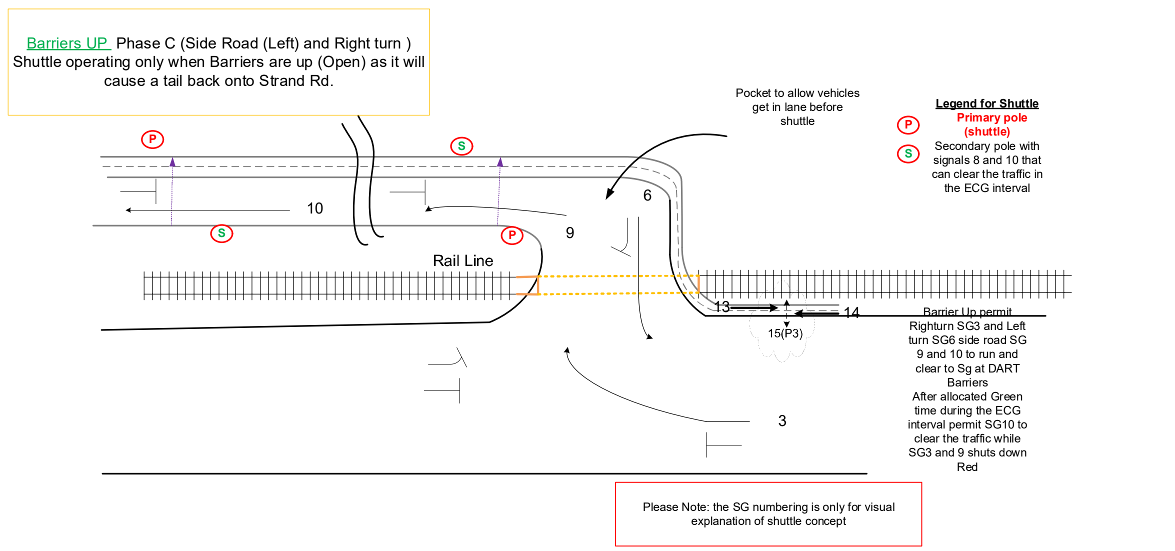
A1


Barriers Down! Phase A1 (Main Road) No shuttle rest on red
Pocket to allow vehicles get in lane before shuttle
Legend for Shuttle
Primary pole (shuttle)
Secondary pole with signals 8 and 10 that can clear the traffic in the ECG interval
7
8
9
10
Rail Line
12 (P2)
13
14
15(P3)
11 (P1)
If P1 and P2 demanded when barrier down permit peds to run in a variant phase DART barriers set to Red (DOWN)
Please Note: the SG numbering is only for visual explanation of shuttle concept

B


Barriers UP Phase B (Site Road) Shuttle operating only when Barriers up (Open) as it wll cause a tail back. This phase should automatically run after barriers are raised
Pocket to allow vehicles get in lane before shuttle
Legend for Shuttle
Primary pole (shuttle)
Secondary pole with signals 8 and 10 that can clear the traffic in the ECG interval
7
8
5
6
9
Rail Line
13
14
15(P3)
Barrier Up permit side road SG 7 and 8 to run and clear to Sg at DART Barriers
After allocated Green time during the ECG interval permit SG8 to clear the traffic while SG7 shuts down Red
Please Note: the SG numbering is only for visual explanation of shuttle concept

C


Barriers UP Phase C (Side Road (Left) and Right turn) Shuttle operating only when Barriers are up (Open) as it will cause a tail back onto Strand Rd.
Pocket to allow vehicles get in lane before shuttle
Legend for Shuttle
Primary pole (shuttle)
Secondary pole with signals 8 and 10 that can clear the traffic in the ECG interval
10
6
9
Rail Line
13
14
15(P3)
3
Barrier Up permit Righturn SG3 and Left turn SG6 side road SG 9 and 10 to run and clear to Sg at DART Barriers
After allocated Green time during the ECG interval permit SG10 to clear the traffic while SG3 and 9 shuts down Red
Please Note: the SG numbering is only for visual explanation of shuttle concept

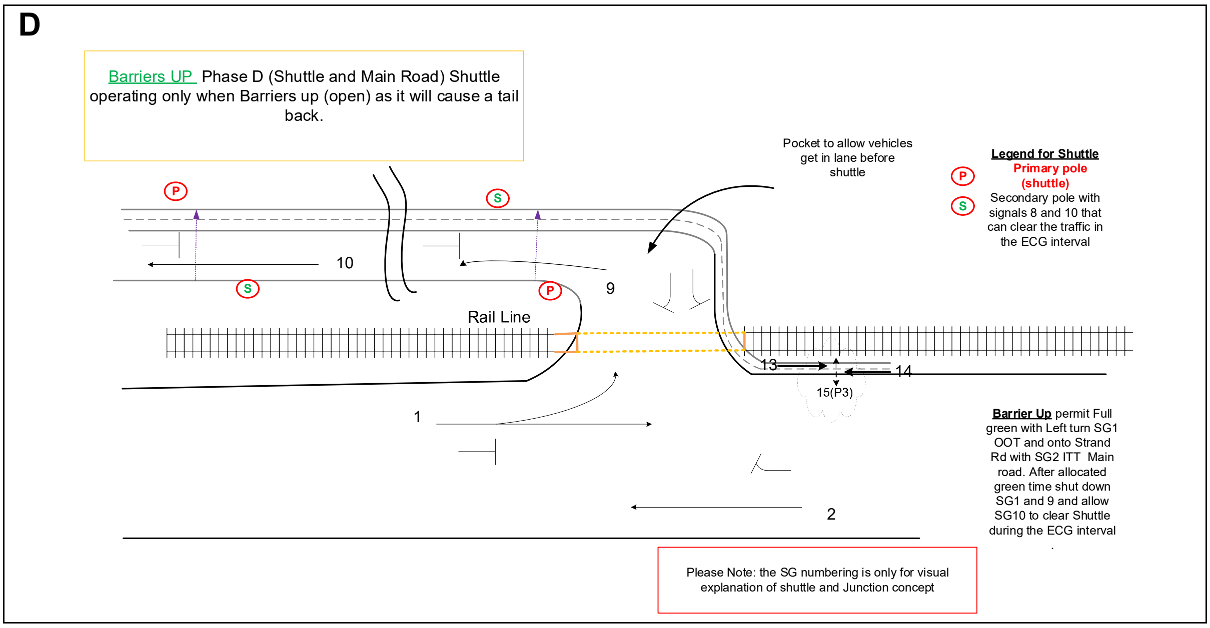


Figure 5: Phase Definition for Site 441 Incorporating Strand Road Shuttle

Referring to Figure 5 above, the phase definition may be summarised as follows. In Phase A (the barrier is down) and the shuttle rests in red (both northbound and southbound approaches are held on a red signal). The variant of this phase is A1 which permits the pedestrian crossing, P1, on Merrion Road to run under the conditions described above. In phases B, C and D the barrier is up - where B services the southbound shuttle operation, C and D service the northbound shuttle movements, as set out above.

Aside from the potential for capacity/queuing issues (which we examine in the subsequent sections of this note) other potential issues identified with the shuttle operation include the difficulty residents on Strand Road will have in joining the shuttle due to uncertainty over which side is running at a particular point in time.

3.3 Minimum Required Intergreens

The intergreen period refers to the period of time between the end of the green signal giving right of way for one phase and the beginning of the green signal giving right of way for the next phase. The normal minimum is three seconds amber and two seconds all red but this is quite often longer for larger junctions and relies upon the identification of critical collision points (CCPs) and the time required for a vehicle to clear a CCP before subsequent traffic phases commence. All traffic signals operated by the City Council must comply with best practice and guidance for the calculation of the minimum base intergeens (for example UK Department for Transport Traffic Advisory Leaflet 1/06 Part 4 of 4). These are the minimum intergreen periods which must be met but in reality they are often higher following on site observations and adjustments.

Typically signalised shuttles tend to have long intergreen periods which give rise to inefficiencies. The Strand Road shuttle, as proposed, measures approximately 280 metres from stop line to stop line leading to a minimum intergreen period of 35 seconds (or a total of 70 seconds for both directions) to meet the usual safety requirements of the City Council and in line with DfT TAL 1/06 4 of 4 referenced above.

3.4 Phase Intervals

For simplicity, in the analysis, it is assumed that the same amount of green time is allocated to both northbound and southbound movements in the shuttle. In reality it is unlikely to deviate too much from this assumption as the flow volumes are broadly similar so only at night time at low volumes will it alter.

Figure 6 below depicts the phase intervals considered in the analysis as indicative of timings for the shuttle to run for a cycle length of 80 seconds (currently the maximum cycle length at which the City Council operates traffic signals), 100 seconds and 120 seconds (the maximum pre-COVID19 cycle length).

80 CL									
SG	A Phase SB				B Phase NB				SUM
SG7	5	3	30	2	40				80
SG8	5	30	3	2	40				80
SG9	40				5	3	30	2	80
SG10	40				5	30	3	2	80

100 CL									
SG	A Phase SB				B Phase NB				SUM
SG7	15	3	30	2	50				100
SG8	15	30	3	2	50				100
SG9	50				15	3	30	2	100
SG10	50				15	30	3	2	100

120 CL									
SG	A Phase SB				B Phase NB				SUM
SG7	25	3	30	2	60				120
SG8	25	30	3	2	60				120
SG9	60				25	3	30	2	120
SG10	60				25	30	3	2	120

Interval	Green	Early Cut Off Green	Amber	Red
Colour				

Figure 6: Phase Intervals for Shuttle Operation under Various Cycle Lengths

Running the shuttle at 80 seconds cycle length results in 5 seconds green time for the shuttle which is a departure from standards. The Traffic Signs Manual (Chapter 9 – Section 9.3.50 states: "*The minimum green period is the shortest period given to any phase allowing particular traffic streams to move while all others are held. It is long enough for vehicles waiting between the detector and the Stop Line to get into motion and clear the Stop Line. The minimum value is 6 seconds, except for indicative arrow or filter arrow stages which may be less*". It is impossible to run the shuttle at 80 seconds and be compliant with the TSM requirements. Even 6 seconds would not be adequate to allow enough vehicles enter the shuttle system to make running it worthwhile. Therefore, the analysis will proceed by simply examining the shuttle option for Cycle Lengths of 100 and 120 seconds.

At an operating cycle of 120 seconds (typical pre-COVID maximum operating cycle length throughout the City Council functional area), the signal groups controlling entry into the shuttle (SG 7 southbound or Signal Group 9 northbound) can only run for a maximum of 25 seconds per cycle and these numbers essentially dictate the capacity of the shuttle - of which more later. Taking just the southbound direction (A Phase) this means a 25 seconds green interval, followed by a minimum 35 second intergreen period, to allow a vehicle passing the stop line at signal group 7 in the last second of the green interval to safely clear the stop line downstream, before the subsequent northbound phase commences. In other words signal group 7 cuts off 30 seconds earlier than the downstream (secondary shuttle signal) to allow vehicles enough time to clear out of the shuttle length during the Early Cut Off Green (ECG) interval. The key takeaway from this is that long intergreens (as required by guidance and standards) impact the capacity of the Strand Road shuttle and that the key variable dictating capacity is the amount of green time allocated to the signal groups controlling entry into the shuttle from either end. Running too low of a cycle length risks not allowing enough vehicles through in each cycle thereby increasing delays since the intergreen requirements are fixed. Running too high of a cycle length (in spite of the attractiveness of higher green time) risks queues building up at either end as one side must wait much longer for their turn to enter the shuttle and is further complicated here by the possibility of disruption due to the barrier going down at Merrion gates causing even longer wait times and delays.

In practice also drivers tend not to observe very long red signals > 120 seconds.

4.0 Methodology

In this section an outline is provided of the method by which the capacity of the shuttle system was calculated using basic/standard Traffic Engineering techniques and methods.

4.1 Base Saturation Flow

Base Saturation Flow is a common concept in Traffic Engineering and often used in capacity calculations. For a signalised junction it can be thought of as the maximum amount of flow crossing a stop line if the signals were permanently on green. As such it implies a constant vehicle demand. The base saturation flow is given by the relationship:

$$s = \frac{3600}{h}$$

where: s refers to saturation flow (veh/hour); h refers to saturation headway in (secs/veh) and 3600 is simply the number of seconds in one hour. So for example a headway value of 2secs/veh gives a Saturation Flow, s, of 1800 veh/hour. Note – this value refers to the base or unadjusted saturation flow. It is often likely to be lower since it is negatively impacted by lane width (narrower traffic lanes tend to have lower saturation flows), gradient of the traffic lane (uphill implies slower vehicles and lower saturation flows), turning radii (again slower movements leading to lower saturation flow values) and the traffic composition (presence of slower moving heavy vehicles for example), among other things. For simplicity, we assume a best case (optimistic) value of 1800 veh/hour although we note that it is likely to be even lower. This assumption can be easily relaxed in our analysis in future if necessary.

4.2 Effective Green Time

The concept of Effective Green Time is also important in calculating the capacity of a signalised junction. It is best understood by the simple relationships described in curve shown in Figure 7 below.

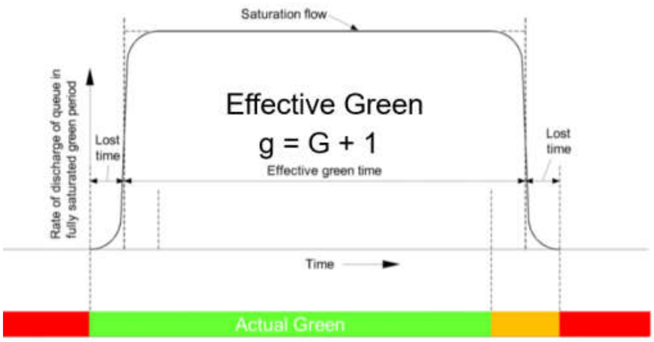


Figure 7: Concept of Effective Green Time

In simple terms, Figure 7 implies that there is lost time or starting lag (approximately 1 seconds) at the start of a phase when signals first turn green but that this is exceeded by the end gain as the signals turn to amber (often considered to be 2 second) leading to the following relationship between effective green time, g, and actual green time, G.

$$g = G + 1$$

For example, referring to Figure 7 above, if the shuttle were to operate at 120 seconds cycle length then the effective green time, g, is likely to be 26 seconds.

4.3 Capacity of an Approach to a Signalised Junction

The capacity of a single lane approach to a signalised junction is given simply by the following relationship:

$$c = s \times g/C$$

where: c is the capacity in veh/hour,
s is the saturation flow in veh/hour,
g is the effective green time (s),
C is the cycle length in seconds.

For example, if the shuttle operates at 120 seconds Cycle Length with a saturation flow of 1800 veh/hour and effective green time of 26 seconds then the capacity in each direction is simply 390 veh/hour assuming that northbound and southbound approaches receive an equal amount of actual green time. Furthermore, this is the maximum capacity of the shuttle and does not account for disruptions due to the barrier closure at Merrion Gates. We examine the effect of this in the next section.

4.4 Adjusted Capacity of the Shuttle due to Barrier Closure

Referring to section 2.2 above (Merrion Gates Train Barrier Data) we note that the average number of gate closures per hour between 07:00 – 21:00 is approximately 9 per hour with an average duration of 135 seconds. For simplicity we assume that 9 such disruptions per hour reduces the number of cycles per hour by 9. It's likely to be higher depending on the cycle length adopted and when the disruption actually occurs (e.g. mid-cycle etc.). Therefore, this assumption is considered to be the best case scenario.

We relax this assumption later in the study via a sensitivity analysis for a more pessimistic view on the number of barrier occurrences per hour to capture this uncertainty. Continuing with the example used above, an operating cycle length of 120 seconds implies 30 cycles of the traffic signals per hour i.e. 120*30 = 3600 seconds or 60 minutes.

For a capacity of 390 vehicles per hour this implies a capacity of 13 vehicles per cycle. However, only 21 cycles actually occur (or are usable due to the train barrier being down) which implies an adjusted hourly capacity of 273 vehicles per hour. A similar analysis is applied for all cycle lengths.

4.5 Adjusted Travel Demands

Similar to the capacity adjustments shown above it is also necessary to adjust the hourly travel demand to account for the reduced number of 'usable' or uninterrupted cycles. Referring to Table 1 in Section

2.2 the southbound travel demand between 07:00 – 08:00 is estimated to be 553 vehicles per hour. Assuming an even spread of this demand over 30 cycles implies an average demand of 18.4 vehicles per cycle. However, this same travel demand now has only 21 usable cycles per hour implying that the adjusted cycle by cycle travel demand increases to 26.3 vehicles per cycle.

4.6 Measures of Performance

To compare between scenarios a number of measures of performance are utilised in this study.

- Volume to Capacity Ratio (also known as Degree of Saturation) – measures the level of congestion on Strand Road by dividing the adjusted volume by the adjusted capacity (where both variables are adjusted to account for barrier closure as per sections 4.4 – 4.5 above).

- % Cumulative Unsatisfied Travel Demand – as volume exceeds capacity in each hour there will inevitably be a level of unsatisfied travel demand at the end of each hourly period. Cumulative unsatisfied travel demand is simply the sum of unsatisfied travel demand at certain point in time. In this measure of performance we express it as a percentage of cumulative travel demand.

- Queue Length is simply the residual queue (unsatisfied travel demand) at the end of each hourly period expressed in terms of kilometres (km) assuming an average car length of 5m and average spacing (under saturated conditions) of 1m.

- Estimated Time to Clear the Queue – for each cycle length used in the capacity analysis we provide an estimate of the time to clear the queue for a particular point in time.

5.0 Capacity Analysis of the Shuttle - Results

5.1 Capacity of the Shuttle with Barrier Disruption at Various Cycle Lengths

In this section the results of the capacity analysis are presented for two different cycle lengths – 100 seconds and 120 seconds with an average of 9 occurrences per hour of the barrier being closed at Merrion Gates between 06:00 – 21:00. To compare between scenarios, the measures of performance set out in section 4.6 above are utilised.

<u>100s Cycle Length</u>
For an operating cycle length of 100 seconds the percentage of cumulative unsatisfied travel demand to cumulative travel demand is approximately 48% in each hour for northbound traffic rising to 55% for southbound traffic.

<u>120s Cycle Length</u>
For an operating cycle length of 120 seconds the percentage of cumulative unsatisfied travel demand to cumulative travel demand is approximately 34% in each hour for northbound traffic rising to 43% for southbound traffic.

In general, cycle lengths that are too short do not provide adequate green time for all phases and result in cycle failures whereas longer cycle lengths result in increased delay and queues for all users.

Table 3 below shows the volume to capacity ratios for all scenarios of cycle length where v/c ratios less than or equal to 1 are highlighted in red font. The v/c ratio, also referred to as degree of saturation, is a measure of performance to represent the ability of a junction to accommodate the vehicular demand. A v/c ratio less than 0.85 generally indicates that adequate capacity is available and vehicles are not expected to experience significant queues and delays. As the v/c ratio approaches 1.0, traffic flow may become unstable, and delay and queuing conditions may occur. Once the demand exceeds the capacity (a v/c ratio greater than 1.0 known as flow breakdown), traffic flow is unstable and excessive delay and queuing is expected. Relative to each other, v/c ratios with darker red shading imply very high v/c ratios (poor level of service) and v/c ratios with lighter green shading imply somewhat better level of service but still represent very congested (flow breakdown) conditions overall.

Table 3: Volume to Capacity (v/c) Ratios for all Cycle Lengths

Volume to Capacity Ratio (v/c)				
Hour Ending	100s Cycle Length		120s Cycle Length	
	NB	SB	NB	SB
07:00	1.51	1.51	1.20	1.4
08:00	2.23	2.23	1.76	2.0
09:00	2.15	2.15	1.70	2.0
10:00	2.15	2.15	1.70	2.0
11:00	1.99	1.99	1.58	1.8
12:00	1.91	1.91	1.51	1.7
13:00	1.93	1.93	1.52	1.8
14:00	1.96	1.96	1.55	1.8
15:00	1.84	1.84	1.46	1.7
16:00	2.05	2.05	1.63	1.9
17:00	1.79	1.79	1.42	1.6
18:00	1.78	1.78	1.41	1.6
19:00	1.88	1.88	1.49	1.7
20:00	1.68	1.68	1.33	1.5
21:00	1.25	1.25	0.99	1.1

Taking the results of these two measures together (% of unsatisfied travel demand and v/c ratio) it is apparent that it would not be possible to operate the shuttle at 100 seconds cycle length. The reason for this is straightforward – there is very little green time available to operate the shuttle relative to the fixed minimum intergreen period required. Therefore, for brevity, no further capacity analysis results are presented here for this cycle length. However, these results are available upon request.

It is also apparent that the volume to capacity ratio and % of unsatisfied travel demand improves with increased cycle length (e.g. 120 seconds). Beyond that maximum value the capacity benefits increase somewhat although to a lesser degree and there is a trade-off between somewhat slightly improved benefits versus the considerable longer waiting time that motorists would have to endure for their side of the shuttle to run. In any event it seems unlikely that this shuttle would operate at a cycle length of greater than 120 seconds since (pre-COVID-19) the City Council have usually only run junctions at 120 seconds maximum cycle length. The slightly greater benefit (in theory at least) of running the shuttle at higher cycle lengths than this would be offset by driver frustration at longer delays, increased risk of red light running and a considerably greater risk that when one sides turn would finally come to enter the shuttle a barrier event would occur downstream leading to even greater delays. Moreover, maintaining coordination (vital for progression) with adjacent traffic signal sites would be very difficult, if not practically impossible to achieve. Therefore, we do not present the capacity results for cycle lengths greater than 120 seconds but note that they have been assessed. Since the most likely maximum cycle length we would consider for the shuttle is 120 seconds we present a full set of capacity analysis for this below.

Table 4 and Table 5 describe, respectively, the northbound and southbound hourly average cycle travel demands and capacity due to barrier disruption for respectively, northbound and southbound shuttle operations at 120 seconds cycle length.

Table 4: Northbound Shuttle Capacity and Unsatisfied Demand

Cycle Length	120	Adj Capacity (veh/hr)	v/c Ratio	Cumulative	Unsatisfied	Cumulative	As % of Cumulative
# Adj Cycles	21	273.0	per cycle	Travel Demand	Demand	Unsatisfied Demand	Travel Demand
Hour End	Vol veh/cycle	Cap veh/cycle		veh/hr	veh/hr	veh/hr	
07:00	16	13	1.20	327	54	54	17%
08:00	23	13	1.76	808	208	262	32%
09:00	22	13	1.70	1273	192	454	36%
10:00	22	13	1.70	1737	191	645	37%
11:00	20	13	1.58	2167	157	802	37%
12:00	20	13	1.51	2579	139	941	36%
13:00	20	13	1.52	2995	143	1084	36%
14:00	20	13	1.55	3418	150	1234	36%
15:00	19	13	1.46	3816	125	1359	36%
16:00	21	13	1.63	4259	171	1529	36%
17:00	18	13	1.42	4647	115	1644	35%
18:00	18	13	1.41	5031	111	1755	35%
19:00	19	13	1.49	5438	134	1889	35%
20:00	17	13	1.33	5801	91	1979	34%
21:00	13	13	0.99	6071	-3	1976	33%

Table 5: Southbound Shuttle Capacity and Unsatisfied Demand

Cycle Length	120	Adj Capacity (veh/hr)	v/c Ratio	Cumulative	Unsatisfied	Cumulative	As % of Cumulative
# Cycles	21	273.0	per cycle	Travel Demand	Demand	Unsatisfied Demand	Travel Demand
Hour End	vol veh/cycle	Cap veh/cycle		veh/hr	veh/hr	veh/hr	
07:00	18	13	1.4	376	103	103	27%
08:00	26	13	2.0	929	280	383	41%
09:00	25	13	2.0	1464	261	645	44%
10:00	25	13	2.0	1997	260	905	45%
11:00	24	13	1.8	2492	222	1127	45%
12:00	23	13	1.7	2966	201	1328	45%
13:00	23	13	1.8	3444	205	1533	45%
14:00	23	13	1.8	3930	213	1746	44%
15:00	22	13	1.7	4388	185	1931	44%
16:00	24	13	1.9	4898	237	2168	44%
17:00	21	13	1.6	5344	173	2341	44%
18:00	21	13	1.6	5785	169	2509	43%
19:00	22	13	1.7	6253	195	2704	43%
20:00	20	13	1.5	6671	145	2849	43%
21:00	15	13	1.1	6981	37	2886	41%

For example, referring to table 5, the time period 07:00 – 08:00 shows a travel demand of 26 vehicles per cycle (assuming 21 operational cycles due to barrier disruption) and a corresponding capacity or departure rate of 13 vehicles per cycle. This results in an average of 13.34 veh per cycle unable to enter the shuttle each cycle leading to queue build up. The column with colour shading records the unsatisfied travel demand in each hour – for 07:00 – 08:00 this equates to 21 cycles multiplied by 13.34 veh/cycle meaning 280 vehicles approx. were unable to enter the shuttle in this period. The column to the right of this simply shows the cumulative unsatisfied demand or the residual queue from a previous time period plus the resulting queue from the existing period. Referring to Table 1 (Section 2.2) the hourly travel demand (both directions) is 1034 veh/hour for the period 07:00 – 08:00. The hourly capacity of the shuttle (northbound and southbound) combined is 273 veh/hour meaning that 488 vehicles cannot get through the shuttle in this period or 47% of the total travel demand.

Figure 8 and Figure 9 depict, respectively, the cumulative number of vehicles queuing (the cumulative unsatisfied travel demand depicted in table 4 above) on Merrion Road northbound (for Strand Road Northbound) and the associated queue lengths in kilometres.

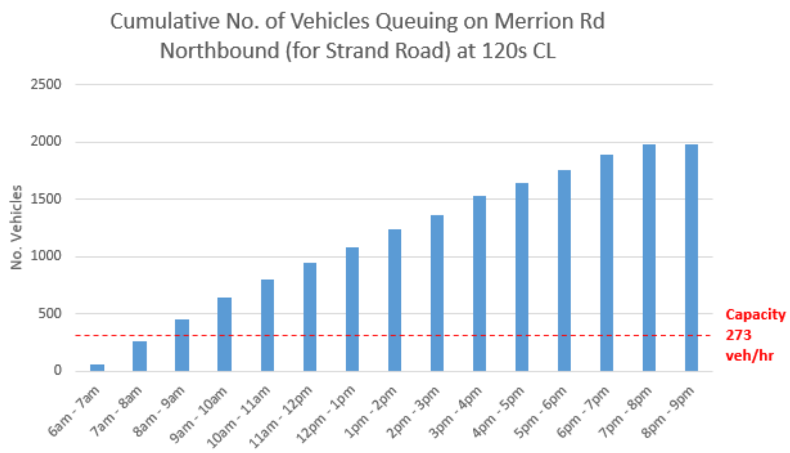


Figure 8: Cumulative No. of Vehicles on Merrion Road Northbound for Strand Road

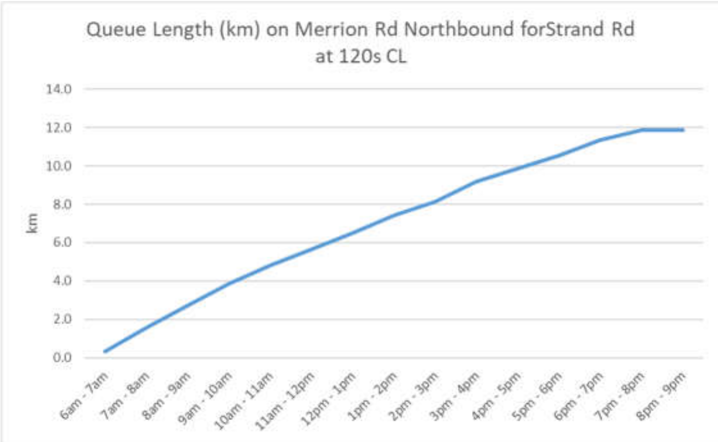


Figure 9: Queue Length on Merrion Road Northbound for Strand Road

Figure 10 and Figure 11 depict, respectively, the cumulative number of vehicles queuing (the cumulative unsatisfied travel demand depicted in table 5 above) on Strand Road southbound and the associated queue lengths in kilometres.

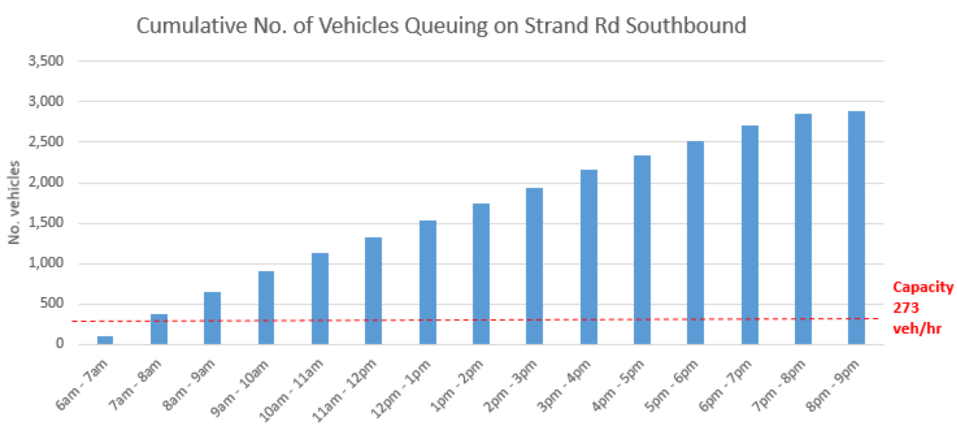


Figure 10: Cumulative No. of Vehicles on Strand Road Southbound

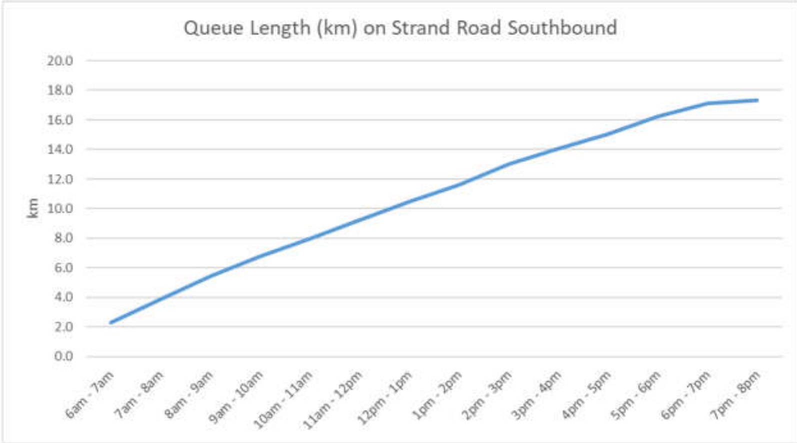


Figure 11: Queue Length on Merrion Road Northbound for Strand Road

An example best illustrates the poor level of service and excessively long queues seen in both the northbound and southbound approaches to the shuttle operation on Strand Road. For example, if a vehicle joins the back of the southbound queue for the shuttle at exactly 13:00 there is already a residual queue of 1328 vehicles ahead. Including the new vehicle that joins the queue brings this to 1329 vehicles. With a shuttle capacity (due to barrier closures) of on average 273 veh/hour (i.e. a departure rate of 273 veh/hr) then this implies that it would take 1329 vehicles divided by 273 veh/hour or approximately 4 hours 52 minutes (plus the length of time to wait for the lights to go green again but this is negligible when set against the overall time to clear the queue). Therefore, this particular vehicle will not clear the queue until approximately 17:52. For comparison, the equivalent time to clear the queue at 100s cycle length is 20:44.

These numbers are stark and somewhat theoretical since in practice few rational road users would join a queue of this length but they are, however, illustrative of the problem with trying to run a shuttle subject to relatively high daily travel demands over such a long distance with resulting long intergreens and the constant disruption to its operation throughout the day due to the closure of the Merrion Gates. It is also worth bearing in mind that this represents something close to a best case scenario since we have utilised a very optimistic value for Saturated Flow of 1800 veh/hour. In practice this is likely to be much lower (and consequently the capacity of the shuttle will be lower) for the reasons outlined earlier in this note.

Furthermore, our data reveals that barrier occurrences per hour may often be higher (with longer duration) and are likely to only increase due to future railway capacity expansion on this line. To capture this uncertainty we carried out a sensitivity analysis on the number of times the gates are assumed to close per hour. This is described in the next section.

5.2 Sensitivity Analysis of Barrier Disruption

Recall from section 5.1 above that for an operating cycle length of 120 seconds the percentage of cumulative unsatisfied travel demand to cumulative travel demand is on average 34% in each hour for northbound traffic rising to 43% for southbound traffic. A sensitivity analysis on the capacity and hence on the potential throughput of the shuttle was carried out to ascertain the impact of the Merrion Gates opening more frequently than an average of 9 times per hour. Figure 12 below presents a summary of the main results again expressed in terms of average percentage of cumulative unsatisfied travel demand for the hours of 06:00 to 21:00.

The results demonstrate a steady linear increase in the percentage of cars unable to travel through the shuttle which accumulates hour by hour. For northbound shuttle operations this rises from 34% on average each hour to 43% (maximum number of barrier closures shown here). Similarly, for the southbound shuttle operations the percentage unsatisfied demand increases from 43% to 51%. The linear relationship arises from the simple assumption used in our analysis that increased disruptions will have the same impact whereas in fact the relationship is likely to be highly non-linear. Beyond a certain 'tipping point' there is likely to be a much greater impact of, for example, two or more successive barrier closures occurring within a very short time frame – the likelihood of which increases rapidly when we increase the frequency of disruption.

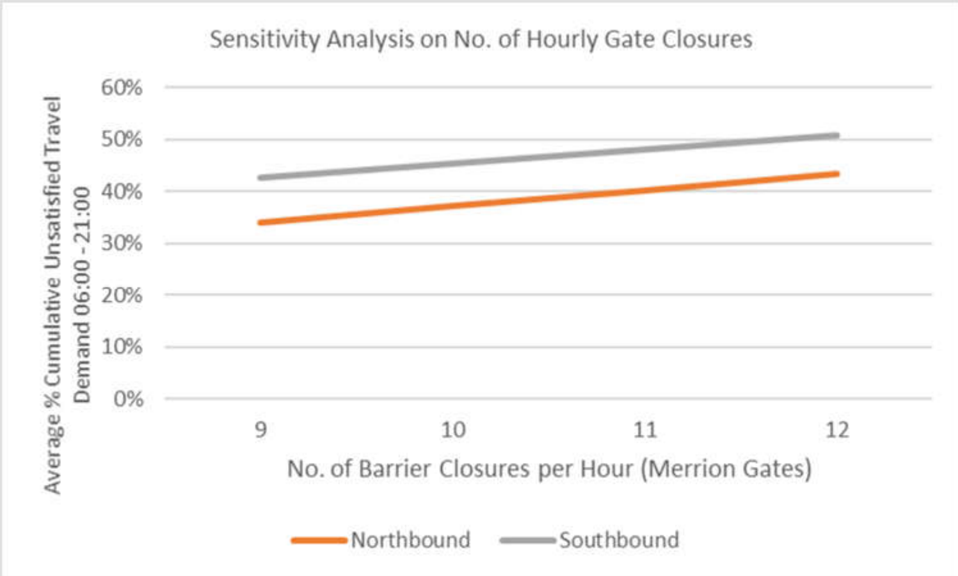


Figure 12: Sensitivity Analysis on No. of Hourly Gate Closures

6.0 Concluding Remarks

This technical note has provided a capacity analysis and assessment of a signalised shuttle operation on Strand Road. An outline shuttle operation was provided with likely associated signal timings. Analysis of available traffic data generated a likely profile of daily traffic demands and a review of barrier data revealed an average of 9 occurrences of the barriers being closed per hour for the hours of 06:00 – 21:00. This value, and the average duration of disruption, were verified from a DCC CCTV camera survey. A method was proposed to calculate the capacity of the shuttle system considering the impact of disruption due to the operation of the train barriers at Merrion Gates. This analysis was carried out at 100s and 120s using various measures of performance described above. A sensitivity analysis was also carried out to capture the effect of increased disruption to the shuttle capacity due to a higher number of gate closures resulting from random events and expanded rail services in future.

The results clearly demonstrate the difficulties in achieving appropriate capacity for the shuttle system to work effectively. Regardless of the cycle lengths chosen, very long queues result from such a system which only increase further as the number of gate closures increases. The results show some improvement as we increase the cycle length from 100s to 120s but still not enough to justify this type of operation. We also considered the impact at cycle lengths greater than 120 seconds and some further (limited) benefits were found but there is an element of diminishing returns about these benefits as the additional cycle length does not produce much more benefit for the considerable longer waiting time that motorists would have to endure for their side of the shuttle to run. As noted above, the slightly greater benefit (in theory at least) of running the shuttle at greater than 120 seconds would be offset by driver frustration at longer delays, increased risk of driver non-compliance and a considerably greater risk of capacity degradation due to gate closures (i.e. long wait times for the shuttle green signal compounded by the risk of gate closure downstream before the queue has an opportunity to discharge).

In summing up it is important to emphasise the extent to which the capacity results represent a best case scenario. This is due to: the minimum number of disruptions assumed in the main analysis (9 per hour); the likelihood that these disruptions will only disrupt exactly 9 cycles (in practice likely to be higher); the fact that the traffic data volumes are based on data collected during level 3 restrictions and not higher pre-COVID volumes; and finally the very optimistic level of Saturation Flow assumed (1800 veh/hr). A lower value of Saturation Flow, for example, 1600 veh/hour instead of 1800 veh/hour would imply an each way capacity for the shuttle of 243 veh/hour. Applying this departure rate to our queuing example above would imply that a vehicle arriving at the back on the queue at exactly 13:00 would encounter a residual queue of 1746 vehicles and the time to clear the queue would be 7 hours and 12 minutes (i.e. it would be 20:12 before this vehicle could clear the queue and enter the shuttle versus 17:52). In other words relaxing the saturation flow capacity assumption by approximately 10% would, in this particular example, produce an additional delay of 2 hours and 20 minutes for this particular vehicle.

There are a number of reasons for not recommending this option:-

1. The lack of capacity which this option has and which would lead to long standing queues on both Strand Road and the Blackrock Road leading to Merrion Gates.

2. The sensitivity tests show that there is no capacity to absorb any traffic increases or increase in the duration or frequency of the barrier closures in the future.

3. The likely queues on both roads would severely affect the operation of Public transport services.

4. Traffic on Strand Road in a one lane queue will either have to endure excessive queueing time impacting all vehicular movements along the Strand Road and potentially Sean Moore Road and Ringsend or will be forced to divert via the side roads.

5. Safety issues concerning lack of sight lines along the one lane section and the unresolved issues of how residents in this section may safely exit their driveways.