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## Package C130 Combined Legion Modelling - Year 2026

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## 1 Introduction

### 1.1 Background

Combined Legion models were created by URS Scott Wilson in 2011, incorporating the Crossrail (CRL) station box and Network Rail (NR) station. These models were submitted to NR for audit in February 2011.

An external audit was undertaken by Movement Strategies on behalf of NR and the models were officially signed off by the NR Senior Station Capacity Specialist in May 2011. A comprehensive assumptions document (reference C130-SWN-T1-XMO-B071-50004) accompanies the models, which provides full technical details.

This work follows on from a year 2026(+28%) Impact Assessment commission previously carried out by URS Scott Wilson on the CRL station box design. Prior to this the CRL station box had been designed to a year 2016(+35%) demand forecast, as part of the Departures Road Scheme (document reference C130-SWN-Z-XMO-B071-00001).

Following the issue of the year 2026(+28%) demand forecast, URS Scott Wilson were instructed to carry out a pedestrian modelling impact assessment on the design. This was completed and submitted as document reference C130-SWN-Z-RIA-B071-00001.

### 1.2 Purpose

The purpose of this document is to summarise the modelling for the year 2026 demand scenario - AM and PM peak periods. The models incorporate complete CRL and NR station operations and the analysis covers both of these elements and the interface between them, particularly the CRL Arches and Platform 1 area.

The models allowed a full assessment of the five CRL Arches and the number and orientation of the CRL escalators linking onto Departures Road. It was also possible to observe the passenger circulation at the interface between the CRL Arches, Platform 1 and the NR concourse – a crucial interface within the proposed design. The Bakerloo line interchange link tunnel between the CRL Box and London Underground (LU) Bakerloo line platforms has also been included in the modelling, although not into the LU infrastructure itself.

## 2 Key Modelling Assumptions

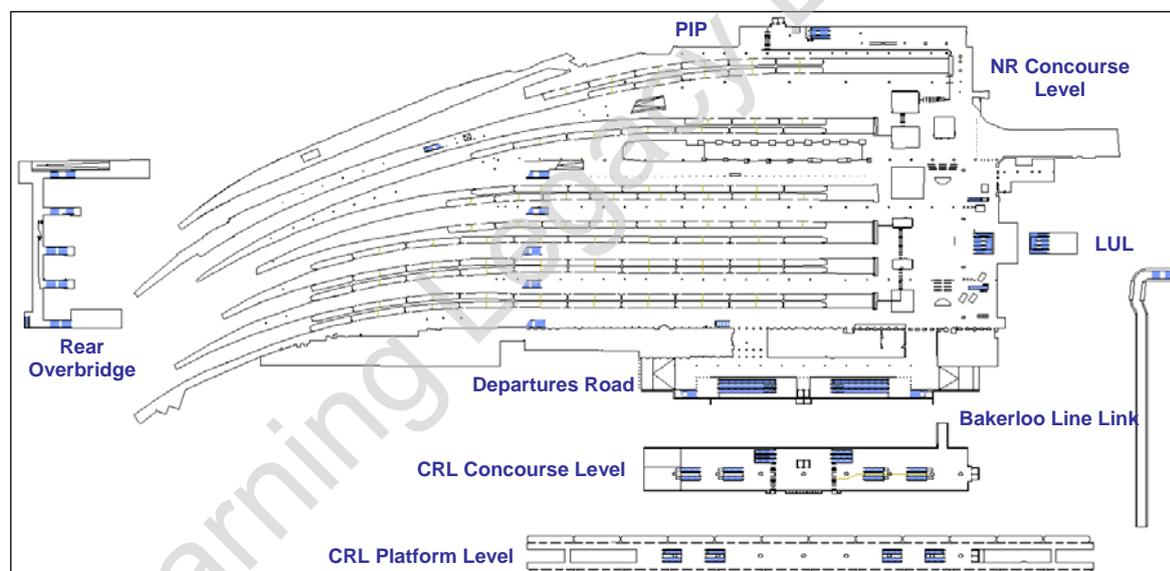
A comprehensive list of assumptions is contained within the C130 Paddington Station Combined Legion Models Assumptions document (reference C130-SWN-T1-XMO-B071-50004). Some key assumptions to the year 2026 demand modelling scenarios are detailed below:

### 2.1 Model Extents

The Legion models cover the area shown below in Figure 2.1.1. This plan is based on a combination of the currently proposed CRL station box and Bakerloo line interchange link, a section of the Paddington Integrated Project (PIP) scheme, and the existing NR concourse. Although the new taxi deck itself has not been modelled, the associated passenger flows are modelled up and down the vertical circulation bank adjacent to Platform 12.

The models are fully integrated, incorporating complete NR and CRL train timetables, whilst also including flows into and out of the LU District/Circle (D+C), Bakerloo and Hammersmith and City lines (via both NR and CRL), although the LU stations themselves were not modelled.

**Figure 2.1.1 Legion Model Extents**



### 2.2 Passenger Demand

The passenger demand figures used in the modelling are the year 2026 NR matrices provided by CRL, which have been agreed by NR, CRL and LU. The full matrices are included in the C130 Paddington Station Combined Legion Models Assumptions document (reference C130-SWN-T1-XMO-B071-50004). A summary of passenger numbers is given in Table 2.2.1 below:

A provisional timetable for the year 2026 was provided by NR and all modelling undertaken for 2026 and beyond is based upon this future timetable (this is a work in progress Intercity Express Programme (IEP) schedule). In modelling the timetable it was

identified that some services were operating well over capacity whilst others were operating significantly under capacity.

In agreement with CRL and NR the allocation of entities to platforms was revised to better reflect realistic train loadings. Further detail on the methodology used has been provided in the C130 Paddington Station Combined Legion Models Assumptions document (reference C130-SWN-T1-XMO-B071-50004).

**Table 2.2.1 Passenger Demand Summary – Year 2026**

AM Peak 3 Hours (07:00-10:00)				PM Peak 3 Hours (16:00-19:00)			
	NR	CRL	Total		NR	CRL	Total
NR	40074	12110	<b>52184</b>	NR	40426	11978	<b>52404</b>
CRL	11040	15650	<b>26690</b>	CRL	13672	20350	<b>34022</b>
<b>Total</b>	<b>51114</b>	<b>27760</b>	<b>78874</b>	<b>Total</b>	<b>54098</b>	<b>32328</b>	<b>86426</b>

**NR** NR platforms, LU links from NR and all entry/exits to street.

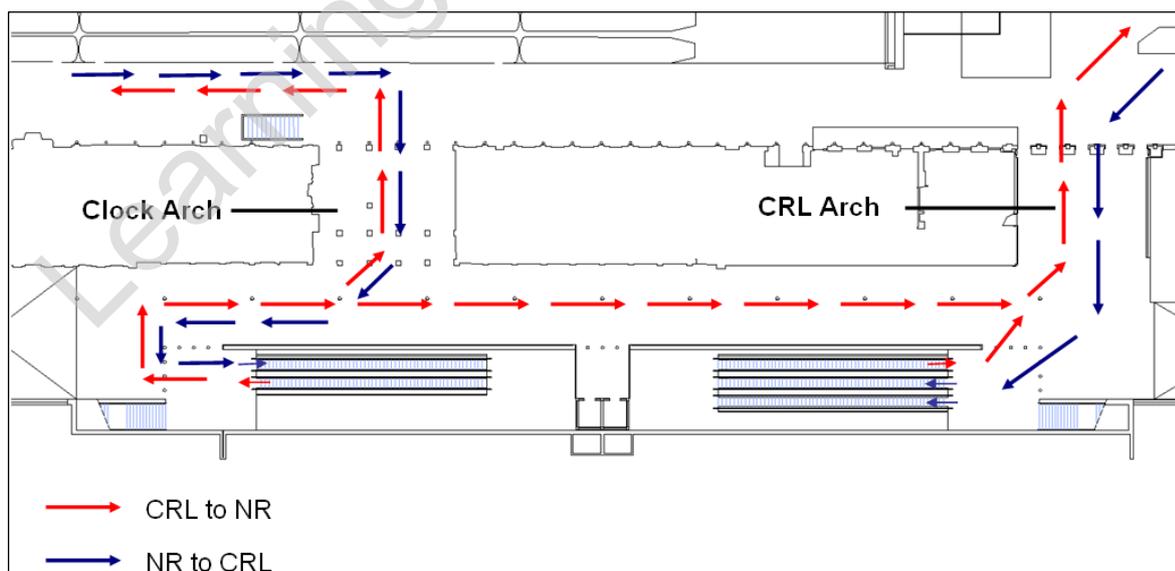
**CRL** CRL platforms and interchange links between LUL and CRL.

As agreed with the Crossrail sponsors the D+C link is not included in this design. CRL have instructed that modelling should be carried out based on the full demand matrices as included in the Crossrail Project Functional Requirements (CPFR). All passengers wishing to transfer between Crossrail and the D+C lines do so via the NR Concourse.

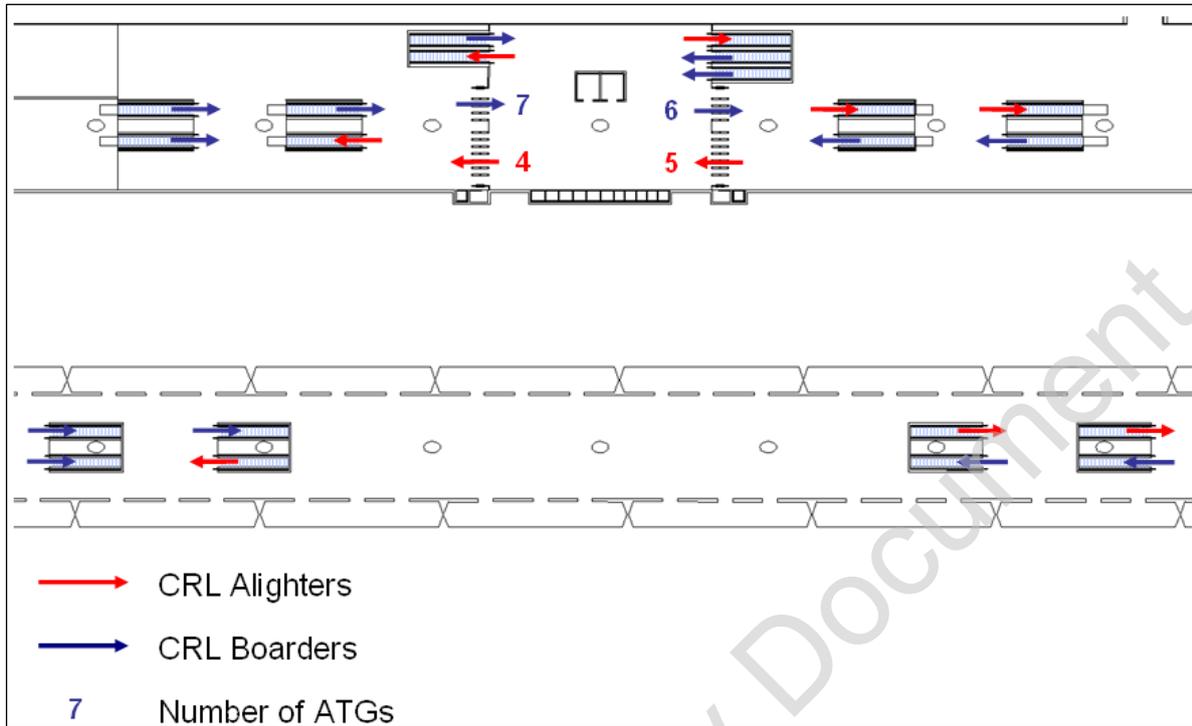
### 2.3 Routing Assumptions

Figures 2.3.1 - 2.3.4 below show the passenger routing assumptions used in the modelling. The orientations of the CRL escalators and automatic ticket gates (ATGs) are also shown, which varies between the AM and PM peaks to best reflect passenger flow volumes and direction.

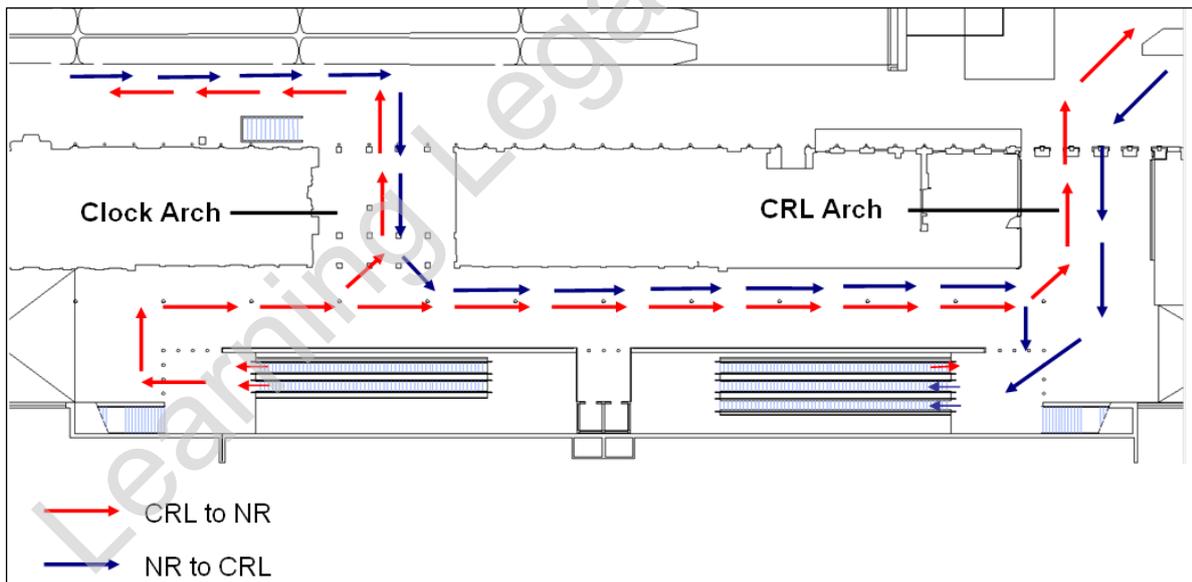
**Figure 2.3.1 Departures Road Passenger Routing – AM Peak**



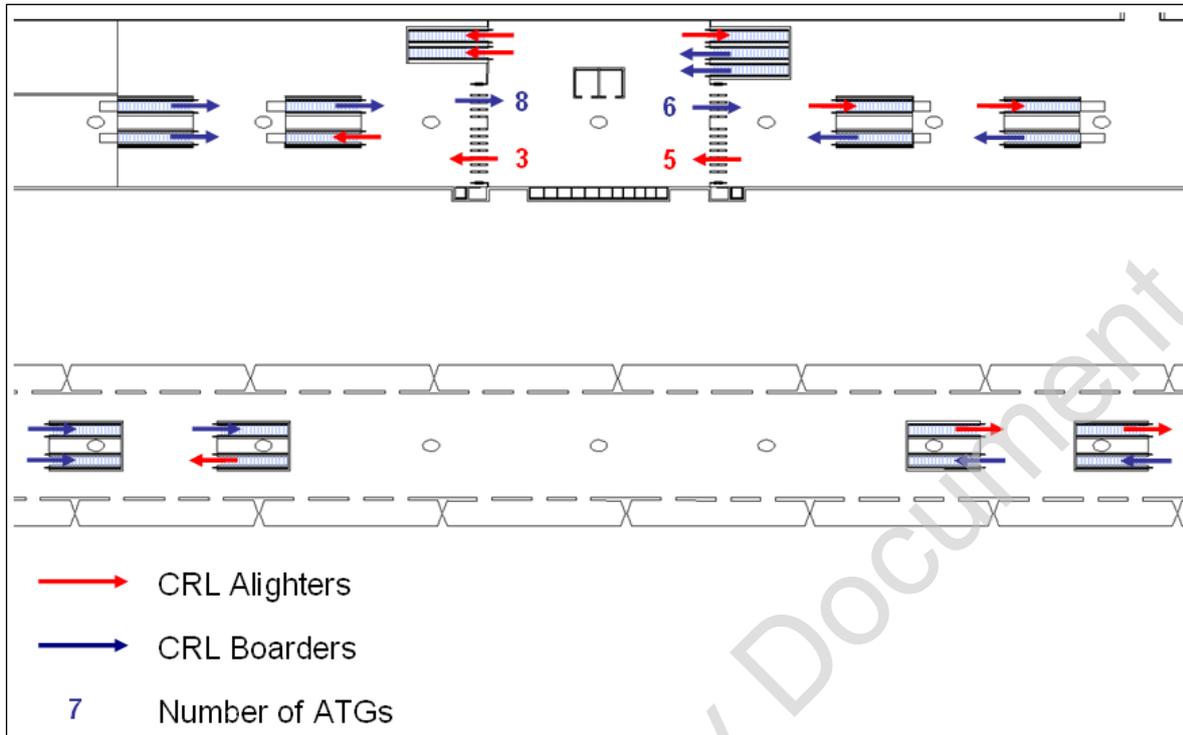
**Figure 2.3.2 CRL Station Passenger Routing – AM Peak**



**Figure 2.3.3 Departures Road Passenger Routing – PM Peak**



**Figure 2.3.4 CRL Station Passenger Routing – PM Peak**



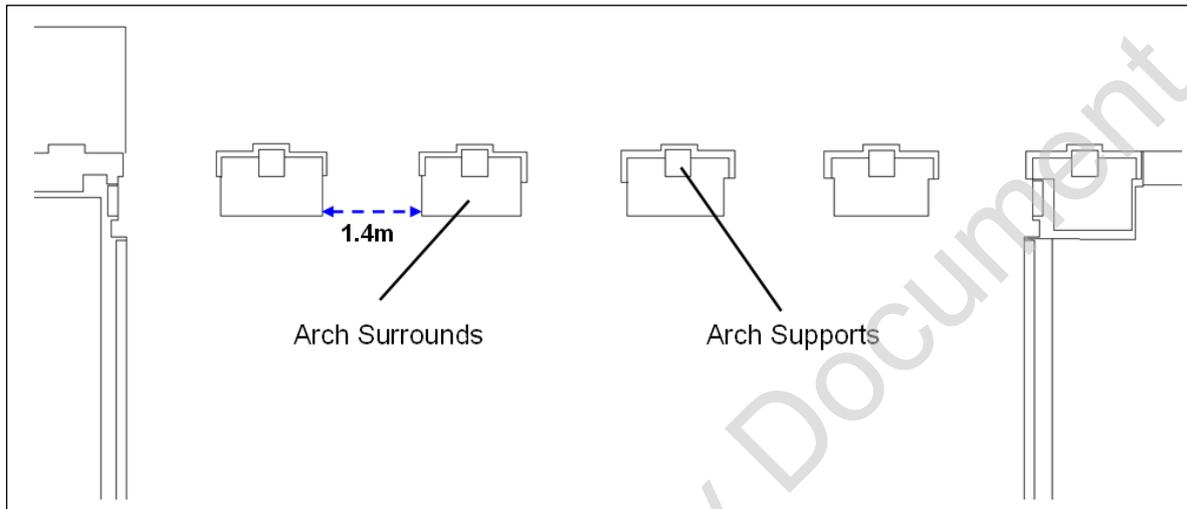
This preferred arrangement has been determined using the passenger demand data provided to identify the predominant flow directions and capacity requirements. Escalator and gateline orientations were then arranged to minimise cross-flows and provide passengers with the most straight-forward routes between Departures Road and platform level. Refinements were then made to the arrangement during a number of Legion modelling iterations in order to arrive at the best solution.

The routing pattern has also been arranged to stress test the CRL Arch. The only passengers using the Clock Arch are those interchanging with trains on Platform 1, and those using the overbridge to access the Hammersmith and City LU station and the Paddington Basin entrance.

## 2.4 CRL Arches

Figure 2.4.1 below shows the CRL Arches as they have been modelled - the width between individual arches is limited to 1.4m due to the projection of brick feature nibs. However the depth of each arch is approximately one metre, which provides passengers with good visibility through to the open spaces both behind and in front of the arches.

**Figure 2.4.1 CRL Arch Widths**



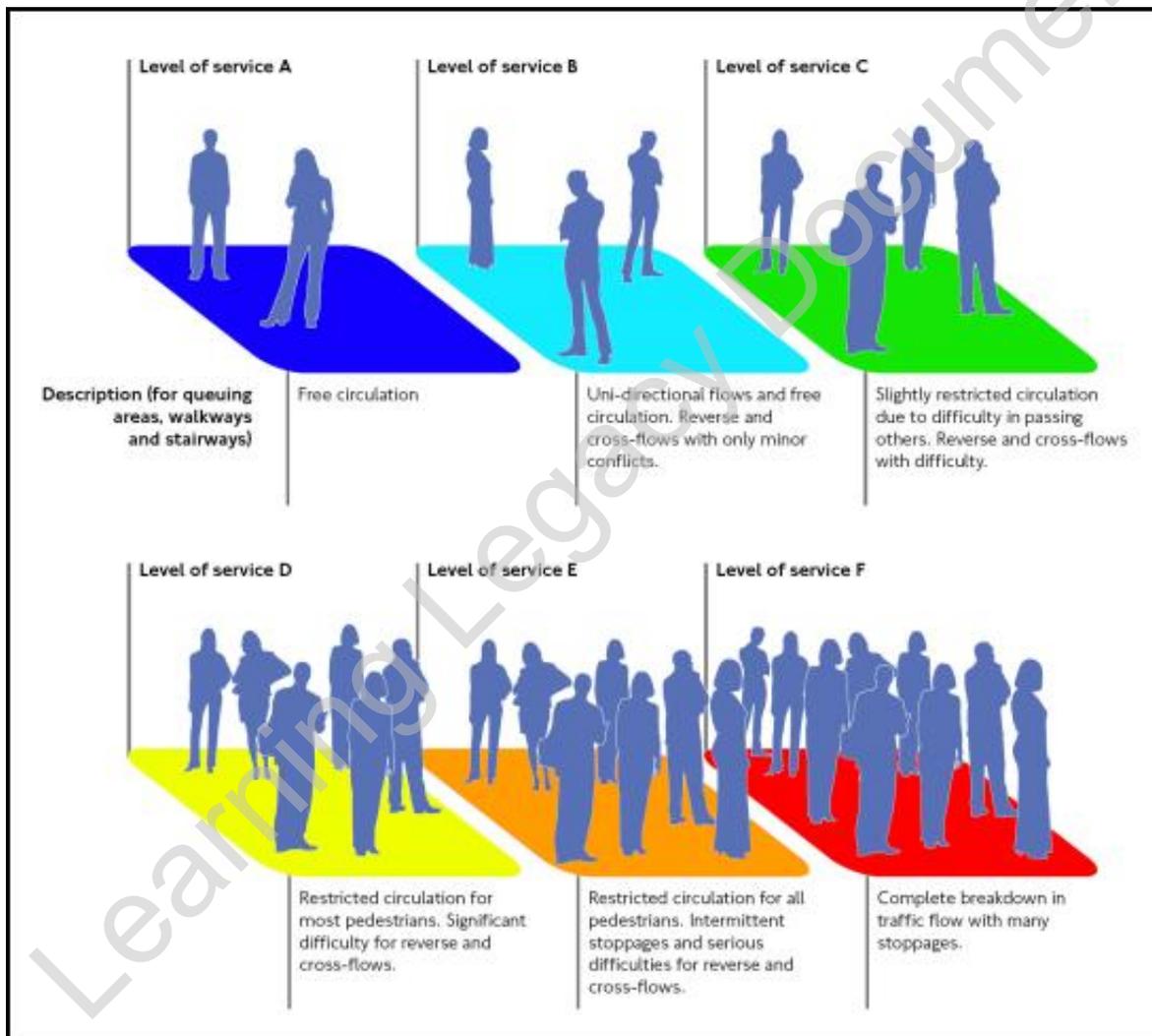
### 3 Modelling Results – NR Concourse and CRL Interface

For the combined Legion models results have been obtained based on the year 2026 demand forecast for both AM and PM peak periods.

#### 3.1 Interpretation of Results

Figure 3.1.1 below identifies the six categories of Fruin Levels of Service (LOS), along with a brief description of the operational conditions they represent. The modelling results presented in this report are depicted graphically in relation to Fruin LOS.

**Figure 3.1.1 Fruin Levels of Service**



Source: Pedestrian Planning and Design (Fruin, 1971)

All of the results presented in this report represent the peak 15 minutes of the overall AM and PM peak periods. Cumulative Mean Density (CMD) maps and Cumulative High Density (CHD) maps have been used to analyse the results. CMD maps show the average LOS over each peak 15 minute period; whereas CHD maps show the length of time that a particular LOS is exceeded for.

For the purposes of this modelling exercise, LOS C has been used as the threshold above which CHD maps begin to be recorded. LOS C or below is seen as the desired LOS for areas of the station where passengers are walking (as opposed to waiting of queuing), so this is the target LOS for any new infrastructure.

However the operational performance of the station as a whole has been evaluated in relation to the acceptance criteria defined by NR which, depending on the area of the station under consideration and the direction of flow, LOS between A and D are considered acceptable. Any area above LOS D, E or F for a prolonged period indicates congestion exceeding an acceptable level.

### 3.2 Peak Time Periods

Peak hour and peak 15 minute periods have been determined for the purposes of obtaining results, and are calculated in Legion based on the total number of pedestrians present in the model. Due to the large size of the models in question it is beneficial to split the station into sections for individual analysis.

The CRL Box is analysed in Section 4 below. For the NR Concourse and CRL Interface, the southern section of the NR concourse and the CRL interface area of Platform 1, the CRL and Clock Arches and Departures Road have been isolated. The peak periods calculated for this section of the station are shown in Table 3.2.1 below, and have been used to generate the results that follow.

**Table 3.2.1 Model Peak Time Periods**

	AM	PM
Peak 15 minutes	08:32 – 08:47	18:01 - 18:16
Peak Hour	08:00 – 09:00	17:38 – 18:38

### 3.3 AM Peak Results

Figures 3.3.1 and 3.3.2 below show CMD and CHD maps for the AM peak 15 minute period, focusing on the CRL-NR interface. The interface between the CRL and NR station generally operates well; LOS C or below being maintained across the vast majority of the space. Large volumes of passengers interchange between NR and CRL via the CRL Arch. Surge flows are particularly high from NR train services to CRL during the AM peak.

A slightly higher LOS (LOS D) is observed within two of the bays that make up the CRL Arch (Figure 3.3.1), but LOS C is only exceeded for a maximum of five minutes during the peak 15 minute period (Figure 3.3.2). This higher LOS is due to entities waiting to pass through the gaps in the arch while others move through in the opposing direction.

Passengers within the Legion models are left to choose which of the five bays to pass through, which is predominantly based on shortest distance to their destination. In reality passengers will base their decision also on congestion, hence in all probability avoiding the predicted local LOS of D for two of the arches. The results are therefore deemed acceptable.

The five CRL escalators linking Departures Road and the CRL station concourse operate well during the AM peak 15 minutes and are sufficient to process the year 2026 forecast passenger demand. The current design also includes passive provision for a sixth escalator that could be installed as passenger numbers approach 2026(+28%).

Figure 3.3.1 CMD (Walkways LOS) Map – AM Peak 15 Minutes (08:32 – 08:47)

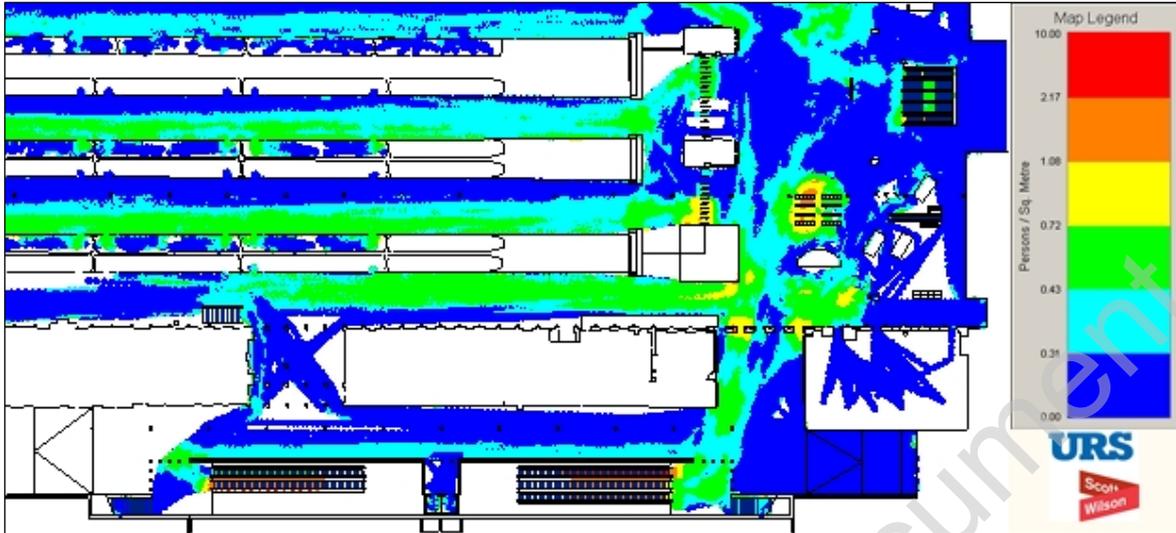
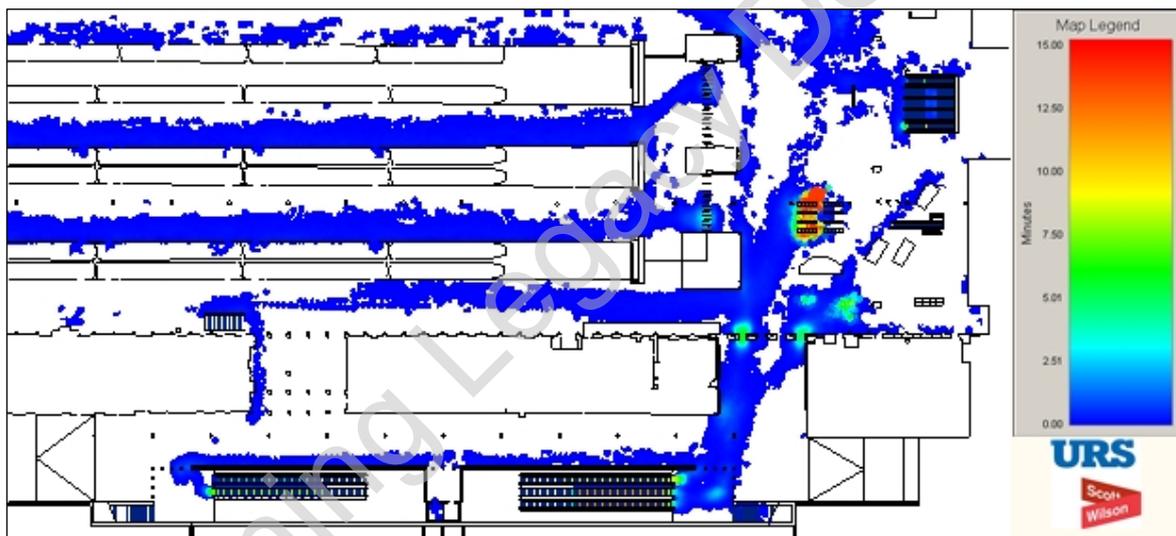


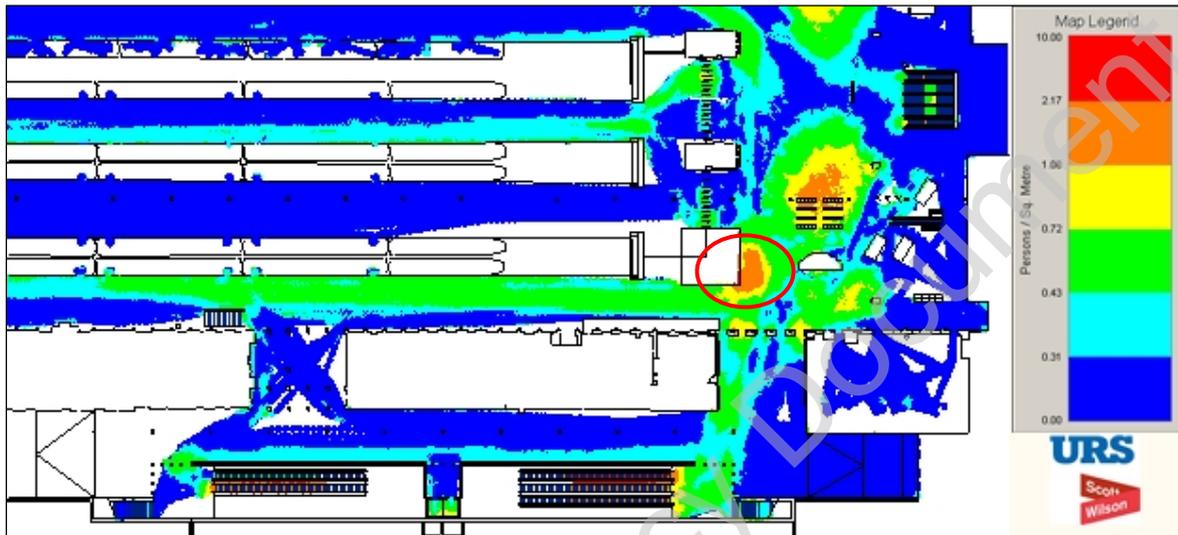
Figure 3.3.2 CHD (LOS C) Map – AM Peak 15 Minutes (08:32 - 08:47)



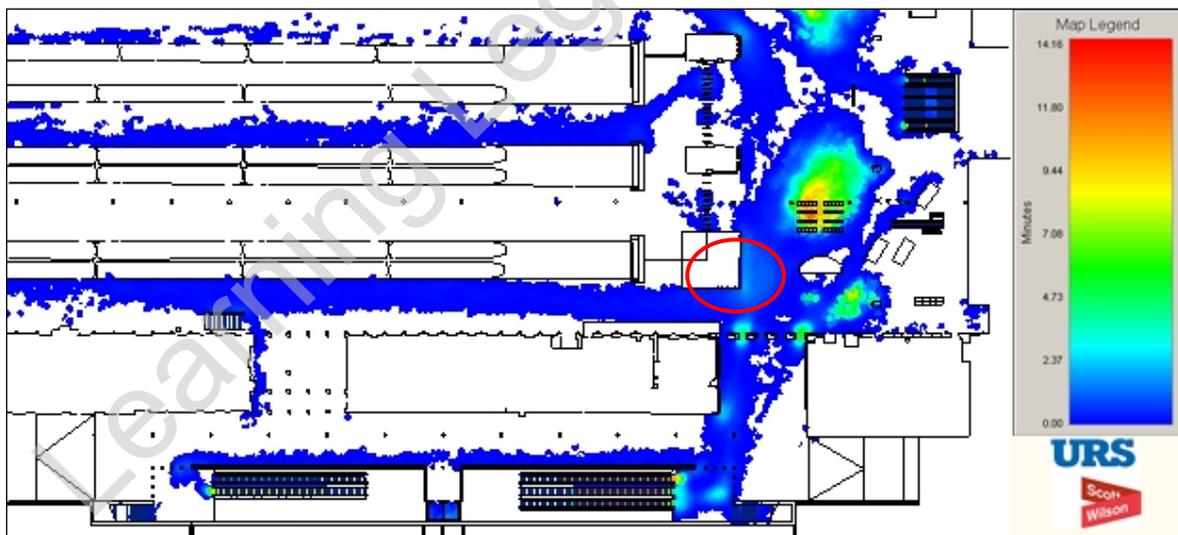
### 3.4 PM Peak Results

Figures 3.4.1 and 3.4.2 below show equivalent CMD and CHD maps for the PM peak 15 minute period. The passenger flows observed between CRL and NR are very similar to the AM peak and a similar LOS is identified. Again this consists of small areas of LOS D within two of the five bays that make up the CRL Arch, but LOS C is only exceeded for a maximum of five minutes during the peak 15

**Figure 3.4.1 CMD (Walkways LOS) Map – PM Peak 15 Minutes (18:01 – 18:16)**



**Figure 3.4.2 CHD (LOS C) Map – PM Peak 15 Minutes (18:01 – 18:16)**



During the PM peak there are greater volumes of passengers dwelling on the NR concourse waiting for platforms to be allocated. A key element of the proposed station design is the area at the top of Platform 1 where a number of passenger flows converge close to the CIS.

Current modelling work replicates site observations of existing waiting patterns in that the majority of dwelling passengers wait on the northern side of the CIS where the seating is located. A smaller number of passengers dwell in front of the ticket office on the southern side of the CIS, and do not hinder interchanging CRL passengers in the modelling.

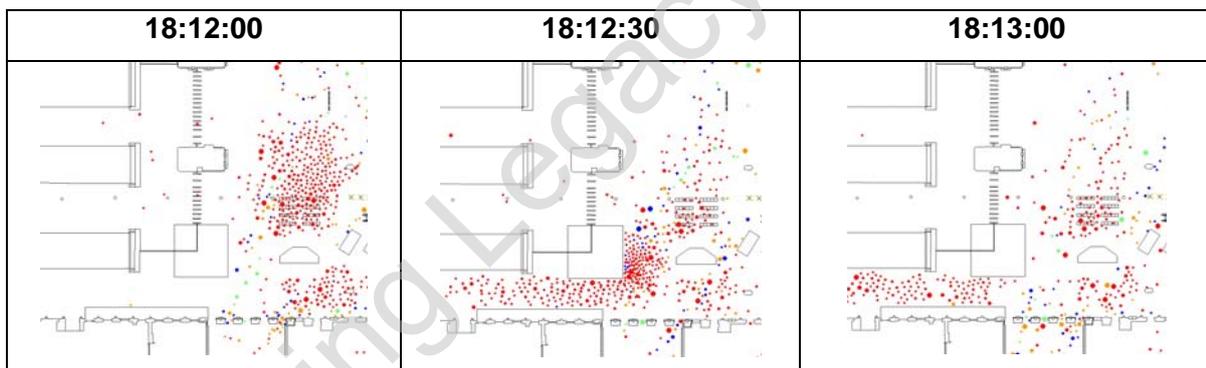
The CMD results above show a pinch point in the area around the corner of the Paperchase retail unit, as shown by the red circle in Figure 3.4.1. This occurs when a train departing from Platform 1 is allocated on the CIS and a surge of passengers proceed onto the platform.

Although this is to be expected during such times it does not cause significant congestion and clears quickly, as shown in the equivalent CHD map. This is shown by the red circle in Figure 3.4.2, which shows that LOS C is exceeded for less than two minutes of the peak 15; equivalent to the surrounding platform and concourse areas.

Legion software also routes passengers by a shortest distance route, which can lead to crowding on and around corners such as this. In reality passengers are more likely to fan out around a corner rather than head for the apex as they do here. It is therefore felt that removing the Paperchase retail unit is not necessary at this time.

Figure 3.4.3 below shows a screenshot sequence for a one minute period from when the train service on Platform 1 is announced. It can be seen that passengers queue slightly around the corner of the Paperchase unit, before completely clearing in less than a minute.

**Figure 3.4.3 PM Peak Screenshot Sequence**



The Costa coffee seating area located opposite Paperchase at the head of Platform 1 has been included in the models as an obstruction meaning that, as in reality, passengers cannot utilise this area. It has been assumed for modelling purposes that this seating area will remain once the CRL Arch has been built and Crossrail is operational.

However it is understood that NR is developing plans for an Over Sight Development (OSD) in the Bomb Gap immediately above the planned CRL Arch location, which would be completed circa 2016/17. It is thought this OSD will contain an element of retail space, and it is recommended that once the OSD plans become apparent the modelling should be revisited to assess the likely impact on passenger flows. A space utilisation analysis could be used to ensure that these activities are not located on desire lines.

## 4 Modelling Results – CRL Box

The following section relating to the CRL station box forms an update to the results included in the previously submitted 2026(+28%) Impact Assessment Interim Report (document reference C130-SWN-Z-RIA-B071-00001). The above report provides additional detail and background and should be referred to if required.

### 4.1 Peak Time Periods

Again due to the large scale of this model it was decided to focus on the area in question, which in this case is the CRL box. The peak periods calculated for this section of the station are shown in Table 4.1.1 below and have been used to generate the results that follow.

**Table 4.1.1 Model Peak Time Periods**

	AM	PM
Peak 15 minutes	08:33 – 08:48	18:07 - 18:22
Peak Hour	08:11 – 09:11	17:29 – 18:29

### 4.2 AM Peak Results

Figures 4.2.1 - 4.2.3 show CMD (Walkways and Queuing) and CHD maps for the AM Peak 15 minutes. Overall the results show a significant increase in LOS at platform level when compared with the previous 2016(+35%) demand to which the infrastructure was originally designed (document reference C130-SWN-Z-XMO-B071-00001).

#### Concourse Level:

The concourse operates efficiently during the AM peak – typical LOS ranging from A to C. Small areas of LOS D-E are identified as passengers slow and queue slightly for gatelines and escalators, which is to be expected. Passenger interchange with the Bakerloo link connection on the eastern side of the concourse also works well.

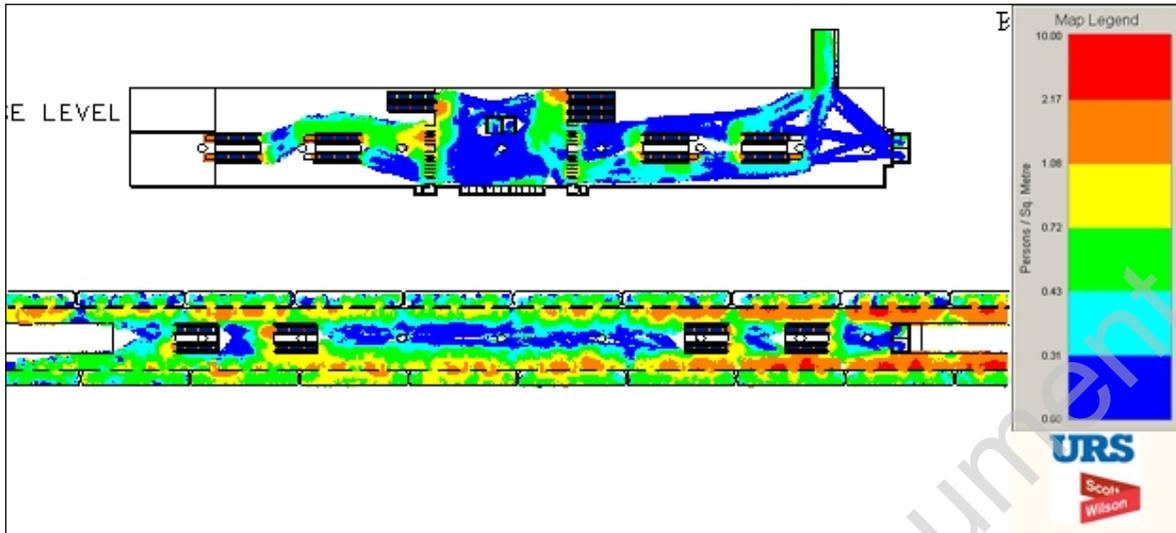
#### Platform Level:

During the AM peak there is a predominant boarding flow onto the eastbound platform, where areas of LOS D, E and small areas of LOS F can be seen along the platform edge. A similar pattern is seen on the westbound platform as passengers wait longer for lower frequency services.

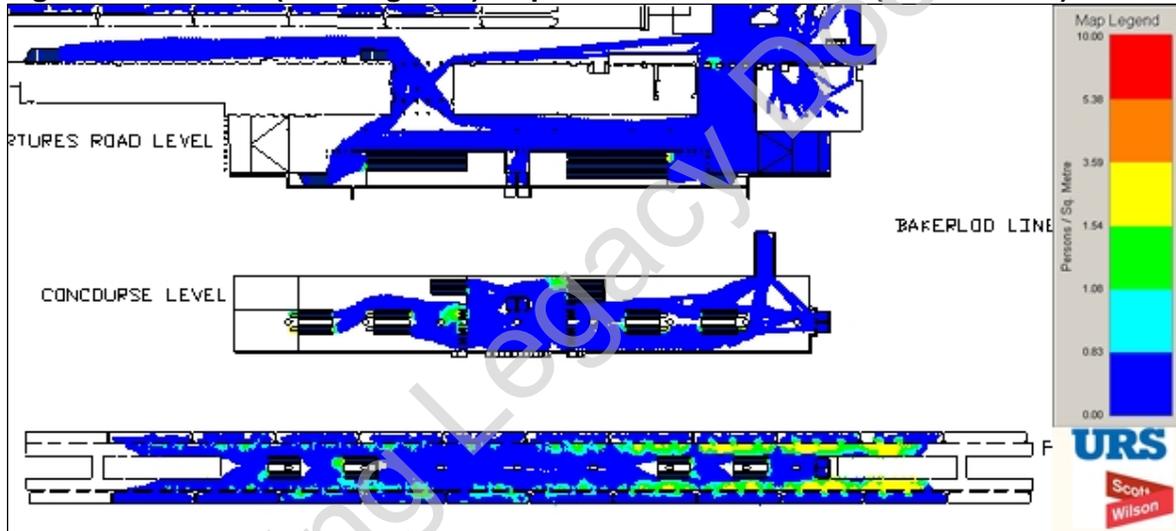
This occurs because passenger volumes are more heavily concentrated at the eastern end of the platforms. The layout of the station means that all passengers utilising the Bakerloo link, along with a proportion of those entering/exiting, use the two eastern escalator banks.

This causes a clustering of passengers at the eastern end of the platforms and, due to the orientation of the escalator banks, leaving central platform areas relatively underutilised. Although density levels are higher at the eastern end the station still operates safely during normal operations due to the high train frequency, and passengers are able to step off the escalators safely onto the platforms.

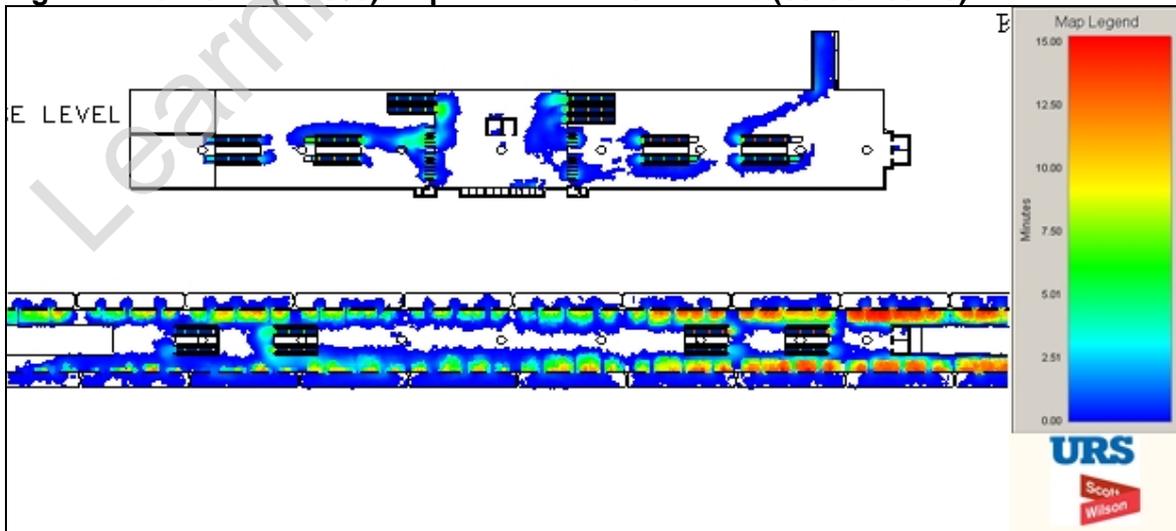
**Figure 4.2.1 CMD (Walkways LOS) Map – AM Peak 15 Minutes (08:33 – 08:48)**



**Figure 4.2.2 CMD (Queuing LOS) Map – AM Peak 15 Minutes (08:33 - 08:48)**



**Figure 4.2.3 CHD (LOS C) Map – AM Peak 15 Minutes (08:33 - 08:48)**



### 4.3 PM Peak Results

Figures 4.3.1 - 4.3.3 show CMD (Walkways and Queuing) and CHD maps for the PM peak 15 minutes. Results again show a significant increase in LOS at platform level when compared with the previous 2016(+35%) demand to which the station infrastructure was originally designed (document reference C130-SWN-Z-XMO-B071-00001).

#### Concourse Level:

The concourse generally operates well during the PM peak – LOS does not exceed LOS C over the majority of the space. Areas of LOS E are however identified at the western gateline and the base of the western escalator bank as passengers queue slightly following heavy alighting surges from CRL trains.

This does not cause an issue on the eastern side of the concourse as a large proportion of passengers exit the station via the and Bakerloo line link. On the western side all passengers utilise the gateline, which causes the capacity to be breached during busy periods.

The gateline has been maximised within current CRL box width restrictions and passengers are forced to queue for a maximum of a few seconds during busy periods. In terms of safety this does not cause passenger queues to extend back towards the top of the escalators and passengers are all clear of the gateline before the next surge arrives.

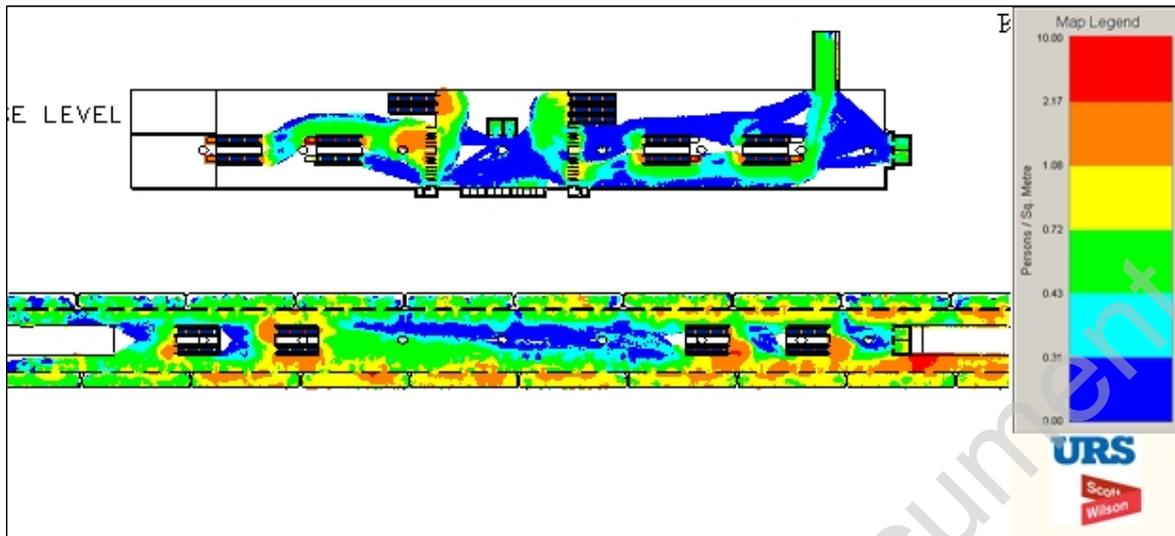
#### Platform Level:

During the PM peak there is a predominant alighting flow from the westbound platform and areas of LOS E can be seen at the base of escalators as passengers' walk speed slows. This is a consequence of high alighting surge flows combined with limited escalator capacity from the platforms.

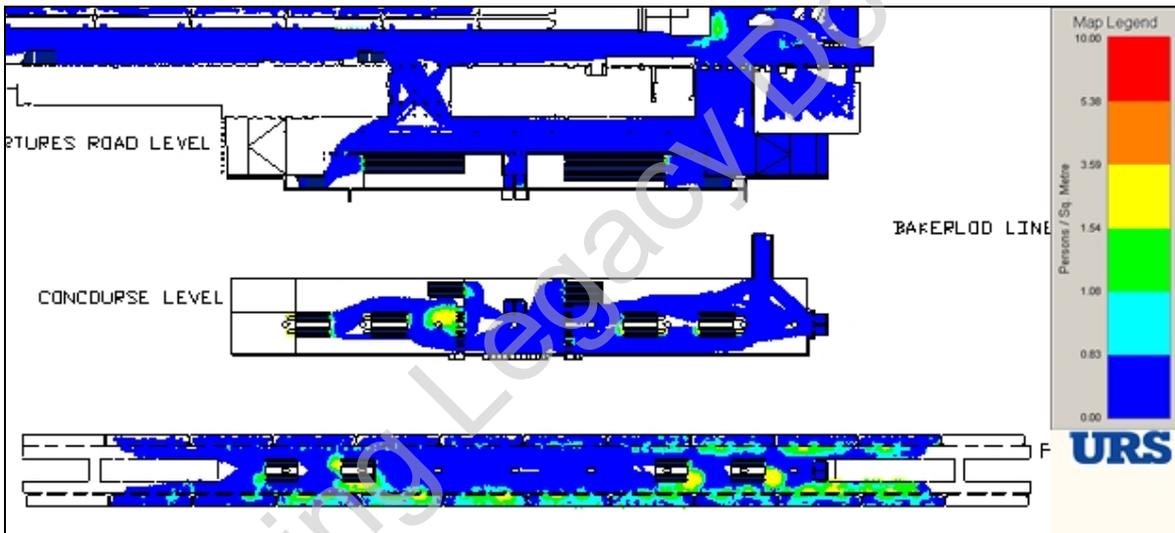
A key factor in analysing vertical circulation performance from a platform is to look at platform clearance times; to ensure that all passengers have left the platform before the next train arrives. This analysis has been carried out and results show that platforms do clear adequately (see report reference C130-SWN-Z-RIA-B071-00001), based on of 24 TPH timetable as required by CRL.

To summarise – alighting passenger loads are able to clear the platform before the next train arrives on the same platform (the heaviest loads being from westbound services during the PM peak). Train timetabling patterns mean that services do sometimes arrive on the eastbound platform before alighters from westbound services have completely cleared. This situation is normal and does not cause any safety concerns.

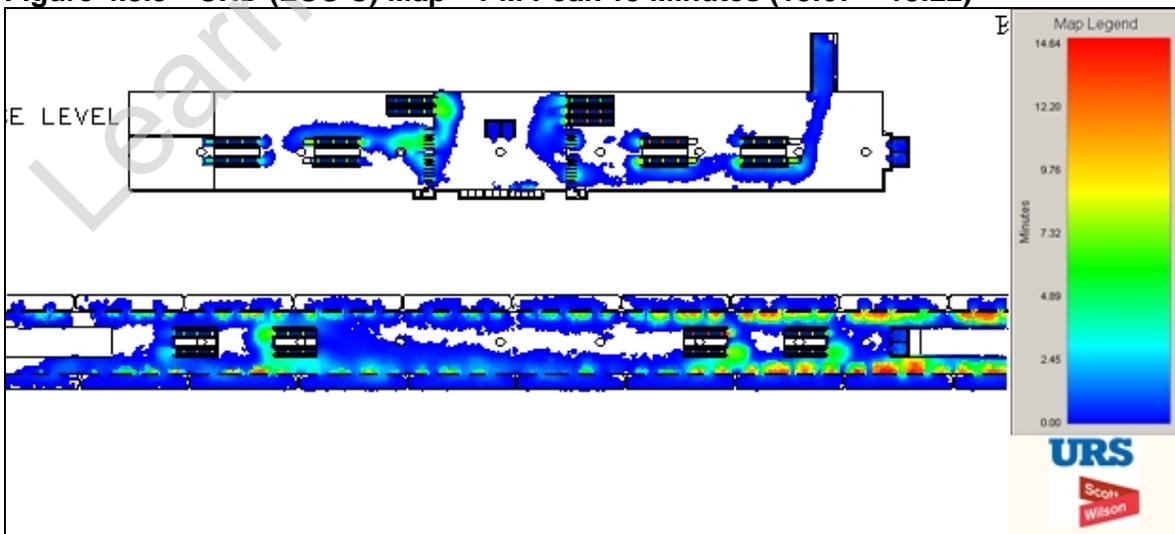
**Figure 4.3.1 CMD (Walkways LOS) Map – PM Peak 15 Minutes (18:07 – 18:22)**



**Figure 4.3.2 CMD (Queuing LOS) Map – PM Peak 15 Minutes (18:07 – 18:22)**



**Figure 4.3.3 CHD (LOS C) Map – PM Peak 15 Minutes (18:07 – 18:22)**



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#### 4.4 Mitigations

At platform level there are areas of crowding which do not comply with CR-STD-305. This overcrowding is around the eastern escalator banks and is caused by higher passenger numbers using these escalators to reach the Bakerloo line link. The Bakerloo line link cannot be reached from the western escalator banks without passing through the gateline.

Staff management during the peaks would ensure that passengers move along to the less crowded central part of the platform. Management will also ensure that waiting passengers in the constricted area beside the escalator banks do not obstruct those wanting to move along the platform. This would mitigate these areas of crowding at platform level.

Learning Legacy Document

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## 5 Conclusions

In conclusion, based on the modelling carried out:

- The five arch opening is adequate for the year 2026 passenger demand forecast.
- The five CRL escalators are adequate for the year 2026 passenger demand forecast.
- The CRL box operates safely although density levels are greater than those observed for the original year 2016(+35%) demand forecast.
- During the AM peak boarding passengers concentrate at the eastern ends of the platforms due to the station layout and escalator orientations. However the high train frequency ensures that platform operate safely.
- During the PM peak passengers' walk speed slows as they approach the base of escalators at platform level, resulting in areas of Los E-F. However alighting passenger loads safely clear the platforms before the next train arrives in the same direction.
- Following a review of alternative escalator and gateline arrangements, it can be confirmed that Figures 2.3.1 to 2.3.4 show optimised operational layouts for both the AM and PM peak periods.
- The CMD results show a pinch point in the area around the corner of the Paperchase retail unit at the main station concourse end of platform 1. Although this is to be expected during such times, the CHD map indicates that it does not cause significant congestion and clears quickly.
- It is recommended that the Paperchase unit and Costa coffee seating area be reviewed beyond year 2026 in light of other planned schemes at Paddington such as IEP and OSD.