HELIOS

Management and technology consultants

Heathrow Hub

Ground Movement Modelling

an egis company

V1.1 01 October 2014

Version control

Version	Change
V0.1	Initial draft
V0.4	Easterly slides added
V0.8	Updated conclusions – 2023 delay graphs added
V1.0	Draft version issued to Heathrow Hub
V1.1	Update following comments

Contents

Overview

We need to show that the introduction of the independent in-line runway operations do not adversely impact ground movement operations

Overview

The introduction of the third runway and its positioning in-line with a shortened existing northern runway requires the overall new configuration of runways of the Heathrow Hub concept to be analysed for workload/bottlenecks (e.g. peak arrival/departure mode on northern runways), obstructions of line-of-sight, runway incursions/ excursions (including during construction) and associated Tower coordination of the runway modes.

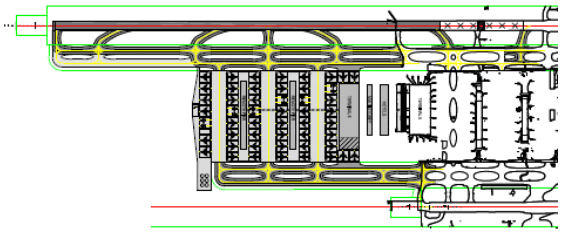
This report looks at the ability of the supporting taxiways' and ground movements' capability to support the runway movements expected in 2023 and beyond, taking account of infrastructure between the three runways, as well as with the further option of Terminal 4 remaining as part of the Heathrow Airport infrastructure.

The analysis is based on a simulation of arrivals and departures, to influence appropriate positioning of runway entry and exit points, including rapid exit taxiways (RETs), and reduce/improve runway incursions/excursions.

The analysis used the AirTOp fast time simulation software which was used to:

- Examine how the airport would operate
- Highlight future areas of focus in terms of ground layout
- Understand if there are significant pinch points or congestion
- Understand how best to configure ground operations to optimise delays and taxi-times
- Give a visual representation of the concept

HH Ground Layout



Focus Area

There are some specific aspects for which we undertook focussed analyses

Opening date and time when theoretical capacity reached i.e.

- 2023 – Opening date – some increase in movements from 2014 to 523k per annum
- 2045 – 700k movements per annum

How well the airport operates:

- In each of the runway modes
- During Easterly and Westerly operations

Operation of the southerly runway and in particular:

- Runway crossings to and from Terminal 4
- Whether the airport can be operated without Terminal 4

The requirement for additional taxiways:

- Dual taxiways to the south of T6
- Additional north-south taxiway to the west of the airport

Is there capacity for towing aircraft to the remote stands and the BA Maintenance base ?

Approach

We have followed a clear methodology in developing our AirTOp simulation

Methodology

Through discussions with the Heathrow Hub team we agreed the requirements and inputs for the model.

We had already created schedules for the years of interest, using a current schedule as the starting point. These schedules were based on forecasts from Aviation Economics and had previously been used for the runway model to determine arrival and departure rates.

We interpreted the designs that we have seen from the Heathrow Master Plan and URS for Heathrow Hub in order to create appropriate taxiways, stands, holding points, and runway entrance and exit points.

The model needed to be built in stages as each run of the model showed where there may be issues. Through analysis of the outputs of each run we were able to determine whether any issues were as a result of shortcomings in the model assumptions or whether adjustments were needed to the layout or ground movement rules. Through this iterative process we were able to optimise the flow around the airport.

For each of the years, periods of interest, and mode changes we could then highlight potential areas of conflict or bottlenecks

Outputs

Tables and visual outputs (screen shots and video) could then be produced:

- In order to show possible periods or physical areas of interest
- For use by Heathrow Hub to demonstrate the operational feasibility of the concept

Schedule creation

We developed detailed schedules for the future dates of interest in order to be able to simulate individual flights

Forecast traffic growth

Forecasts of annual movements were provided by Aviation Economics, which take into account growth forecast by aircraft code. Hence traffic growth is accompanied by an increase of larger aircraft in the fleet mix, including adjustments to allow an expected increased rate of adoption of A380 aircraft (based on Heathrow Airport and airline press releases). Forecasts are shown by ICAO aircraft design code with Air Transport Movements (ATMs) peaking in 2045. See Figure 1.

Annual forecasts have been translated into hourly movements, with some schedule smoothing, and all airport operations are assumed to occur between 06:00 and 23:00.

Aircraft are distributed taking into account the capacities of the runway operating modes and expected terminal usage. Figure 2 shows the runway modes that will be applied at different times of the day to deliver respite and capacity.

The schedule included turnaround timings to simulate realistic stand usage.

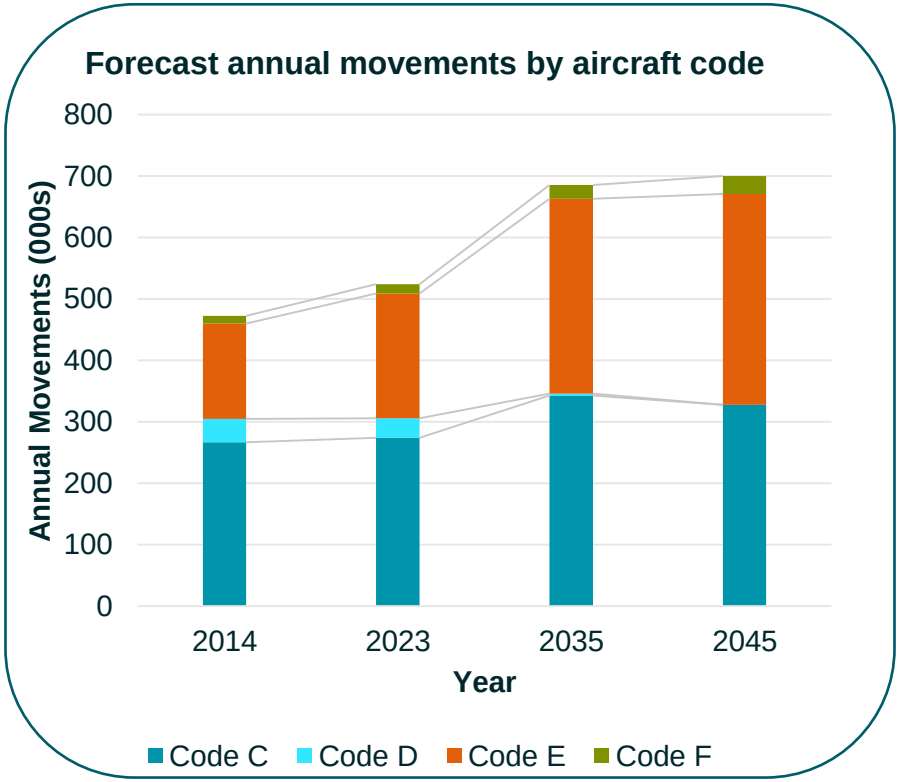
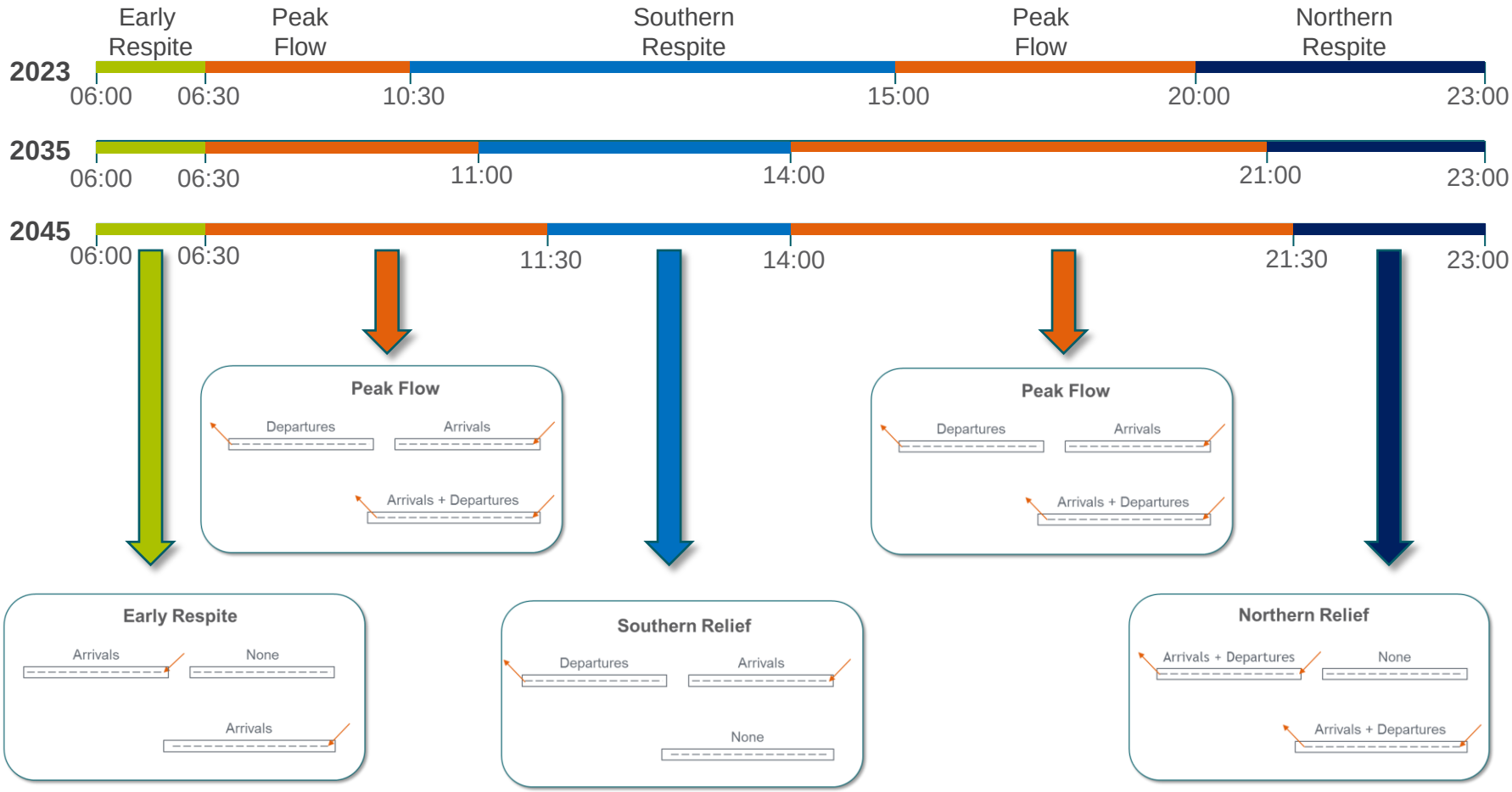


Figure 1: Forecasted annual movements by aircraft code

Changes to the runway operating mode reflect the need to increase the peak periods to accommodate the increase in aircraft numbers



Not to scale

Figure 2: Heathrow Hub operational runway modes to deliver respite and capacity (westerly operation shown)

Capacity for the different operating modes were taken directly from the previous airspace simulation

Capacity during operating modes

Airport capacity has been simulated for different years, calculated from simulations which were based on the expected fleet mix at that time. The capacities are an average of the hourly flow rates from the simulations.

Hourly flow capacities are combined to provide daily and annual capacities. Figures shown are for normal operations in good weather in a steady state.

Changes between runway modes, weather constraints, go-arounds, runway closures or other operational events mean that average delivered capacity will be slightly lower unless the peak operating modes are extended.

The simulation results from the airspace model are shown in Table 1. The overall increase in movement is due to the lengthening of the peak periods. Differences in movements e.g. 84 from 81 movements in the Southern respite are due to changes in the mix of aircraft during the mode.

Airport capacity	2023	2035	2045
Hourly			
Early respite	46	46	46
Morning peak flow	124	125	123
Southern respite	81	84	82
Afternoon peak flow	128	129	129
Northern respite	87	83	83
Daily	1,709	1,922	1,949
Annual	623,602	701,347	711,385

Table 1: Simulated airport capacity for operational runway modes

Distribution between terminals was determined from expected demand, matched to stand availability

Distribution between terminals

The flights within the schedule were distributed between the terminals in the following order:

- Cargo traffic was not increased
- Any increase in traffic was initially scheduled for Terminal 6
- Remaining traffic was split as per the forecast, which anticipates a reduction in traffic to Terminal 4

The model was then run and rules were applied so that if an aircraft could not be allocated a stand at its preferred terminal it was sent to another one. This terminal was then used as its “home” terminal in order to determine the final distribution.

Terminal	Percent of flights
2	38%
4	7%
5	28%
6	26%
Cargo	2%

Table 2: Modelled split of aircraft between terminals

Model assumptions

The assumptions are in line with the previous air space simulation and the most recent layouts

Assumptions to generate the fast-time simulation

Assumptions are made in order to generate a fast-time simulation of movements, to assess potential congestion and design requirements.

Schedule

- Fleet forecasts from Aviation Economics were adjusted to reflect Heathrow Airport and airline press releases relating to earlier fleet changes (namely early A380 introduction).
- Flights have been smoothed within the different phases so the schedule is less peaky than at present, although not fully optimised.
- All operations occur between 06:00 to 23:00 which has meant some redistribution of current early (pre 06:00) flights
- Proportions of movements by aircraft category and by time of day remain unchanged from today.
- Timing of runway configuration was taken from the previous runway modelling.

Layout

- The airport masterplan layout has been modelled using drawings supplied by URS as of July 2014.
- Where there are uncertainties in the layout, a similar arrangement to the current operation has been taken (e.g. the proportion of stand sizes).

Runway and taxiway concepts

- Arrivals and departures are considered to be independent with adequate airspace capacity.
- Aircraft separations are predicated upon current separation standards from NATS, ICAO 4444 and CAP493.
- No weather constraints, go-arounds, runway closures or other events are simulated.
- Runway crossing are not executed at high energy points.
- Arrivals for and departures from Terminal 4 will operate on the southerly runway where possible. This will help to reduce the need for crossing of the active runway.

Technology assumptions are also in line with the runway model and expected changes

Assumptions used to generate a fast-time simulation - continued

Technology

- There is sufficient automation to enable the planning and management of the ground operation.
- Independent arrivals and departures.
- Any constraints on taxiway use due to ILS positioning are removed by 2045.

Taxiway assumptions

- Aircraft queuing for the runway entry points are arranged to be held on the taxiways and queued away from the runway exits on the arrivals runway(s). This ensures that arrivals leaving the runway do not come into conflict with queuing aircraft.
- In 2023 due to the location of the ILS, Code F aircraft departing from Terminal 4 when in a westerly operation will need to cross the runway.

Towing assumptions

- We included a number of towing operations to make the baseline a more realistic and to confirm whether the airport is operable with minimal delay under normal operations.
- At the start of the day BA flights in the maintenance base are towed to their stands 45 minutes before scheduled departure time.
- Arriving BA flights are towed from stands to the maintenance base after disembarkation if they are not scheduled to depart.
- After disembarkation flights are towed to remote stands if they are available and there is a large time interval before the next departure.

Simulations are close to but not exactly real life models

Modelling constraints to bear in mind

- Stand allocation is such that aircraft are allocated the closest applicable stand within an allowable group e.g. the terminal of operation, on landing or when towed to departure.
- The Ground Movement Controller is able to be more flexible (within safety grounds) in the use of taxiways that can be set in the model. For example they may use temporary variations on the one way system to improve the flow.
- The default speeds of push back, moving from stop bars, size of holding points etc. are conservative and may therefore result in slower movement than can be achieved in real life.
- More optimisation is possible e.g. the number of aircraft allowed to move at one time, push back rules etc.

Modelled taxiway operation

Westerly operation required the introduction of some one way systems to improve the flow. The assumptions made are described below.

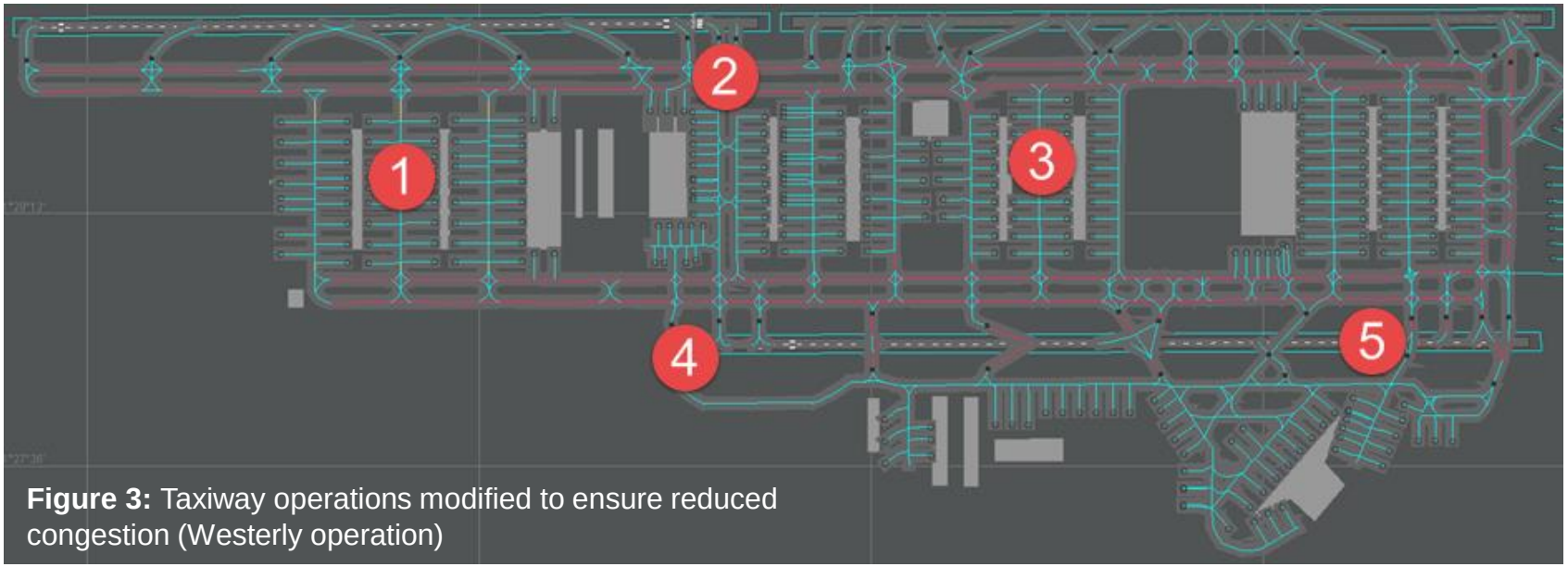


Figure 3: Taxiway operations modified to ensure reduced congestion (Westerly operation)

1. One way system in place when 27Rext is in arrivals and departures mode, to permit stream of arrivals to pass through to taxi to Terminal 4 and Terminal 2 whilst keeping northern airfield clear for 27Rext departures.
2. North of Terminal 5 area is closed for arrivals moving north to allow feeding of 27Rext runway entries.
3. Arrivals are prevented from taxiing down between terminals close to 27R runway exits, in case they get blocked by a departure, to allow constant vacating from 27R. Arrivals instead head south once they have backtracked along the northern outside clockwise taxiway.
4. This area is closed except for Terminal 4 arrivals when 27L is closed.
5. This runway crossing is only used by aircraft of code E and F departing from Terminal 4 when 27L is open for departures. Codes up to C can depart from the southern runway entry.
6. Across entire airfield: ‘inner’ taxiways have been configured anti-clockwise, ‘outer’ taxiways have been configured clockwise.

Easterly operation required a number of one way systems in order to improve the flow. The assumptions made were set as below.

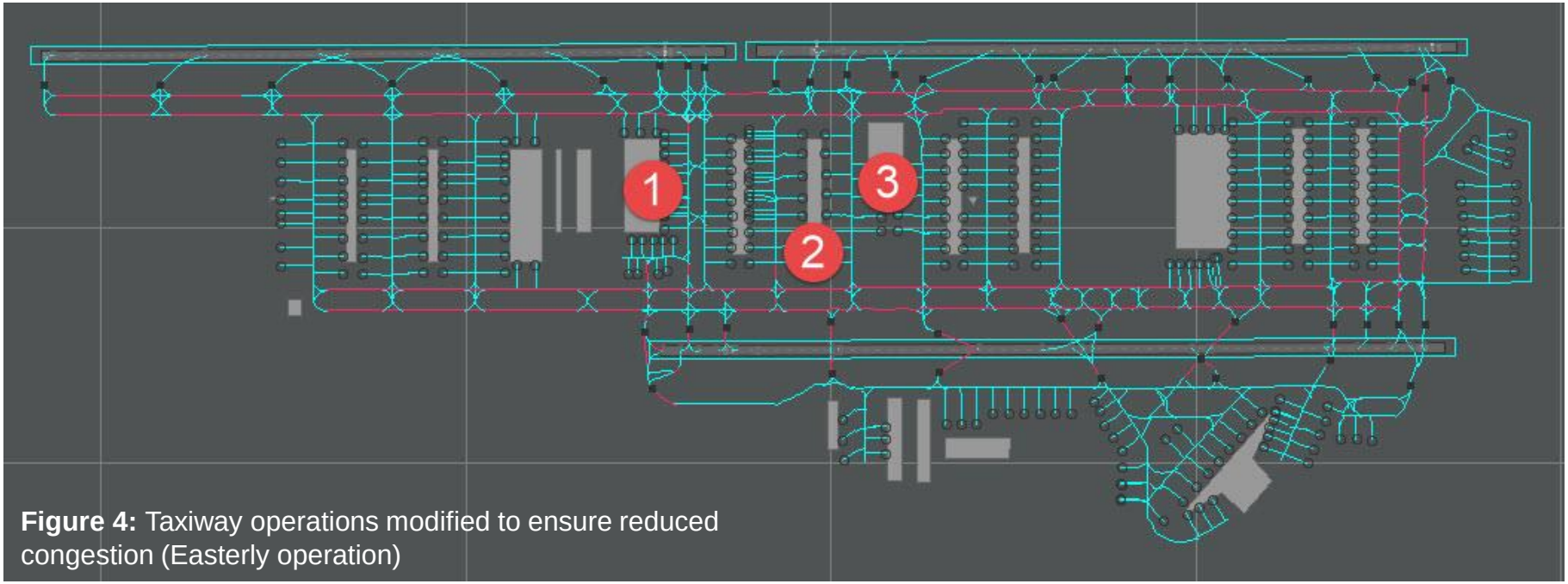


Figure 4: Taxiway operations modified to ensure reduced congestion (Easterly operation)

1. One way system in place in southerly direction to allow aircraft to vacate from 09L
2. Taxiing not allowed in the northerly direction
3. Taxiing not allowed in southerly direction
4. Across entire airfield: ‘inner’ taxiways have been configured anti-clockwise, ‘outer’ taxiways have been configured clockwise.

Model outputs

Westerly operation

There are some areas of congestion which reduces runway capacity

Operability

The model showed that there is a high level of ground movements throughout the day that need managing closely with significant challenges posed by 2045.

Figure 5 indicates the potential congestion zones. These are where departures need to queue for the runway and may cause congestion with arriving aircraft.

Figure 5: Potential taxiway congestion zones

Due to the time taken to get to and from the runways it was found that the overall capacity per hour was reduced from the runway model. Arrivals taxiing took longer and departures could be blocked or did not flow as readily to depart in order to allow arriving aircraft to exit the runway.

Operating Mode	Arrival /hr	Departure /hr	Total
Early respite	46	0	46
Morning peak flow	59	63	123
Southern respite	30	27	57
Afternoon peak flow	52	59	110
Northern respite	45	42	87

Table 3: Achieved maximum flow (2045 Westerly)

Potential bottlenecks will need to be monitored so that mitigation against queues can be introduced

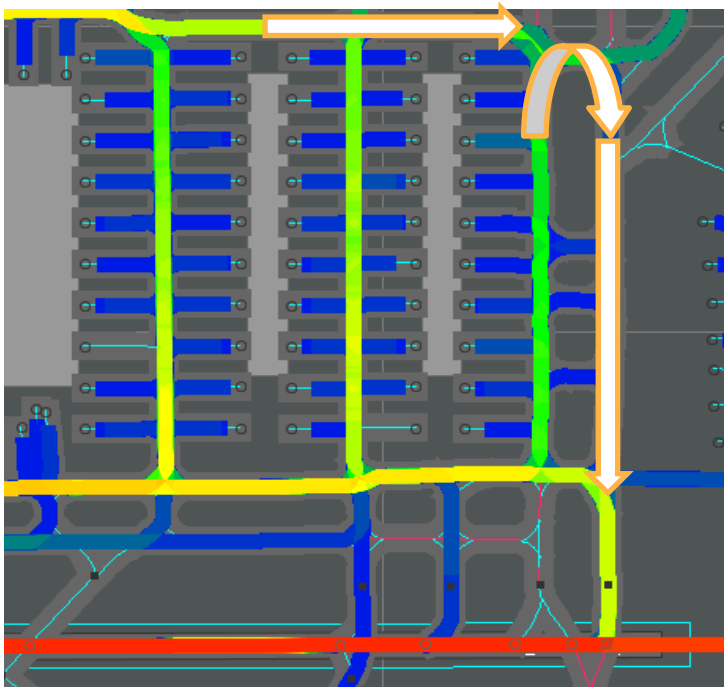


Figure 6: Departure queue bottleneck (27L)

Aircraft queuing for departure at 27L can block aircraft wishing to taxi to Terminal 2 stands, or aircraft wishing to taxi clockwise around the outer taxiway.

This can be mitigated by ensuring at peak times queueing aircraft for 27L use the outer clockwise taxiway to queue, freeing up the taxiways through Terminal 2 gates as cut-throughs for other traffic.

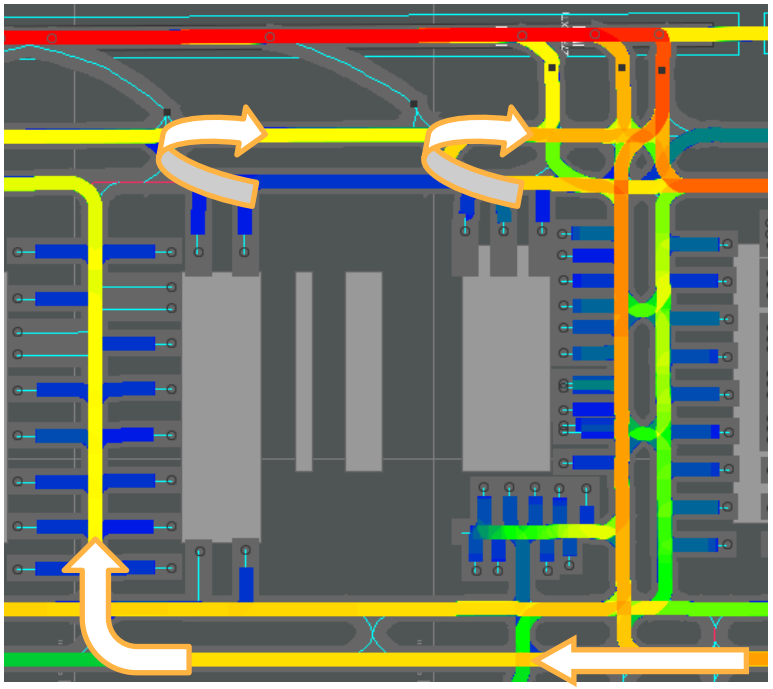


Figure 7: Departure queue bottleneck (27Rext)

Queues at 27Rext can congest the Terminal 5 stand area, or tail back to prevent 27R arrivals from taxiing. Congestion can be avoided by extending the 27Rext queue up the outer taxiway, freeing up the areas of Terminal 5 gates and 27R exits.

Terminal 2 and Terminal 4 departures can remain to the south of the airfield before passing up through Terminal 6, if necessary to clear congestion.

There is heavy use of some areas associated with runway entrances and exits

Overall there is a high level of utilisation of the available taxiways. For westerly operation the dual taxiways to the south of T6 are used, although not extensively but they do alleviate the pressure from other busy north-south routes. The existing taxiway to the west is used but due to the low usage it was not felt that a further North-South taxiway to the west of the airport was required.

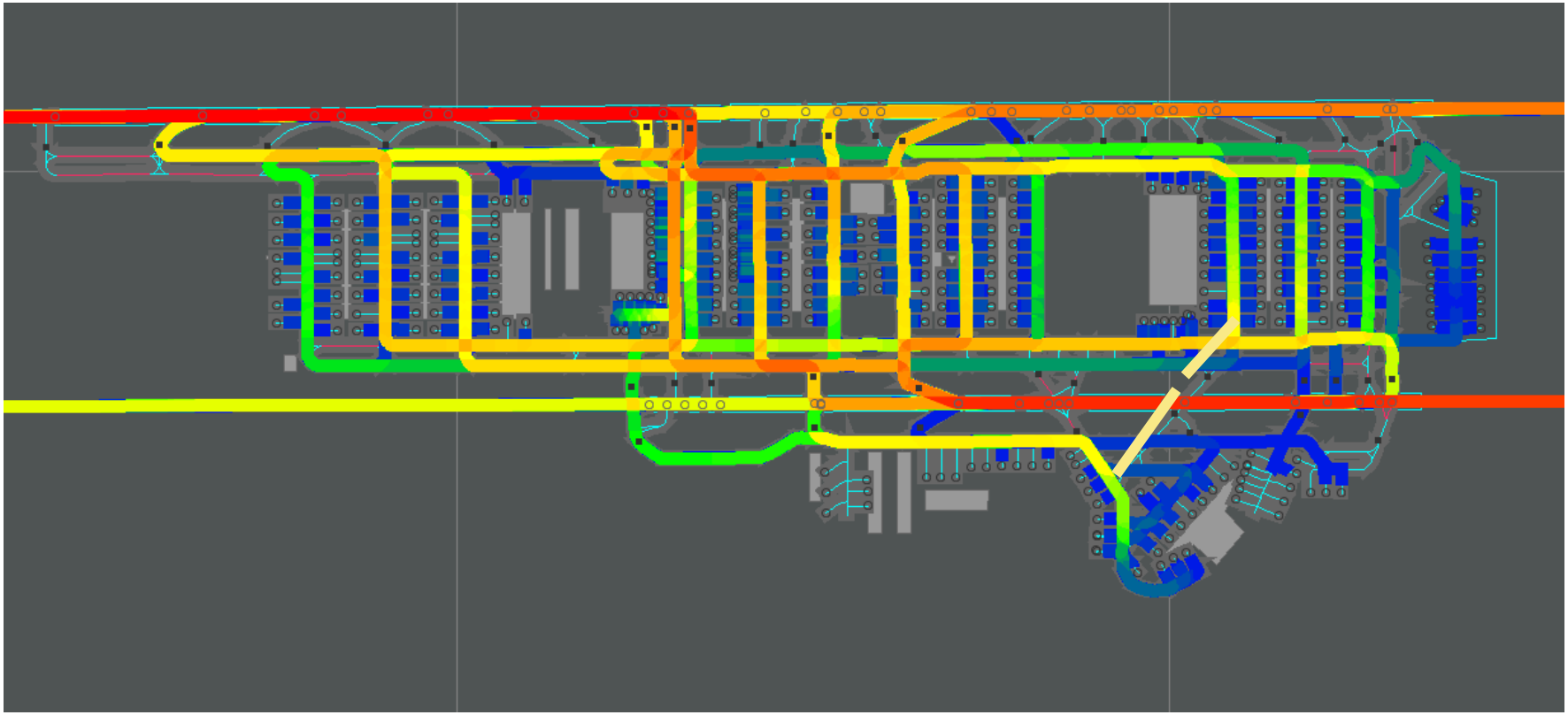


Figure 8: Westerly taxiway heat map

Taxi times and delays due to ground movements

Taxi times and delays

The average taxi time for arrivals excluding ground delays was found to be 6.5 minutes in 2023 and 7 in 2045. For departures these times were 11.8 minutes and 13.8 minutes respectively.

There were some ground movement delays due to taxiway congestion and queueing for departures in both years.

The primary reason for delays was congestion caused by queuing departures especially when arrivals were bunched together at the end of a peak mode. Such matters could be overcome in practice through tactical extension of peak flow modes with a departure preference.

For 2045 push back, taxiing and runway delays became large especially during the relief periods. In the model this combined delay could be over 30 minutes. In practice the available capacity would need to be increased and the peak flow modes will potentially be required to operate for greater portions of the day

The graphs of delay for 2023 are shown in figures 9 and 10.

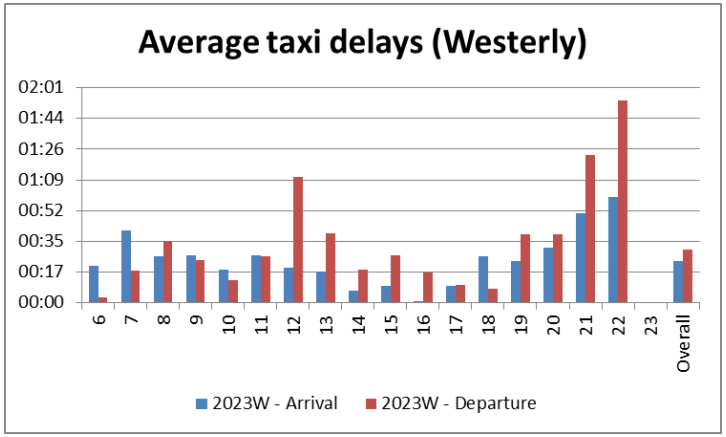


Figure 9: Westerly taxiing delays

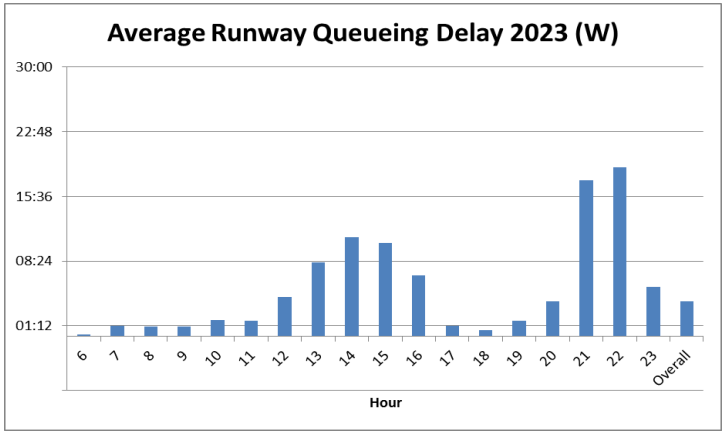


Figure 10: Westerly runway holding delays

Ways to avoid the ground movement delays

Mitigating factors against ground delays

It is anticipated that Ground Movement Controller tool support (e.g. SMAN) will be required. This is required both to plan the optimum taxi routes, taking into consideration other factors, as well as provide guidance to aircrew as to the routeing to take.

Departure Manager will also need to take into consideration the level of queues on the airfield and prevents pushback when congestion is building to prevent significant blockages occurring.

The schedule will need to be optimised to better match the available capacity of both the terminals and the available taxiway network.

On westerly operation in 2045 the relief periods will need to be shorter than we have modelled in order to allow all movements whilst also giving some availability of contingency in case of an issue e.g. an aircraft breaking down on a taxiway etc.

There will need to be clear definition of which runway an aircraft uses for arrival and departure which will need to be taken into account when assessing the terminal allocation during the creation of a live schedule. For example we have given some preferences to the model e.g. Terminal 4 aircraft should arrive and depart from the southern runway but this alone is not enough.

Stand location within terminals will need to be taken into account also to ensure that aircraft are sent to or received from the nearest runway (including RET, holding point etc).

Achieving the necessary capacity requirement in 2045 will require optimisation of the current design

Stand allocation

It was found that in the peak periods (i.e. around 10:00 and 17:00 and there were insufficient stands available to meet the demand in the 2045 scenario.

During both peak periods the model failed to find stands for approximately 30 aircraft. The majority of which had been allocated to Terminal 6. Note that this will partially be a result of the schedule used which was based on the assumptions made. With different assumptions (e.g. aircraft sizes, peak period timings and overall number of flights etc.) the actual shortfall could be lower. A more in depth study of the schedule will be required to determine this fully.

Southern Runway Operation

Due to the reduced level of operation of Terminal 4 there were few flights in the 2023 model that were required to cross the runway. The amount of delay that this created was found to be only a small contribution to overall delay and therefore is not considered as a major factor affecting the operability of the airfield. Due to the stand requirement for 2045 highlighted above if Terminal 4 is removed more stands will be required elsewhere i.e. to the east or west of the central area.

Figure 11: Location of runway crossing

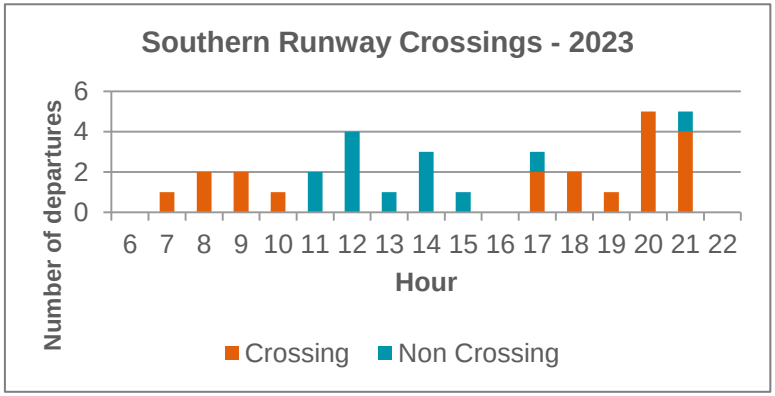


Figure 12: Terminal 4 aircraft crossing runway

Aircraft tows

The towing of aircraft was analysed and delays to the towing operation were not considered significant overall though should be avoided if possible in peak hours. However a balance is needed between stand availability and ease of ground movement.

Model outputs

Easterly operation

There are some areas of congestion which reduces overall runway capacity

Operability

As for the Westerly scenarios there is a high level of ground movements that need managing throughout the day.

Figure 13 indicates the potential congestion zones from fast-time simulation. These are associated with the queuing area from departures on 09L Ext and 09R.

Figure 13: Potential taxiway congestion zones

Due to the time taken to get to and from the runways it was found that the overall capacity per hour was reduced from the runway model. Arrivals took longer to clear the runway and departures could be blocked or did not flow as readily to depart.

Operating Mode	Arrival /hr	Departure /hr	Total
Early respite	48	0	48
Morning peak flow	68	47	115
Southern respite	29	51	80
Afternoon peak flow	57	60	118
Northern respite	55	25	80

Table 4: Achieved maximum flow (2045 Easterly)

Potential bottlenecks will need to be monitored so that mitigation against queues can be introduced

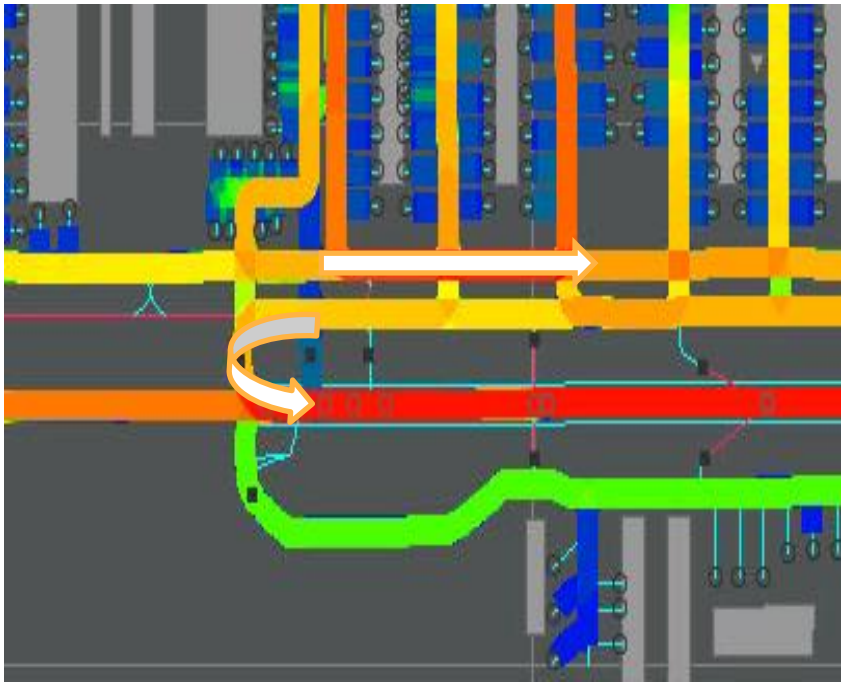


Figure 14: Bottleneck area to 09R

Aircraft queuing for departure at 09R can block aircraft wishing to taxi to Terminal 2 stands, or aircraft wishing to taxi clock-wise around the outer taxiway.

This can be mitigated by ensuring queueing aircraft for 09R use the outer clockwise taxiway to queue, freeing up the taxiways through Terminal 5 gates as cut-throughs for other traffic.

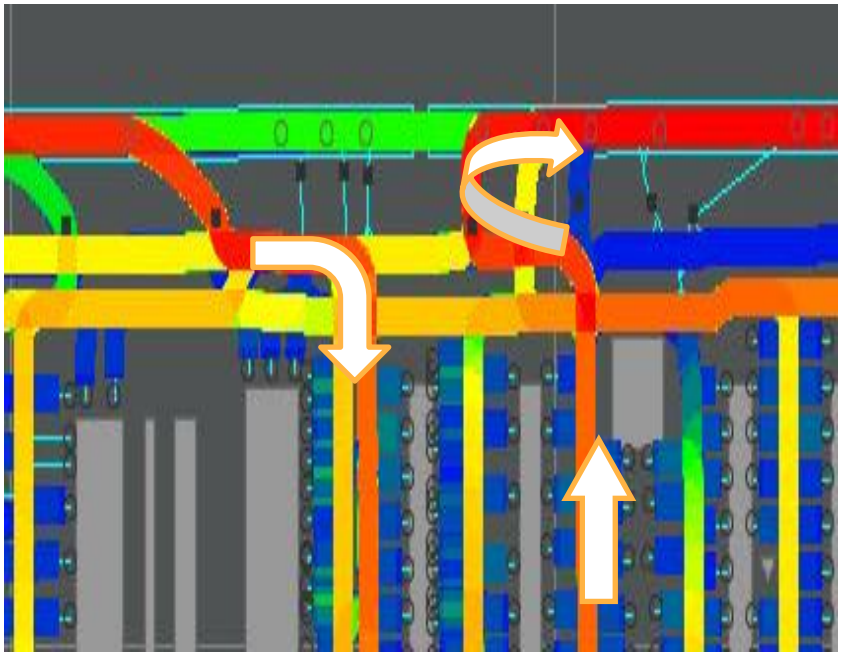


Figure 15: Bottleneck area to 09Lext

Queues at 09Lext can congest the Terminal 5 stand area, or tail back to prevent 09L arrivals from taxiing. Congestion can be avoided through the use of a number of one way systems

Terminal 2 and Terminal 4 departures can remain to the south of the airfield before passing up through Terminal 6 if necessary to clear congestion.

There is heavy use of some areas associated with runway entrances and exits

Overall there is a high level of utilisation of the available taxiways. For Easterly operations the dual taxiways to the south of T6 are not utilised however the existing north-south taxiway in the west is used more extensively than for westerly operation but it was not felt that a further north-south taxiway to the west is required.

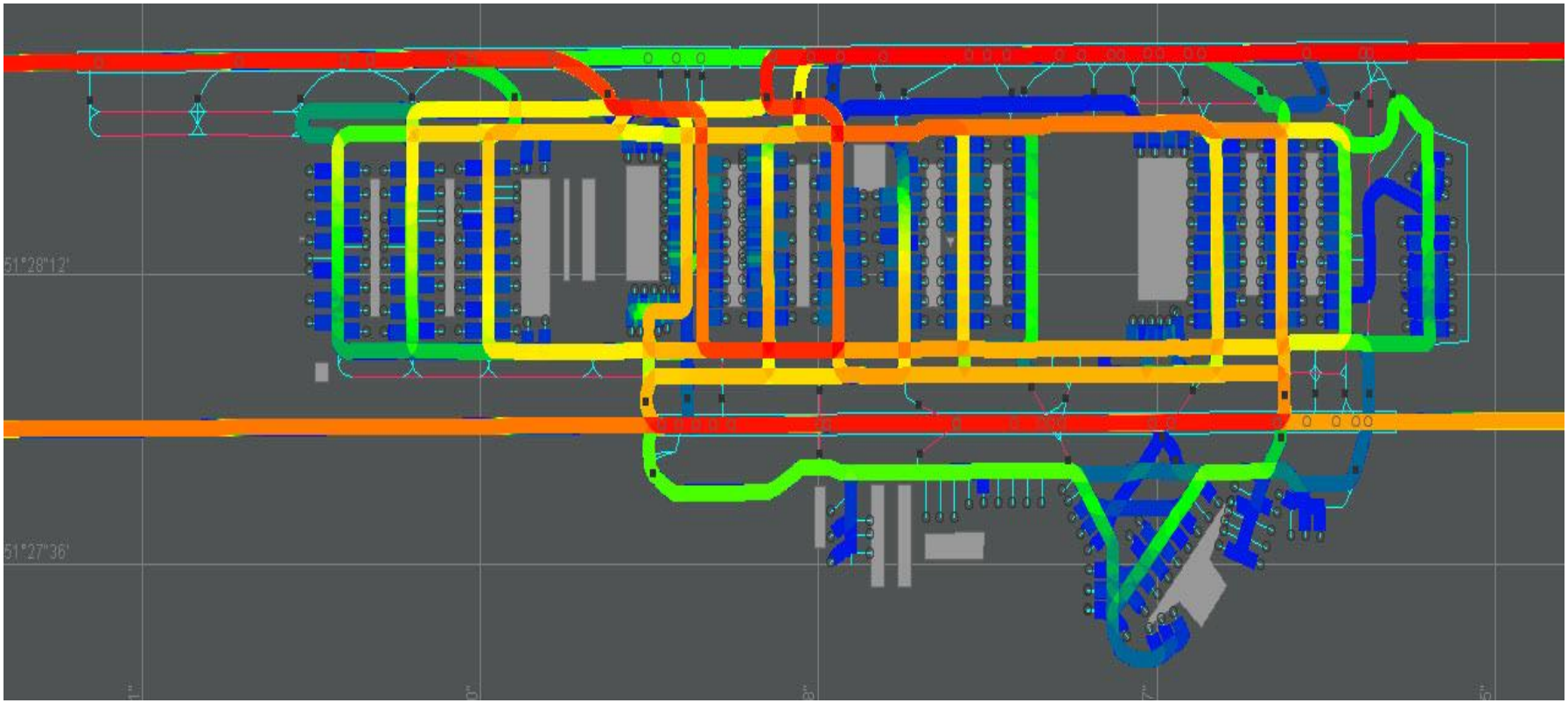


Figure 16: Easterly taxiway heat map

Average Runway Queue time and average runway flow achieved

Taxi times and delays

The average taxi time for arrivals excluding ground delays was found to be 7.8 minutes for both 2023 and 2045. For departures these times were 8.5 minutes.

There were some ground movement delays due to taxiway congestion and queueing for departure in both years.

The main reason for delay was that in the model taxiways became blocked as aircraft queued for departure. Again this was partly due to the arrival and departure runway having a preference set for arrivals. The situation for Easterly operation was worse than for Westerly.

Due to the one way systems and these queues, arriving aircraft were found to potentially be held up for long periods. These occurred in the areas indicated in the previous pages. In 2045 push back, taxi way and runway delays became large during the relief periods. In the model this combined delay could be over an hour.

The graphs of delay for 2023 are shown in figures 17 and 18. Note – no push back delays were seen for 2023.

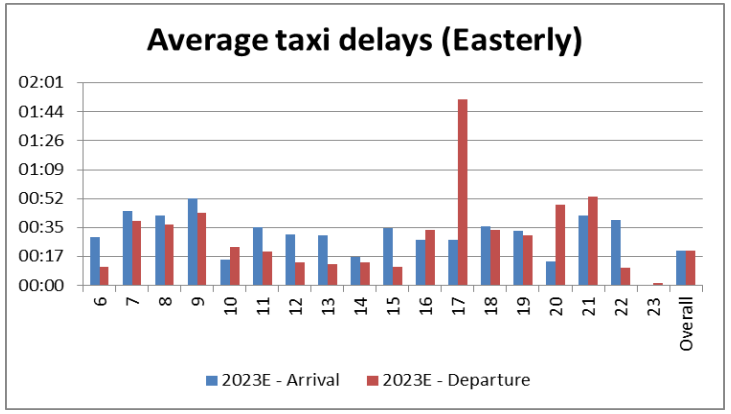


Figure 17: Easterly taxiing delays

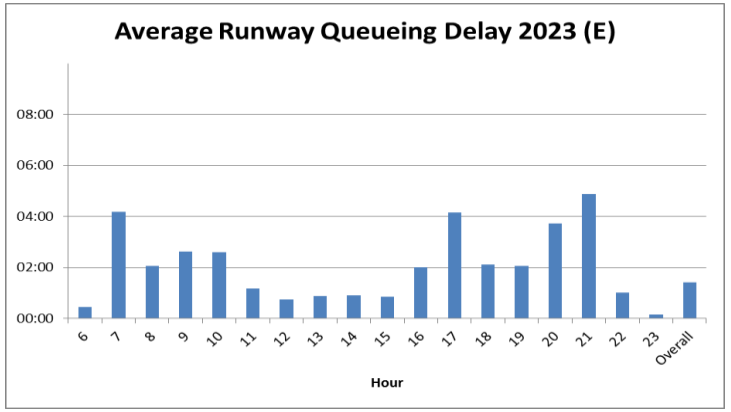


Figure 18: Easterly runway holding delays

Optimisation of the design will be required before 2045 to ensure ground delays are not excessive

Mitigating factors against ground delays

The same mitigating factors will need to be introduced for the Easterly operation as stated for Western above with the following additions.

There may be a need for further taxiway segments or further parallel taxiways to be introduced around the problem areas. This may also allow for some respite as in 2045 with the current layout the relief periods may need to be shortened or removed entirely in order to allow all movements and to give some availability of contingency in case of an issue e.g. an aircraft breaking down on a taxiway etc.

Stand allocation

It was found that in the peak periods there were insufficient stands available to meet the demand in the 2045 scenario even with the use of terminal 4.

During both peak periods the model failed to find stands for approximately 30 aircraft. The majority of which had been allocated to Terminal 6. Note that this will partially be a result of the schedule used which was based on the assumptions made. With different assumptions (e.g. aircraft sizes, peak period timings and overall number of flights etc.) the actual shortfall could be lower. A more in depth study of the schedule will be required to determine this fully.

Southern Runway Operation

There was no requirement for runway crossings due to the location of the ILS for the easterly operation.

Due to the stand requirement for 2045 highlighted above if terminal 4 is removed more stands will be required elsewhere i.e. to the east or west of the central area.

Aircraft tows

The towing of aircraft was analysed and delays to the towing operation were higher than for the Western operation and therefore should be avoided if possible in peak hours. However a balance is needed between stand availability and ease of ground movement.

Conclusions

Conclusions from the modelling

Operability and capacity

The ground operations are complex and the ground movement controller will require automation support to assist with the flows.

The schedule will need to be optimised to better match the available capacity of both the terminals and the available taxiway network.

There will need to be optimisation of which runway an aircraft uses for arrival and departure based on its terminal and stand location.

2023

The operation of the airport is achievable in 2023, though during busy periods some additional optimisations will be required to mitigate delays.

Depending upon these optimisations, peak periods may need to be lengthened to achieve all of the movements required.

2045

In 2045, especially during easterly operations, severe bottlenecks can be caused by departing aircraft queues. Further optimisation of one way systems and the addition of further taxiway segments or parallel stretches may be needed especially to allow more respite as with the current layout peak periods will need to be lengthened to achieve all of the movements.

The model has shown that under the assumptions used to create the schedule there is a shortfall in stands during peak periods in 2045.

In the event that T4 were to be closed additional stands would be required in the central area.

Southern runway operation

Runway crossings during the 2023 operation are not extensive, due to the low use of Terminal 4 and therefore do not affect ground delays.

By 2045, as noted above, Terminal 4 stands plus extras will be required. This means if Terminal 4 is removed its stand compliment and a number of others will need to be created to the east and west of the central area.

Additional taxiway requirement

The dual taxiways to the south of Terminal 6 was used within the simulation and hence is felt to be required however due to the low use of the currently planned north-south taxiway in the west an additional north-south taxiway is not deemed necessary.

Further work would be required by 2045 to ensure that the ground layout did not compromise the ability of the airport to provide respite to the local community.

Towing

The towing operation was not considered a major factor on the overall delays in the airport.