
# CLIMATE RESILIENCE – THE IMPACT OF EXTREME WEATHER EVENTS - A CASE STUDY: HEATHROW AIRPORT

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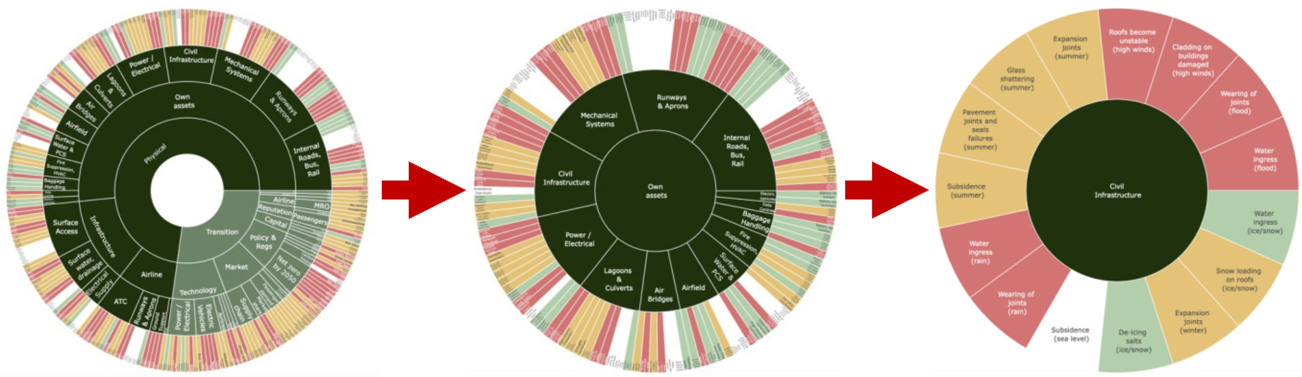
## Abstract

At ICAS 2022, the Climate Resilient Assets Assessment Tool (CRAAT) was described and used, with reference to a number of representative airports, to demonstrate how ICAO guidance could be applied consistently to better inform airport managers [1]. The approach used the sixth iteration of IPCC climate projections, relating them to airport specific design and operational criteria to directly determine climate risks. CRAAT has been developed further to: (i) include the UK subset of CMIP6 climate model outputs; and (ii) provide airport-specific risk matrices, and has been applied to assess the resilience of Heathrow Airport's asset base to extreme weather events that may increase or decrease in likelihood in the future as a result of climate change.

**Keywords:** climate resilience, risk assessment, Climate Resilience Assessment of Assets Tool (CRAAT)

## 1. Introduction

Climate risks are usually considered in terms of transition and physical risks. They are present across the whole business of any airport, including Heathrow. Transition risks are associated with the transition to net zero by the airport operator itself (e.g. Heathrow Airport Limited, HAL), the aviation sector and the economy more widely. Transition risks include: policy and regulation; technology; market; and reputational. Physical risks are associated with the physical effects that climate change will have on assets owned by or relied upon HAL in operating the airport. This also includes the effects of climate change on flight patterns and destination airports. The outcome of a literature review by Susteer of more than 100 publications has identified over 250 climate risks associated with airports (useful synthesis papers include [2],[3],[4],[5],[6] and [7]). Using a climate risk rose, these risks can be categorised with reference to different working areas or functions of the airport and its supporting infrastructure (see Figure 1).




This climate risk rose includes all the individual transition and physical risks relevant to airports with 'missing' risks in the outermost ring indicating risks not relevant to the specific airport being benchmarked.

There is lots of complexity and detail, making the rose difficult to read. This is where the dynamic nature of the tool helps. In this case, the user clicked on "Own Assets" and the rose collapses and expands to include only categories under "Own Risks".

The user can drill down further, to individual risk / opportunity level.

Figure 1 – Example climate risk rose for airports.

In 2002 HAL publicly backed the inclusion of flights in the European Union Emissions Trading Scheme to tackle carbon from air travel. For almost 15 years, HAL has been assessing and reporting on its resilience to physical climate risks and, since 2021, has been providing climate-related financial disclosure on the risks of climate change to the business annually. This work is publicly available via the internet. In February 2022, HAL published its Net Zero Plan [8] based on the three principles of: (i) avoiding the worst effects of climate change requires cutting emissions from today as well as getting as close as possible to zero by 2050; (ii) emissions must be cut as deeply as technically and economically feasible within the aviation sector before other options are considered; and (iii) any offsetting of residual emissions should only be done by removing carbon from the air. Some 95% of carbon emissions at Heathrow are 'in the air', i.e. are associated with aircraft operations, with the remainder being 'on the ground', with 4% from surface access, 1% from the supply chain, 1% from airport vehicles and the remainder from buildings and infrastructure. How HAL will reduce emissions from each of these source categories and remove carbon from the air is described further in the Net Zero Plan. Many, if not all, of these measures to achieve Net Zero are being or are planned to be implemented at other airports. Note that each of these measures represents a climate risk (or opportunity) that is included in the Climate Risk Rose.

HAL has assessed and reported on the physical risk of climate change in 2011 [9], 2016 [10] and 2022 [11]. The latest report, for example, identified 28 physical climate risks associated with climate parameters, including maximum daily temperature, high winds and extreme winter conditions. The work described in this paper builds on this knowledge, providing a more quantified risk assessment approach with significant engagement with asset engineering teams within HAL.

## 2. Methodology

### 2.1 Risk assessment

Climate risks are no different from other risks to a business or organisation that may have an impact on business objectives and can be quantified in terms of likelihood and consequence. Risk encompasses both negative (threat) and positive (opportunity) outcomes.

HAL's Risk Management Procedure (RMP) [12] follows a standard approach in defining risk which is equally applicable to climate risk, noting that an effect is defined by HAL as "a deviation from the expected and can be positive or negative":

*"[Climate] Risk is the effect that uncertainty can have on achieving Heathrow's strategic intents. It is measured as the combination of the likelihood that a specific event will happen and its possible consequences. [Climate] Risks are equally within or outside of our direct control."*

(parentheses in square brackets)

The RMP goes on to describe risk assessment as the overall process of risk identification, risk analysis and risk evaluation:

- Risk identification involves the identification of risk sources, events, their causes and their potential consequences. This can involve review of historical data, theoretical analysis, informed and expert opinions, and consideration of stakeholders' needs.
- Risk analysis is the process of estimating a risk's likelihood and consequence.
- Risk evaluation is the process of comparing the results of risk analysis to determine whether the risk and/or its magnitude (likelihood and consequence) are acceptable or tolerable or whether additional monitoring and controls are required.

HAL's RMP identifies a number of risk sources that have the potential to give rise to a risk, including climate change, which have been reported for more than ten years. The RMP requires the following are considered when identifying risks:

- Have a clearly defined scope so as to make clear which risks should be included and which have been excluded;
- Use a structured approach in order to obtain comprehensive coverage of relevant risks without skipping less obvious problem areas;
- Make use of historical experience, where available, so as to capture the lessons from previous events in the company or industry, as well as being able to reflect on possible lessons from

unrelated industries;

- Be creative so as to encourage identification of risks not previously considered; and
- Consider changes that might have positive impacts as well as events that might prevent strategic intents and business objectives being achieved.

Having identified risk events and their sources, the RMP uses a risk analysis tool (or matrix) to describe the likelihood of the event occurring and its consequences:

- Likelihood is the chance of an event happening. This requires an understanding of the cause of the risk event.
- Consequence is the outcome of an event affecting objectives. An event can lead to a range of consequences and a consequence can be certain or uncertain and can have positive or negative effects on objectives. Consequences can be expressed qualitatively or quantitatively. Initial consequences can escalate through knock-on effects.

The scale of likelihood currently used by HAL includes five categories ranging from 'very low' to 'very high' with further qualitative descriptors provided. Each category also includes a numerical descriptor, from <10% to >80% probability. The scale of consequence currently used by HAL also includes five categories, ranging from 'very low' to 'very high'. Further qualitative descriptors are provided, including a general description of the magnitude of the consequence and indication of the level of management involvement required. These two scales are combined in the matrix to provide a scale of risk rating, from 'Target Risk' to 'Acceptable Risk', with each risk rating including a description of the management control required. As illustrated in Figure 2, the HAL RMP risk matrix is similar to the risk matrix published by the International Civil Aviation Organisation which also uses a five-by-five matrix with the risks of climate change expressed as a function of the probability (or likelihood) of the event occurring and the severity of the consequence of the impacts [13]. The outcome can be referred to as 'risk exposure' and is a measure of the risk that the airport faces in relation to the climate impact. The lower the risk, the more resilient the airport is to climate change.

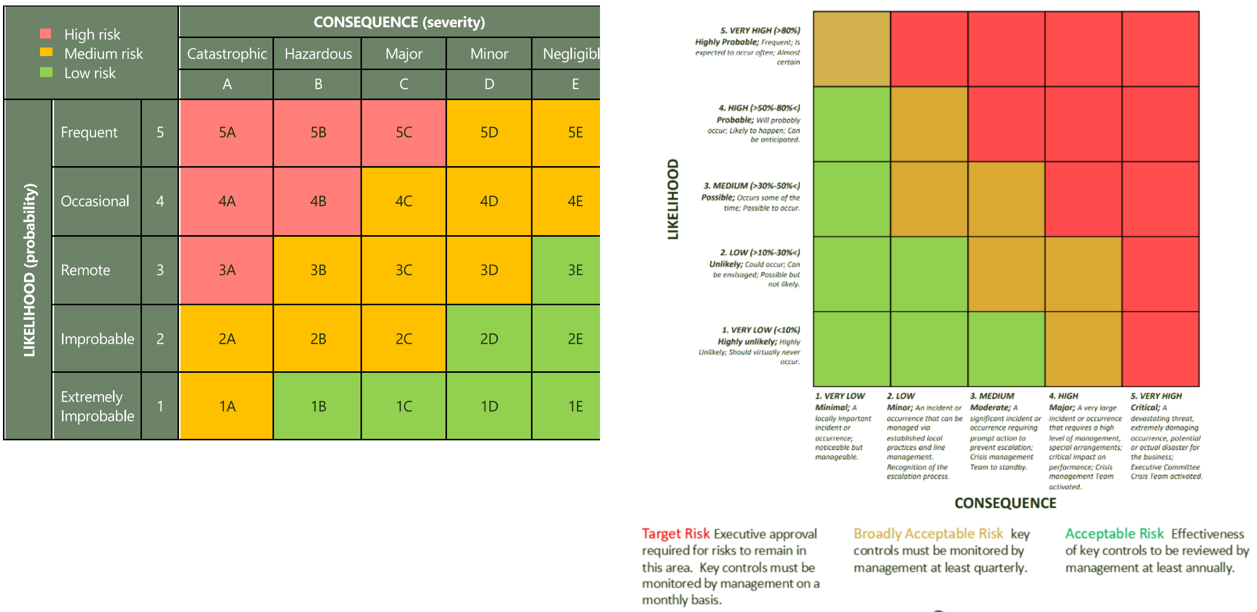



Figure 2 – Risk matrices: ICAO (left) and Heathrow Airport (right).

## 2.2 Scoping and Screening

An extensive list of climate risks has been developed by Susteer - the climate risk profile - that may be associated with airports. This provides the full scope for the assessment of climate risk. The list is structured with four tiers of categories, enabling both a check to be made of whether the coverage of relevant risks is sufficiently comprehensive and to identify lines of responsibility and reporting for individual risks. The first tier identifies whether the risk is transitional or physical. The second tier considers transition risks as either policy and regulation, technology, market or reputational, and physical risks in terms of the airport's own assets, airline operations or supporting infrastructure. The third tier provides a further breakdown in detail, with physical risks for an airport's own assets including 13 tier 3 sub-categories. These three tiers are identified in Figure 3 below. The fourth tier extends the detail of climate risk to identify 268 individual risks and was used to build the climate risk rose presented in Figure 1. The climate risk rose aids communication in being able to illustrate how climate risk for the airport as a whole can be divided into categories and sub-categories. By using the colour of each segment in the outermost ring to represent the risk rating of each individual risk, the key risks can be quickly identified and categorised. This enables the airport operator to quickly identify which team is responsible for individual and collective risks, and provide context when discussing a particular subset, such as the physical risks to an airport's own assets.

| Tier 1 | Tier 2 | Tier 3 |
|---|---|---|
| Transition | Policy and Regulation | National commitment to achieving net zero by 2050 |
| | | Carbon pricing mechanisms |
| | | Regulation on noise pollution |
| | | Emerging environmental regulations |
| | Technology | Net Zero on the ground |
| | | Net Zero in the air |
| | | Disruption from new technologies |
| | Finance & Investments | Access to Capital |
| | | Insurance premiums |
| | | Loss of assets |
| | Market | Market share |
| | | Passenger demand |
| | | Supply chain |
| | | SAF availability |
| | | Positioning as a sustainable hub |
| | | Sustainable Infrastructure Development |
| | Reputational | Investors |
| | | Passengers |
| Physical | Own Assets | Power / Electrical |
| | | Fire Suppression & HVAC Control Systems |
| | | Civil Infrastructure |
| | | Mechanical Systems |
| | | Data Centres |
| | | Electric Vehicles |
| | | Baggage Handling |
| | | Air Bridges |
| | | Runways and Aprons |
| | | Internal Roads, Bus / Rail points of departure and forecourts |
| | | Lagoons and Culverts |
| | | Airfield |
| | | Surface Water and Pollution Control Systems |
| | Airline operations | On the ground |
| | | In the air |
| | Supporting infrastructure | Surface Access |
| | | Electrical Supply |

Figure 3 – Climate Risk Categories for Airports (Tiers 1 to 3).

If required, a preliminary assessment of each risk can be undertaken, using estimates of likelihood and consequence, to identify which risks are not relevant to the airport and which risks require more detailed evaluation (see Figure 1 for an example output). This may be best achieved through internal workshopping, with the likelihood and consequences considered in terms of ‘*expected climate change following a 4ºC world in the period 2050 to 2100*’, for example.

## 2.3 Historical Events

The HAL RMP suggests making use of historical experience to capture the lessons from previous events in the company or industry. This approach was adopted in this work with five extreme and sustained weather events experienced at Heathrow identified and used as the basis for the detailed assessment of physical risks to assets at the airport:

- Hot summer - on 19 July 2022, the temperature reached 40.2ºC at Heathrow Airport.
- Winter ice / snow - from 23 February to 03 March 2018, the minimum temperature remained below zero and dropped to -5.1ºC on 01 March, with freezing rain on five of these days and snow on four.
- High winds - on 31 January 2022 the recorded mean wind speed at Heathrow was 22.8 m/s with peak gusts of 67 m/s.
- Intense rainfall - on 12 June 2023, 25mm of rain fell at Heathrow Airport over a period of two hours.
- Cumulative rainfall event - the relationship between cumulative rainfall and flood risk at Heathrow airport is complex. In addition to the efficacy of the on-airport drainage network, the water catchment response is important, and is affected by existing surface and groundwater levels which will vary as a result of periods of drought or cumulative rainfall. The water catchment area that includes Heathrow is large, extending to the Chiltern Hills (c.30-40 km to the northwest), and rainfall patterns will vary over this area. Moreover, other land uses will also affect drainage and water catchment responses, and the need to include external stakeholders in both the assessment and management of flood risk is evident.

Figure 4 includes an extract of some of the data used to build up the description of historical event at Heathrow.

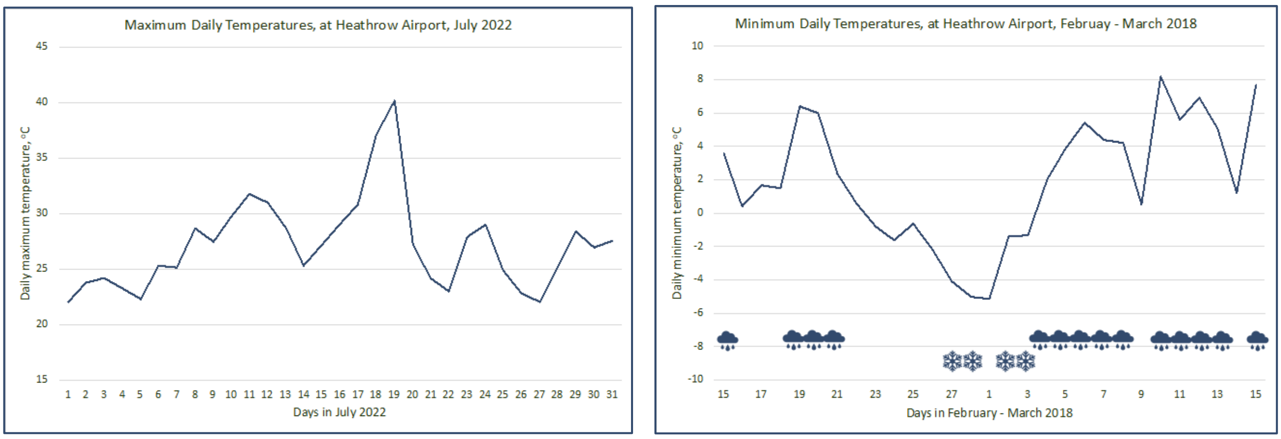



Figure 4 – Extreme weather events Heathrow: hot summer day (left) and winter snow (right).

## 2.4 Describing Consequence

A series of workshops were held to consider the consequences of each extreme and sustained weather event in terms of:

- Which assets were affected and how?
- Were we able to fix any problems immediately?
- Were there any residual effects?
- What could be included in asset management plans to reduce any consequences if the event happened again?

- What if the weather conditions had been more extreme (i.e. 'stretched')?

These workshops were attended by the engineering and sustainability teams of HAL. The outcome is a documented analysis of the consequence of each event, described as either negligible, minor, severe, major or catastrophic with reference to HAL's RMP. This was repeated for a notional 'stretched' event with more extreme climate conditions considered. In addition to capturing practical details on the consequence of actual extreme and sustained weather events when they occurred, reference to real events also had the benefit of increasing interest for the workshop delegates. This included moments of storytelling with delegates describing their personal experiences during these events, all of which increased active engagement and hence, the value of holding the workshops.

## 2.5 Quantifying Likelihood

The likelihood of each extreme and sustained weather event was quantified by: (a) defining each event in terms of its cause, magnitude and duration; and (b) statistical analysis of climate modelling data to determine the probability (likelihood) of that event happening in the future.

The cause of a physical event is expressed using standard weather parameters or variables, such as maximum daily temperature, minimum daily temperature, daily precipitation, etcetera. The magnitude is the numerical threshold, e.g. >40$^{o}$C or <0.1 mm. The duration refers to the number of days the event would occur over (e.g. maximum 1 day, 5 consecutive days, etcetera). The definitions of each extreme and sustained event will be specific to individual airports.

The likelihood of each climate event is determined using published climate modelling data. At a global scale, the Coupled Model Intercomparison Project, now in its sixth iteration (CMIP6) [14] brings together resources of some 134 climate models from 53 modelling centres around the world, requiring the climate models to be run with an agreed set of input parameters (forcings) and configured to produce a set of standardised outputs. The UK participates in this project and, like a growing number of countries, produces its own national dataset, currently referred to as UKCP18 [15]. At any given location, the UK ensemble of climate models includes climate data from a selected set of 12 models. The global ensemble of climate models typically includes data from 15-25 models and for more parameters. Both UKCP18 and CMIP6 have been used to determine the likelihood of events occurring.

For a climate period of 20 years, the UK ensemble generates 240 'modelled years' of data and the global ensemble 300-500 'modelled years' of data. In both cases, the probability or likelihood is determined as the percentage of modelled years which return a positive value for the specific climate event. For example, if we have 240 modelled years and the maximum daily temperature exceeds 40$^{o}$C in 113 of those modelled years, the likelihood is 47%. This would be considered 'Possible' using the HAL scale of likelihood (see Figure 2).

The likelihood of each extreme and sustained event was quantified for time periods that relate to HAL specific business planning cycles as well as time frames used by the Intergovernmental Panel on Climate Change (IPCC) [16]. The time periods used in this assessment are included in Figure 5.

| Time Period | Name | Description |
|---|---|---|
| 2022 – 2026 | H7 | Heathrow is subject to regulations specifying the quality of the services the airport operator must deliver and how much it can charge for them. The current regulatory period is H7. |
| 2027 – 2031 | H8 | |
| 2032 – 2036 | H9 | |
| 2021 – 2040 | IPCC near term | These descriptions are used by the IPCC in its Assessment Reports. |
| 2041 – 2060 | IPCC mid term | |
| 2081 – 2100 | IPCC long term | |

Figure 5 – Time Periods.

## 2.6 Climate Risk Evaluation

The evaluation of climate risks was undertaken by first collating the assessment results for each physical risk cause (i.e. hot summer, winter snow/ice, high winds, intense rainfall, cumulative rainfall) and for each time period. The collated results were then presented on the HAL RMP risk matrix to provide a simple visualisation of which risks are ‘acceptable’, ‘broadly acceptable’ or a ‘target’ risk. How the risk may change over time as the likelihood of a climate event occurring increases or decreases is seen by displaying side-by-side a separate risk matrix for each time period.

The second stage of climate risk evaluation was to specifically identify ‘target’ risks for further evaluation, determining whether additional work was required to assess the need for additional resilience measures beyond those already present at the airport. This was used to draw up a set of recommendations for internal use.

The third stage of climate risk evaluation was to understand if the risk is financially material. In the context of physical risks to HAL’s own assets, the focus was on how these risks might affect HAL’s operational resilience and reputation.

## 3. Results

### 3.1 Scoping and Screening

The outcome of the preliminary scoping and screening indicates that climate change represents a physical risk across Heathrow’s asset base with a total of 33 individual target risks identified. Of these target risks, rainfall is identified as the cause for 14, hot summers for 11, high winds for six and snow / ice for two. The five events identified from the analysis of historical data were all identified as potential target risks.

### 3.2 Consequence

An example of the type of output that can be generated from internal workshops to assign consequences to each event is summarised in Figure 6.

| Consequence | Cause and Potential Consequence |
|---|---|
| Medium | • High winds on civils<br>• Hot summer and high winds on mechanical systems<br>• Hot summer and high winds on baggage handling<br>• Hot summer, intense rainfall and cumulative rainfall on mechanical systems<br>• Winter ice / snow on Air Bridges<br>• Winter ice / snow and intense rainfall on Roads, Rail and Forecourts<br>• Hot summer on lagoons and culverts<br>• High winds on the Airfield<br>• High winds and intense rainfall on Surface Water System (including Pollution Control System and biodiversity) |

Figure 6 – Example Consequences.

### 3.3 Likelihood

For all periods, the likelihood of hot summer and winter ice / snow events is predicted to be ‘low’ or ‘very low’ on the scale of likelihood used in the HAL RMP. The likelihood of high wind events is’ very high’ over all periods. There is some difference in the likelihood of the stretched high wind event depending on the climate model dataset used, with the UKCP18 dataset indicating a ‘medium’ likelihood and the CMIP6 dataset indicating a ‘very high’ likelihood. The likelihood of intense rainfall events moves from ‘medium’ during periods H7 and H8 to ‘very high’ during H9 and in future periods. The likelihood of cumulative rainfall events remains within the range ‘low’ to ‘medium’ for all periods.

### 3.4 Climate Risk Evaluation

The results of using the detailed consequence and quantified likelihood analysis provides an evaluation of climate risk for each event. Example results are presented in Figure 7 for a hot summer day event. The top row includes asset management categories (e.g. ‘civil engineering’, ‘power/electrical’, etcetera, denoted by the letters ‘A’ to ‘M’) with the results for the hot summer day event and stretched hot summer day event (denoted with a small ‘s’, e.g. ‘Cs’ or ‘Ds’) overlaid onto HAL’s RMP risk matrix. The middle row is the risk rose identifying individual risks for the hot summer day event and the bottom row identifies individual risks for the stretched hot summer day event. Note that some risks only occur with the stretched event. The results shown here include periods of five years and 20 years. Climate risks associated with hot summer days are all expected to be 'acceptable' or 'broadly acceptable' for earlier periods. However, by the period 2061-2080, there is an increase in the likelihood of hot summer days that meet the defined threshold, with some additional 'broadly acceptable' risks being identified. No 'target risks' were identified. This analysis was undertaken for each of the five events identified from the investigation of historical data.


A - Power / Electrical systems. B - Fire Suppression and Control Systems. C – Civils. D - Mechanical Systems. E – Data Centres. F – Electric Vehicles. G - Baggage Handling. H - Air Bridges. I - Runways and Aprons. J - Roads, Rail and POD and Forecourts. K - Lagoons and Culverts. L – Airfield. M - Surface Water System, PCS. (s - denotes 'stretched' event)

Figure 7 – Example Climate Risk Evaluation – hot summer.

This evaluation of climate risks can be extended to consider: (i) the need for further evaluation; (ii) operational resilience; and (iii) reputation. An example of this is presented in Figure 8.

| Risk | Operational Resilience | Reputation |
|---|---|---|
| Airfield: increased risk of delays due to de-icers being blown off in uncontrolled areas | Very low impact – can be addressed by operational management | - |
| Baggage handling: increased risk of delays due to stored units, even when secured, becoming loose and damaging planes and buildings | Very low impact – can be addressed by operational management | - |
| Civils: reduced passenger experience, congestion and delays due to cladding on buildings being damaged, requiring maintenance likely to disrupt normal building use | Low impact - can be addressed by operational management but has the potential to disrupt passenger flows. | Medium impact – depends on the scale of damage or if the cladding falls off; images likely to be distributed via social media |
| Civils: reduced passenger experience, congestion and delays due to roofing and inflatable roofs | Low impact - can be addressed by operational management but has the | Medium impact – depends on the scale of damage or if the cladding falls off; images |

| Risk | Operational Resilience | Reputation |
|---|---|---|
| becoming unstable. This may result in damage that requires maintenance likely to disrupt normal building use | potential to disrupt passenger flows. | likely to be distributed via social media |
| Power / electrical: wind damage to roofs of electrical enclosures and failure leading to water ingress with asset life shortened, increasing need and cost for service, maintenance and replacement | Medium impact – requires recognition of increasing need and cost for service, maintenance and replacement | Low impact – unlikely to be seen by the public |
| Air bridges: impact from wind load can cause air bridge to move and be damaged in consequence | Low impact - can be addressed by operational management but has the potential to disrupt passenger flows. | Medium impact – depends on the scale of movement; images likely to be distributed via social media |

Figure 8 – Example Climate Risk Evaluation – high winds.

## 4. Concluding Remarks

This paper demonstrates a robust methodology for climate risk assessment, building on previous work by Susteer, sector specific and best practice guidance including from the ICAO. Examples of how the methodology can be applied are presented with reference to the risk management procedures used by HAL. A generic climate risk profile for airports has been developed, offering a framework for assessing both transition and physical climate risks. This profile can used for screening risks relevant to a specific airport. This paper goes on to describe how the consequence of physical risk events can be determined, drawing on the knowledge and experience of the airport's staff, and how the likelihood of these events occurring can be quantified using the output of climate models. Example climate risks are evaluated using HAL's risk matrix although the same method could be applied to any airport's risk matrix. Further risk assessment was also conducted, considering the need for additional evaluation, operational resilience and reputation.

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## 6. Copyright Statement



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