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Enabling real-time collaborative decision-making between airport and surface transport operations

Edgar Jimenez[a]*, Juan Blasco-Puyuelo[b], Ruben Alcolea[b], Raquel Salamanca[c], Henrik Rothe[a], Rich Moxon[a]

a Centre for Air Transport Management, Cranfield University, College Road, Wharley End, MK43 0AL, UK
b Nommon Solutions and Technologies, Pl. de Carlos Trias Bertran 4, Madrid, 28020, Spain
c ISDEFE, Calle Beatriz De Bobadilla, Madrid 28040, Spain

Abstract

Current developments in collaborative decision-making in the air transport context are restricted to airport and air traffic management operations and stakeholders, disregarding the relevance of airport access and egress in the door-to-door journey for passengers. This paper summarises the IMHOTEP (Integrated Multimodal Airport Operations for Efficient Passenger Flow Management) concept of operations, which extends Airport Collaborative Decision-Making implementations by incorporating surface access. Enhanced situational awareness achieved by extending the monitoring of passenger flows beyond the airport boundaries improve resource allocation and last-minute capacity utilization. It also facilitates the identification of passenger connectivity requirements in terms of links to ground services.

Keywords: Data sharing and ownership; Inter-modality; Innovative hubs; Sustainable and integrated airports; Reliable and seamless connectivity for passengers

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1. Introduction and background

In Europe, the strategic priorities set out in the European Commission white papers on transport have been evolving. The guiding principle of the 1992 policy document was opening up (i.e. liberalising) the transport markets, which resulted in spectacular growth for aviation but proved difficult for railways. The 2001 paper focused on shifting the

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* Corresponding author. Tel.: +44 1234 754257.
E-mail address: e.jimenez@cranfield.ac.uk

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balance between transport modes, with a clear intention to favour rail transport, decrease dependency on road traffic and harmonise growth in air travel with environmental concerns. The 2001 paper understood intermodality as favouring competition between modes and identified the over-fragmentation of ATM systems as a source of inefficiencies that affect air travel competitiveness (European Commission, 2001).

The 2011 paper recognised important achievements, particularly in the implementation of high-speed rail (HSR) and the launch of the Single European Sky, as well as important limitations in developing a sustainable transport system. Crucially, by explicitly stating that "curbing mobility is not an option", this white paper changed the focus towards co-modality and the need to use "the most efficient (combination of) modes" in "three major transport segments: medium distances, long distances and urban transport" (European Commission, 2011).

Yet, limiting the effects of climate change must be a priority (IPCC, 2007) and surface access and egress is responsible for 50% of the local impact at airports (Community Observatory on airport capacity, 2013, p. 17), thus intermodality provides an exciting opportunity to tackle sustainability in aviation by reducing the use of private vehicles and increasing the share of public-transport to and from airports.

Surface access and egress is a key challenge for airport planners and operators (de Neufville & Odoni, 2013, p. 613). It is also a crucial aspect in intermodality involving air transport and the challenging ambition to ensure door-to-door trips below 4 hours in the European context (García-Albertos et al., 2020). The airport access paradigm has progressively supplemented the encouragement of private car use, based on building parking facilities and links with the main road system, with the integration of airports to public transport systems (Budd et al., 2016). Indeed, the integration of airports with HSR networks has gained importance, and it is seen as way of complementing air transport by absorbing part of the demand for short-haul flights, releasing airport capacity that can be used for long-haul flights (Givoni and Banister, 2006). However, despite these efforts, private cars and taxis still play a dominant role in airport access (DLR, 2010).

Digitalisation is a key enabler not only to develop multimodal travel information and ticketing, but also to facilitate information sharing and coordinated decision making across all stakeholders along the transport value chain (European Commission, 2017, 2018). Some airports provide onward travel facilities (so called OTC's – Onward Travel Centres – e.g. at London Heathrow and London Luton Airport) or simply information desks and monitors, which combined with wayfinding, aids passengers in making their decisions about the best alternative for surface egress. In addition, airports have extensively used their websites as the point of contact with passengers to provide information about surface transport alternatives. Airports also embed third-party applications within their websites to allow passengers to plan their journeys to or from the airport. Information available through such applications normally depends on the provision of local authorities or transport operators and may not be complete, particularly regarding public transport options; which leads to individual transport alternatives (private car, car hire, taxi and ride-hailing, for instance) being more prominently presented in many cases.

In order to ensure efficient modal choices, transport networks need to improve integration, particularly at transfer nodes such as airports. Information systems, data availability and interoperability are crucial to facilitate multimodal travel, especially from the perspective of the passengers. The rise in mobility solutions provided by multiple operators hinders seamless coordination along the entire journey as well as the allocation of responsibilities during disruptions. This affects the resilience provided by the transport systems and decreases the likelihood of passengers preferring intermodal alternatives.

The Community Observatory on Airport Capacity (2013) recommends accurate and timely communication with passengers, "including prompt information on delays and rerouting options of all modes". This is something that current access to mobile devices and the data they generate facilitate but still needs to be implemented and tested at a large-scale, considering aspects like liability and differences in passenger rights, taxation and verification of travel across modes, as well as the integration into existing control centres of airports and surface access providers.

Airport Collaborative Decision-Making (A-CDM) implementations enable (air transport) stakeholders affected by a certain decision to share information and agree on a decision-making approach that improves the overall system performance, while balancing against their individual performance needs (Eurocontrol, 2017). A-CDM has delivered a variety of benefits, including time and fuel savings, reduction in delays, improved resource utilisation, better management of adverse conditions, and more accurate prediction of aircraft take-off time (Eurocontrol, 2016). Total Airport Management (TAM) is being developed to improve the integration of airports into the Air Traffic Management network relying on real-time information sharing (Eurocontrol, n.d.). Yet, both applications are confined to air-side airport operations and stakeholders, reducing the potential to impact the whole door-to-door journey and improve passenger experience.

To overcome these limitations, the tools developed for the IMHOTEP Project (Integrated Multimodal Airport Operations for Efficient Passenger Flow Management) extend information sharing to the access and egress legs of air trips, as well as to passenger flows inside airport terminals. This paper presents the Concept of Operations developed for the project to enable real-time collaboration between airport and surface transport stakeholders and improve decision making.

2. Extension of the A-CDM concept

The IMHOTEP Concept of Operations (ConOps) has been developed with the aim to extend A-CDM to surface transport stakeholders, including local transport authorities, traffic agencies, transport operators and mobility service providers. It represents a transition from a flight-centric to a passenger-centric approach that considers the entire door-to-door journey as the central element of information. The ConOps materialises in the A-CDM_Extended system, which collects information about all the passengers who will use an airport on a given day through the different stakeholders involved in their journey, including the passengers themselves, and forecasts their itineraries. By aggregating information of all passengers, it is possible to plan every stage of the door-to-door journey and optimise both the surface transport and airport services based on real-time information. The system can also inform stakeholders about incidents and disruptions, so that they can re-plan their operations and provide alternatives to the passenger to minimise the impact on the initially planned trip.

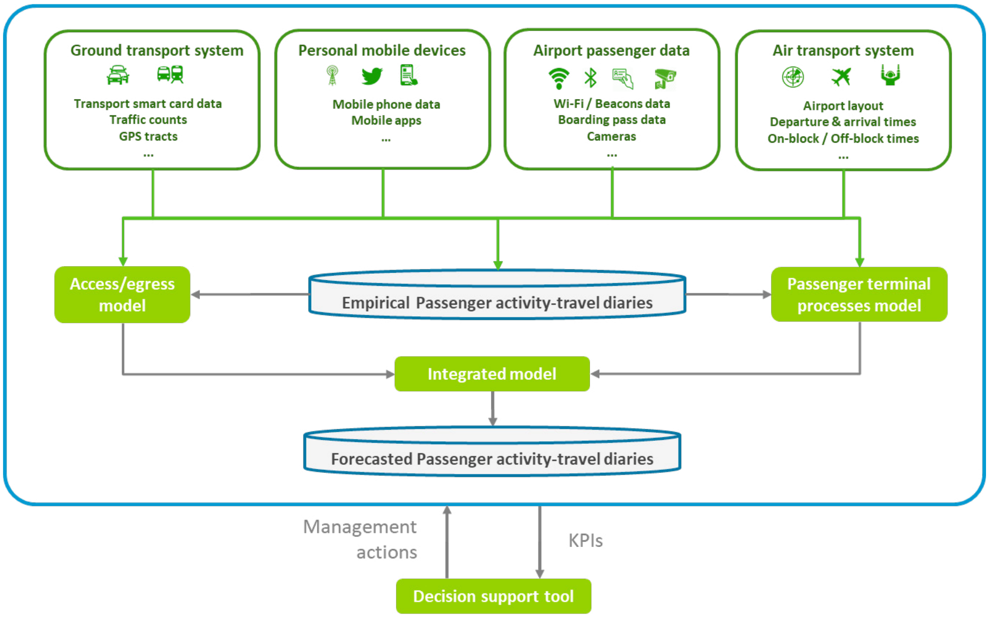

Fig. 1. High level architecture of the IMHOTEP decision support tool.

Fig. 1 shows how different sources of information feed two simulation models, one traditional four-step transport model for the surface access and egress legs and an agent-based model for the passenger processes in the airport terminal. Both models are validated using empirical information collected from the original sources. The results of the simulations are integrated to forecast the itineraries of the passengers expected at a given airport in a particular day and feeds a visualisation tool that enable relevant stakeholders to monitor key performance indicators (KPI) and make decisions based on their actual values. These management actions feed back into the models to simulate their expected effects.

The KPIs enable situational awareness for all stakeholders to: i) optimize normal operations, ii) manage special events, iii) manage surface-transport disruptions, and iv) manage flight disruptions. Moreover, the implementation of data sources that enable passenger profiling may enable additional functionality, such as the personalisation of the passenger journey based on their characteristics and those of their trips, the development of an integrated system that provides real time information back to passengers, or the development and support of off-airport activities.

2.1. Passenger Activity-Travel Diary

The A-CDM_Extended system is built using the concept of a Passenger Activity-Travel Diary (ATD) as the fundamental item of information. An ATD contains the sequence of activities and trip stages performed by each passenger (see Fig. 2 for a graphical representation, in technical terms the ATD is a data table containing records of timestamps with associated attributes for every passenger-journey). Each activity or stage of the journey includes a start time, a start location, an end time, an end location, and a set of additional attributes selected from a list of pre-defined options for each type of activity or stage (e.g., the activity prior to the trip of a departing passenger or the subsequent activity to the trip of an arriving passenger contains an attribute called 'activity type' that may take different possible values: 'home', 'work', 'leisure', etc.; the access and egress legs contain an attribute called 'transport mode' that may take the values 'rail', 'metro', 'bus', 'private car', 'taxi', etc.).

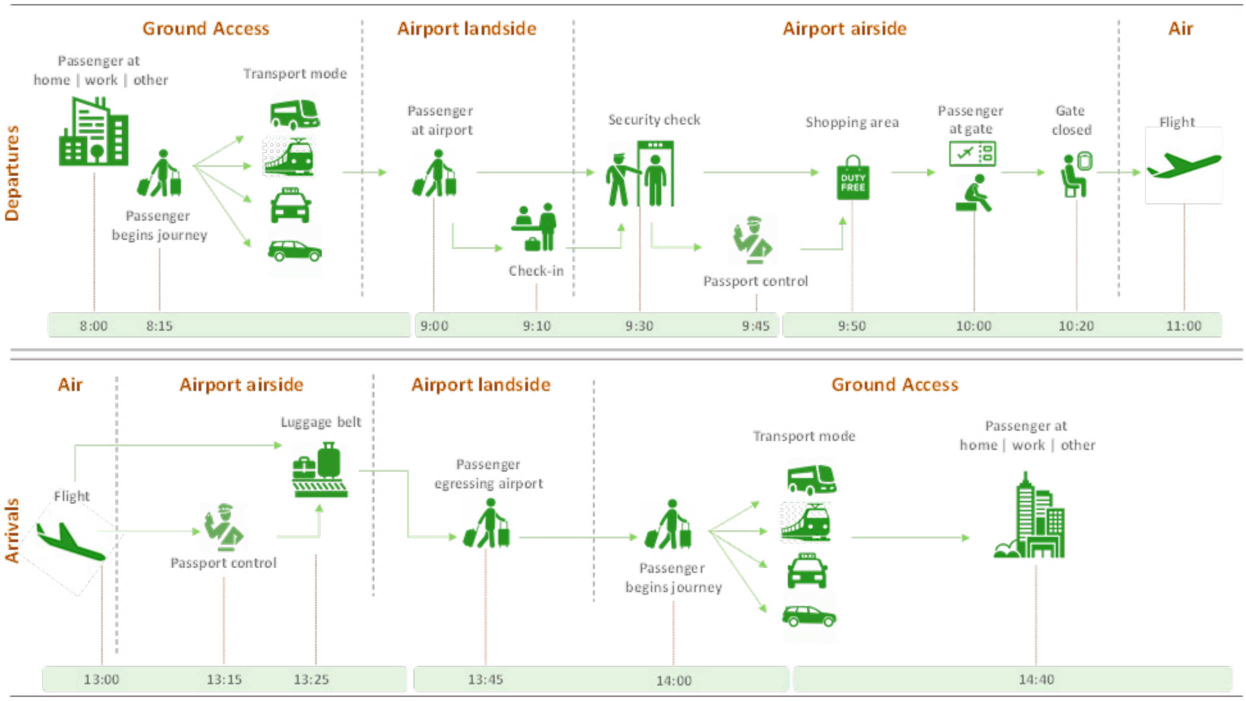

Fig. 2. Visual representation of an exemplar Passenger Activity-Travel Diary (ATD).

For each passenger using the airport, an ATD is created using the two predictive models presented in Fig. 1 (access/egress and airport terminal) prior to the day of operations, and is then continuously updated as more information becomes available as operations unfold. Reconstructing the actual characteristics of individual inter-modal trips in the ATD involves a sequential process that relies on a novel combination of several data sources (see Fig. 3).

First, a basic ATD is identified from mobile phone data records. This stage defines the main characteristics of the trip (origin-destination, duration of stay, outbound/inbound, arrival/departure) and passenger profile (demographics, passenger/worker/driver). Fig. 4 illustrates the use of mobile phone records to identify a departing leg of an air trip, enabling the creation of a basic ATD (Burrizea-Galán et al. (2022) provide more details on this). In the second stage, airport flight schedules are used to adjust the number of trips detected using mobile phone data to ensure agreement with the expected number of total passengers. This stage adds information about the specific origin/destination, flight number, departure/arrival time and terminal gate.

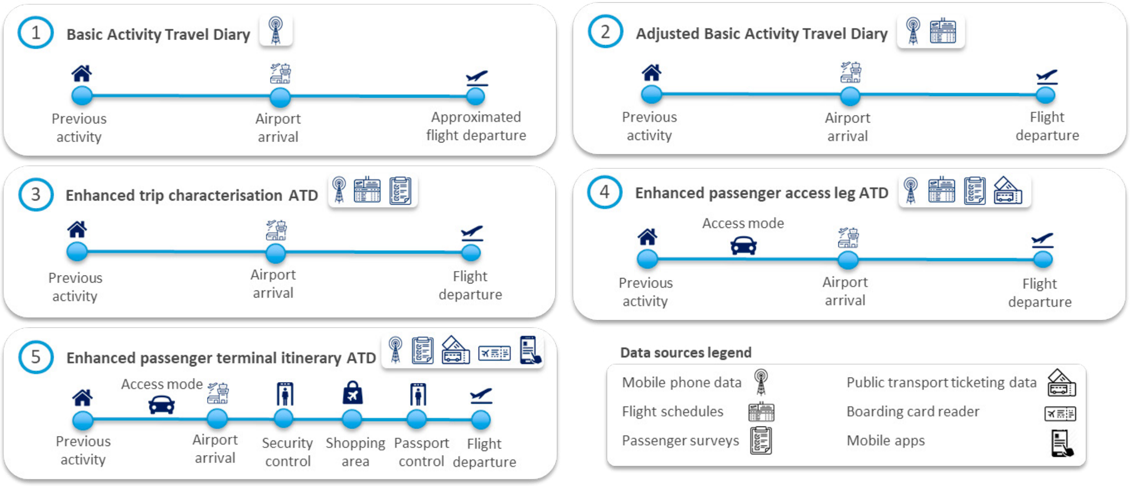

Fig. 3. Reconstruction of the Passenger Activity-Travel Diary.

Fig. 4. Example of the use of mobile phone records to identify a departing passenger and their potential activity and coarse trajectory to the airport (additional intermediate locations are omitted in this sequence).

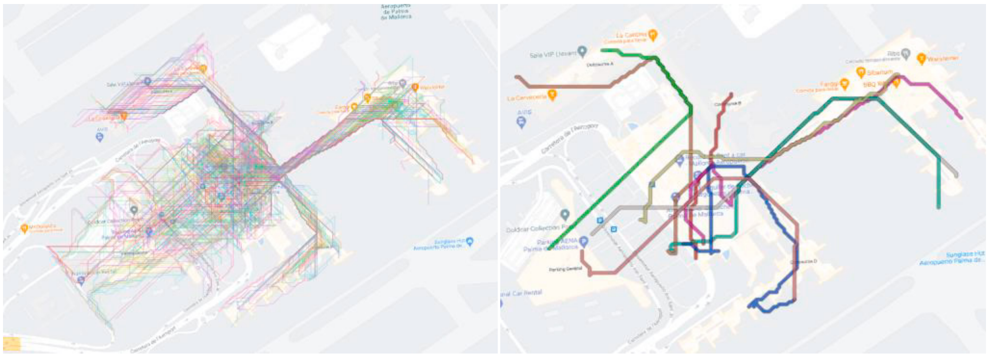

Fig. 5. Example of passenger trajectories identified within the terminal facilities at Palma de Mallorca Airport (left), along with the most representative ones (right).

The third stage enhances trip characterisation by identifying the purpose of the trip (business/leisure) using data from passenger surveys and mobile phone records. Stage 4 enhances the surface access/egress leg by introducing public transport ticketing information, or the lack thereof, which allows the identification of access mode. Both stage 3 and 4 are built around machine learning algorithms. Finally, Stage 5 updates the passenger itinerary by considering the use of airport terminal facilities (see Fig. 5) with recourse to automated boarding card readers (for instance, to prove the passenger status before gaining access to security control) and mobile apps tracking information. All records are anonymised and do not allow for the identification of individuals.

3. A-CDM_Extended functions

The IMHOTEP ConOps establishes the A-CDM_Extended system comprising five functions that define where the data is collected from and how it is used in both models to create and update the ATD (see Fig. 6). Function #1 creates a baseline ATD based on forecasted information. As such, it provides an initial picture of the flows of departing, connecting and arriving passengers at one particular airport prior to the day of operations, which is then continuously updated as more information becomes available during the day of operations, so that the latest update is always available from the A-CDM_Extended system. This would allow different stakeholders (e.g. ground transport operators, airport operators, airlines, ground handlers) to allocate their resources more efficiently.

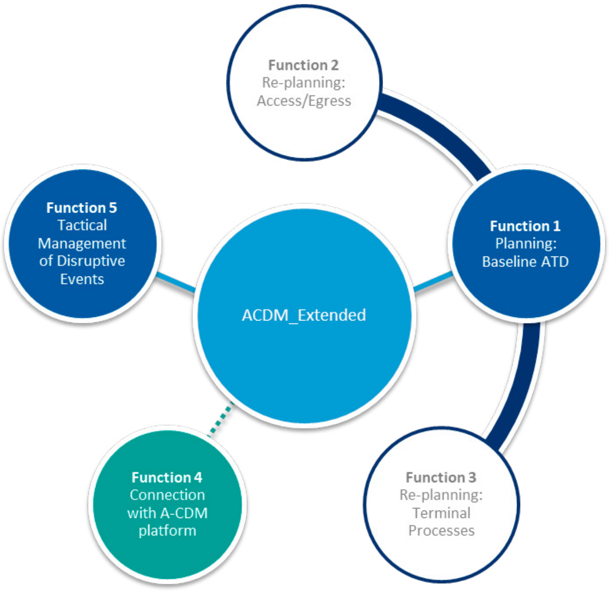

Fig. 6. Schematic representation of the A-CDM_Extended functions.

Function #2 updates the access/egress model with real-time data on the actual state of transport networks and services. In the case of passengers accessing the airport, the updates on the passenger arrival to the airport will trigger Function #3 in order to update the section of the Passenger ATD that concerns the terminal processes. In the case of arriving passengers, the information regarding the passengers egressing from the airport will be used as an input for Function #2 in order to forecast the passengers' egress leg accordingly. Updates use real-time data collected during the day of operations.

One of the premises of the A-CDM_Extended concept is that it should enable its implementation into both CDM and non-CDM airports. Therefore, instead of envisioning this new platform as an extension of the current Airport CDM Information Sharing Platform (ACISP), it has been defined as an independent platform which can be used by any airport without the need of having an ACISP previously implemented. Nevertheless, for A-CDM-enabled airports, Function #4 connects the ACISP with the A-CDM_Extended so that both platforms can exchange information.

Finally, Function #5 is defined for the tactical management of disruptive events by triggering alarms when a deviation from normal operations is identified. The objective of this function is to support the collaborative management of disruptions that could appear during the day of operations. When a deviation from normal operations is greater than a certain threshold previously established by the stakeholders involved in the system, the disruption management process will be initiated through Function #5. The deviation is assessed through the KPIs as defined in the high-level architecture of Fig. 1, and the management process is triggered by stakeholders made aware by the decision support tool that visualises the KPIs in real time.

4. Model calibration

The IMHOTEP ConOps and the decision support tools developed in the project are validated through the application of two case studies: London City (LCY), an urban airport focused on business travel that offers a variety of surface transport options for airport access; and Palma de Mallorca (PMI), an airport with a majority of leisure traffic and access restricted to a single main road. The models used to create the Passenger ATD are calibrated and validated against the results of the predictive models used for surface access and egress, and for terminal operations, as well as against aggregated data from passenger and transport surveys.

Machine learning models estimate the attributes that are not explicitly available in the data sources, for instance trip purpose and access mode are approximated from mobile phone data. To validate these models, first, a five-fold cross-validation process is applied to a construction sample in order to find the hyperparameters that better fit the data (Stone, 1974). Once these hyperparameters are selected, the model is trained with the complete dataset and the final performance is validated against the testing part of the dataset. Fig. 7 shows the training results for the surface transport mode estimation for a sample of trips accessing PMI. The graph is formally known as a *confusion matrix*, values in the rows represent the number of trips identified by the algorithm for each transport mode, whereas values in columns represent the expected true values according to the origin-destination transport survey. For instance, 152 trips were correctly estimated as 'private car' trips, whereas 88 were incorrectly assigned to other transport modes. However, the accuracy increases at the aggregate level, i.e. 238 trips were identified as 'private car' out of 240 true values. In fact, precision is highest for private cars, which is currently the most popular mode to access the airport.

Predicted label \ True label	Private bus	Public bus	Rental car	Private car	Taxi/ Ride-sharing services
Private bus	149	28	80	10	55
Public bus	15	37	14	22	21
Rental car	100	61	106	23	43
Private car	13	16	30	152	27
Taxi/ Ride-sharing services	105	68	58	33	104

Fig. 7. Confusion matrix for access mode identification for trips estimated from mobile phone data records for Palma de Mallorca Airport.

Airport terminal processes are calibrated using passenger presentation profiles, which is a cumulative distribution of the 'time before departure' passengers from a given flight arrive (i.e. present themselves) at security control. This information is gathered from boarding card readers before security. In the case of PMI, the comparison between modelled and actual presentation curves for Schengen flights delivered satisfactory results when using a normal distribution as an approximation (average error 1,4%, maximum error 12,1%) an even better for a gamma distribution (average error 0,7%, maximum error 6,1%).

5. Conclusions and future work

The IMHOTEP Concept of Operations describes five functions that determine a passenger-centric activity-travel diary that collects information on individual door-to-door journeys for air transport passengers. The aggregation of such information and, crucially, its update in real time, enables the extension of current Airport-Collaborative Decision-Making implementations to incorporate surface access and egress legs. This extension, in turn, enables real-time collaboration between relevant stakeholders to ensure adequate situational awareness and prompt response to disruptions beyond the air traffic management scope, therefore responding better to the needs of passengers to ensure a seamless multi-modal journey.

The combination of different data sources has proven valuable to identify milestones and attributes in the passenger journey that are traditionally out of reach of any data owner in the air transport context. Hence the continued development of the IMHOTEP tools has the potential to impact not only the operations of airports under normal and disrupted circumstances, but also to enable innovative solutions for passengers, metaphorically breaking the rigid fences of the airport boundaries. Current work is focusing on the integration of the different computational models in a visualisation tool that interfaces with stakeholders to aid in their decision making. The tool will be tested using pre-determined scenarios for normal and disrupted operations at LCY and PMI.

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