Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-23/28		
4. Title and Subtitle Communicable Disease Transmission in Air Travel: Human Behavior – Phase 1 Report		5. Report Date September 25, 2023 6. Performing Organization Code
7. Author(s) Shelley Roberts,[2] Paul Lebbin,[2] Steve Gwynne,[1] Russ Thomas,[2] Ryszard Dabkowski,[2] Andrew Law,[2] Sebastian Ghinet,[2] Steve Hunt,[1] Ailsa Hamilton-Smith,[1] Hui Xie,[1] Charly Tenon Kone,[2] Dana Sayed Ahmed,[2] Anant Grewal,[2] Max Kinateder[2] and Maxine Berthiaume[2] [1]GHD, Inc., [2]National Research Council Canada		8. Performing Organization Report No.
9. Performing Organization Name and Address GHD Inc. 14585 Avion Parkway, Ste 150 Chantilly, VA, 20151		10. Work Unit No. (TRAIS) 11. Contract or Grant No. AC-23-04576
12. Sponsoring Agency Name and Address Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20591		13. Type of Report and Period Covered Technical Report 14. Sponsoring Agency Code
15. Supplementary Notes Author ORCIDs: Shelley Roberts (0000-0001-9269-350X); Paul Lebbin (0000-0002-7750-9572; Steve Gwynne (0000-0002-2758-3897); Russ Thomas (0000-0003-4765-141X); Andrew Law (0000-0002-7604-0506); Sebastian Ghinet (0000-0001-5501-4950); Max Kinateder (0000-0002-1669-3900); and Maxine Berthiaume (0000-0002-7144-0279) Technical report DOI: https://doi.org/10.21949/1528567		

16. Abstract

The Federal Aviation Administration (FAA) has initiated work to develop a preparedness plan for communicable disease in air travel. The FAA's approach to the planning effort is to use its existing Safety Risk Management (SRM) process, as documented in FAA Order 8040.4, to quantify baseline risk, identify risk controls and quantify residual risk. The FAA will then use the SRM outputs as inputs to the preparedness planning activity, thereby making the later risk-based and data-driven. The FAA established a SRM team in February 2022, which quickly identified a lack of sufficient data and suitable models to proceed through the SRM process. In response, the SRM team commissioned a risk estimation Modeling, Simulation, and Analysis (MS&A) working group to close this gap. The MS&A working group conducted an international workshop in August 2022, and formulated a 24-month research program to develop an open source, validated risk estimation tool with associated data for a narrow body, single aisle passenger transport aircraft use case. The working group's objective is to transition its work products for use by the SRM team, government preparedness planners, and those in industry conducting safety risk assessments as part of airline safety management systems. The research program is being conducted in two phases. The first phase (6 months), completed in August 2023, delivered a comprehensive data acquisition plan and methodology based on the risk estimation model architecture proposed by FAA and industry collaborators. The second phase (18 months) will execute the data acquisition plan in airports, on operational aircraft, and in the National Research Council of Canada's Centre for Air Travel Research and provide the data for model development. Data collected in Phase 2 will also be used to support model validation. This report documents the results of the Phase 1 work developing the data acquisition plan and methodology for the human behavioral elements of the modeling and simulation task.

17. Key Word		18. Distribution Statement	
Aviation medicine, modeling and simulation, preparedness, public health, safety risk management,		Document is available to the public through the National Transportation Library: https://ntl.bts.gov/ntl	
19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price NA
Unclassified	Unclassified	216	

Communicable Disease Transmission in Air Travel: Executive Summary

Shelley Roberts, Paul Lebbin, Steve Gwynne, Russ Thomas, Ryszard Dabkowski, Andrew Law, Sebastian Ghinet, Steve Hunt, Ailsa Hamilton-Smith, Hui Xie, Charly Tenon Kone, Dana Sayed Ahmed, and Anant Grewal

GHD Advisory

National Research Council Canada / Conseil national de recherches Canada

Canada

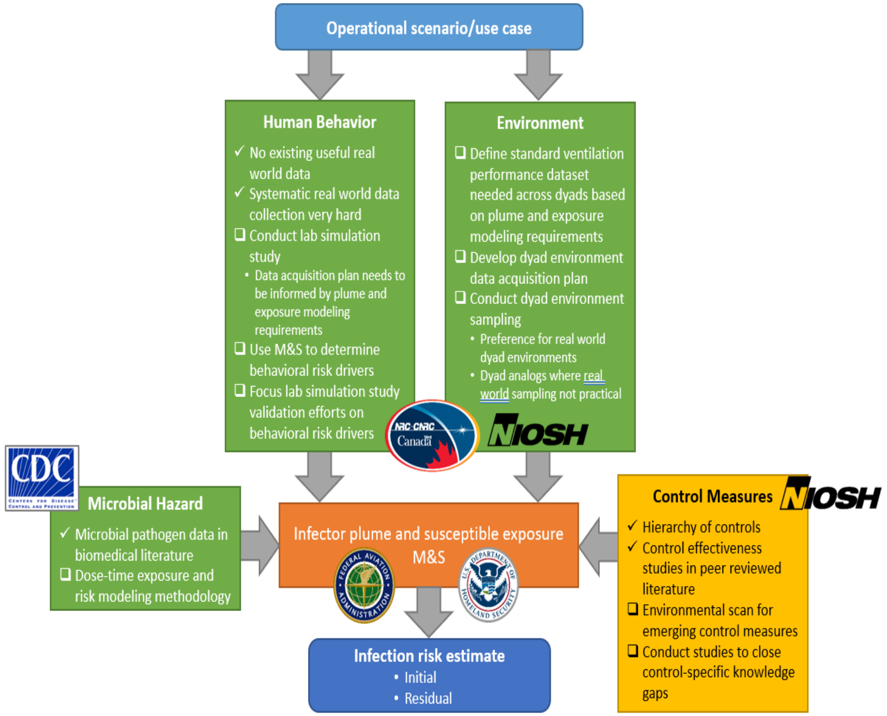
Development of Data Collection Methodology

The Federal Aviation Administration (FAA) funded the National Research Council Canada (NRC) and Movement Strategies (MS, a GHD company) to conduct research into the risk to passengers performing routine actions during air travel given the potential for a future viral outbreak.

This exercise will allow the behavioural and environmental conditions (and the relationships between them) to be modelled, allowing the risk to be quantified for the scenario specified by the FAA (see 1):

- A single-aisle commercial aircraft (e.g., A320 / B737) engaged in scheduled part 121 operations, in single class configuration, and using its auxiliary power unit at the gate during boarding, departs from a gate at Airport 1 in December for a 3-hour uneventful flight (no turbulence, etc.) to Airport 2, where it arrives and deplanes at a gate while using a ground cart for air supply. There are no enhanced disease transmission control measures in place.

The objective of this project (2/23-12/24) is (1) to develop a methodology to capture human behaviour and environmental data in Phase I (2/23-7/23), and (2) to generate data for use in FAA risk assessment models in Phase II (8/23-12/24) by capturing human performance across a set of dyads (from departure gate to arrival gate) and the environmental conditions.



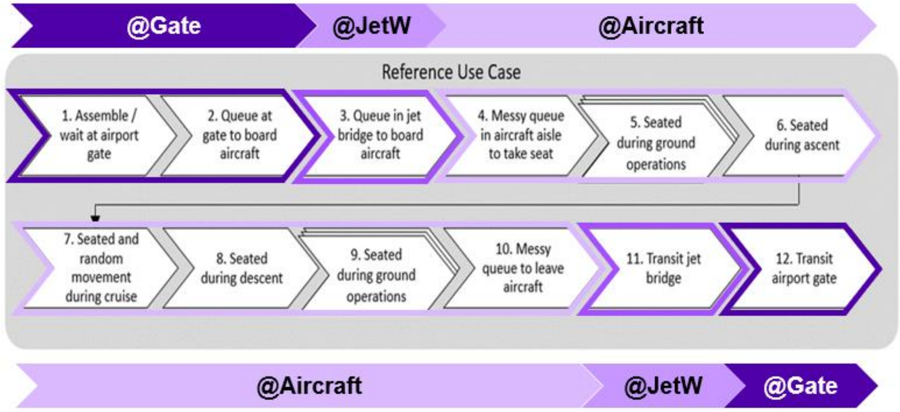
1 FAA Research Structure – key subject domain and interested stakeholders at the outset.

The development of the provisional data collection methodology as part of Phase I has now been completed and will be reviewed in a workshop in August 2023.

Development of Data Collection Methodology

The data collection plan developed in Phase I of this project reflects the development of methodologies that address the following three domains:

- Expected passenger, staff and crew behaviour that might affect viral transmission during their traversal of the dyads (see 2).
- Physiological/respiratory/tactile processes given recorded behaviours.
- Environmental conditions at the gate, jetway, and during the flight given the routine operations of those spaces combined with the passenger activities.



2 ***FAA Dyads – reflecting the episodes of the passenger experience deemed of interest. Each episode requires data on the feedback loop between the passengers and the environmental conditions.***

The approaches adopted are designed to address the data gaps while capturing the interaction between these three domains – allowing the FAA models to represent the coupled nature of the passenger/environmental conditions. **The focus of these documents is on human behaviour (data collection, metrics and methodology) and the metrics explored as part of the environmental data collection that relates to passenger experience.**

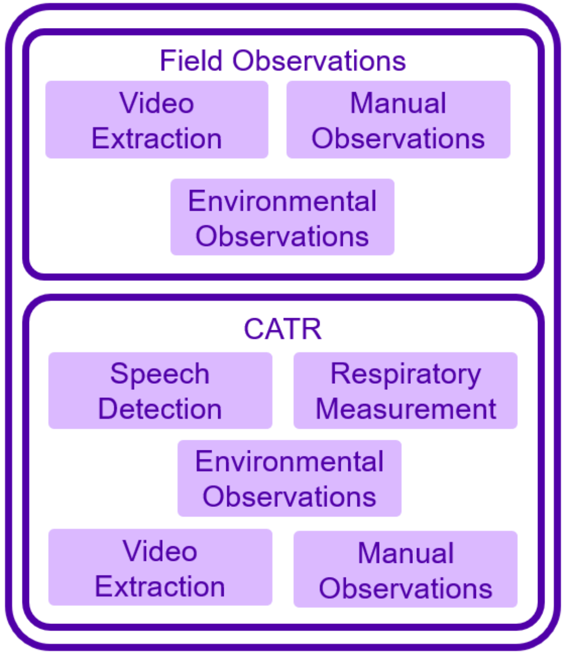
The methodology for environmental data collection is being finalized by NRC and key stakeholders.

Development of Data Collection Methodology

A range of data collection tools will be used in the methodologies developed (see 3). These will be employed in two distinct settings:

- Field observations at two Canadian airports and onboard flights with two operators.
- Controlled observations conducted at the NRC Centre for Aviation Travel Research (**CATR**) facility in Ottawa, Canada.

These settings are explored to enhance ecological validity (i.e., *in situ* behaviour and environmental conditions), while also providing experimental control. They provide opportunities to deploy data collection technologies and isolate situations/behaviours of interest – capturing data at different levels of granularity and scope.



3 Data collection approaches proposed across the two settings.

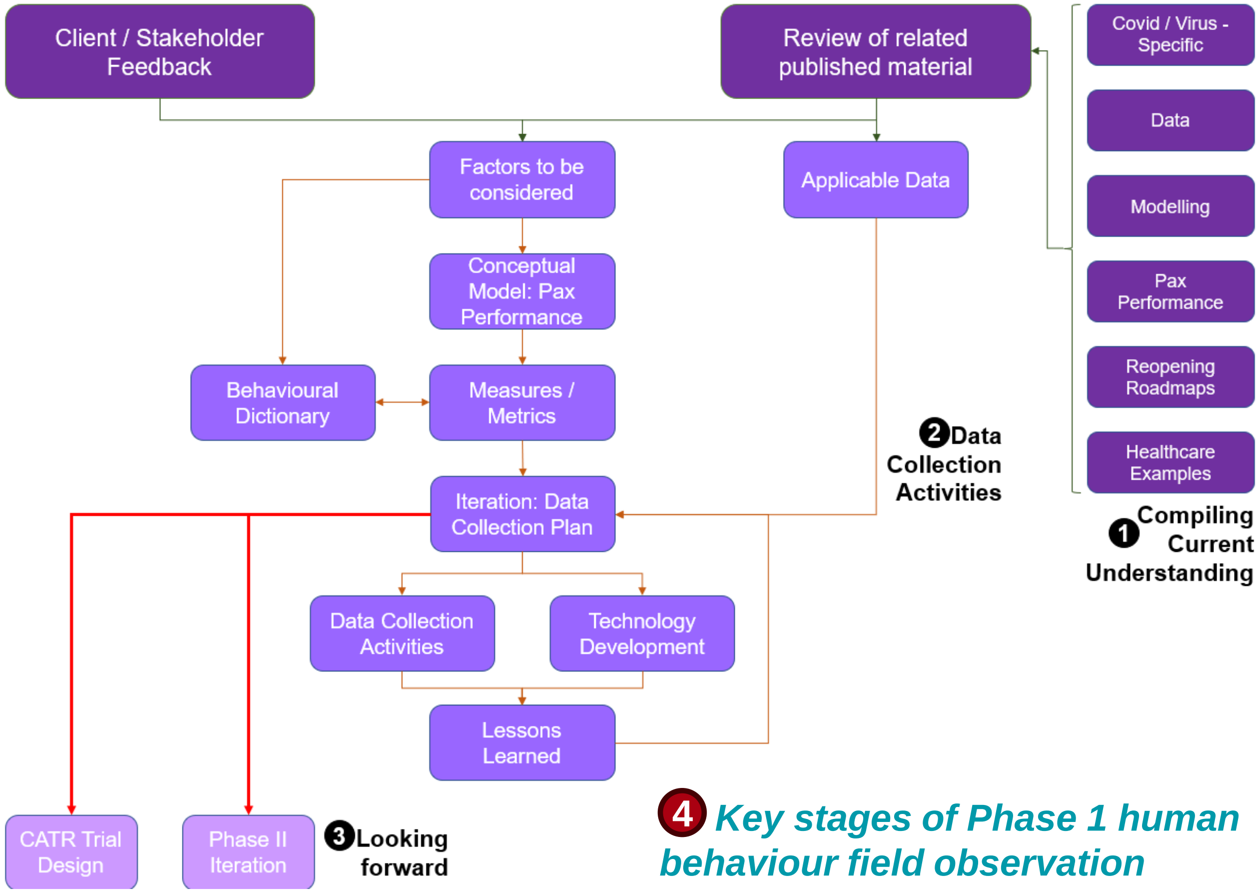
This was essential to build a credible picture of the conditions produced and to inform the development of the FAA models – as to the factors that need to be included and the level of detail at which they should be included.

The field and experimental approaches proposed were examined to identify limitations in the scope and refinement of the data that might be generated. This was done to refine the use of these approaches and to strengthen the completeness of the data and confidence in the findings produced.

Development of Data Collection Methodology: Field Observations – Human Behaviour

The planning for human behaviour field observations was broken down into three stages (see 4):

- **Compile current understanding:** Existing material was reviewed to identify passenger behaviours that needed to be observed, along with influential factors.
- **Conduct data collection activities:** Field observations were conducted in April/May 2023 to test provisional data collection methodologies – to assess their effectiveness and the quality of the data produced.
- **Develop a data collection plan for future field observations and for CATR trials:** Infrastructure, instrumentation and protocol designs were developed to facilitate planned trials in the CATR facility that will allow them to complement future field observations – filling gaps and allowing more diagnostic insights.



4 Key stages of Phase 1 human behaviour field observation methodology development.

A description of these tasks is in the attached libraries: FAA_Field_Observations & FAA_CATR_Experiments.

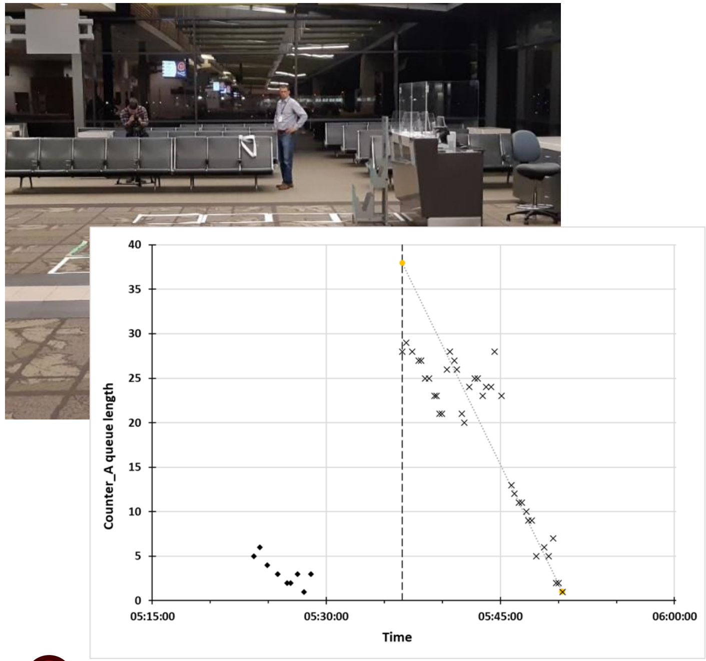
Development of Data Collection Methodology: Field Observations – Human Behaviour

Trial field observations were conducted. The objective of these trials was to test the effectiveness of the provisional plans developed, the manual observation protocols employed, and the assumptions made to ensure that the data collected could be applied within the FAA models.

A sample of the data collected during the Phase I field observations of passenger movement was examined (see 5). It represents a range of locations, observers, attributes/action types (i.e., content types), data formats, and data from different levels (e.g., individual, population, aggregate, etc.), providing an overview of the data that might be captured from manual observations in the field.

MS was previously involved in data collection efforts of people movement during the pandemic. **Video from this work was used to develop and test a protocol for manually extracting data from video footage.** This extraction might be necessary from data collected in the field and in CATR – both as a safety net for automated extraction technology to augment quantitative data with more qualitative insights.

The data captured was also used to configure simulation tools to explore the reliability of the data collection methods employed and the viability of using these tools in Phase II of the project to support data collection efforts (see 6).



5 NRC staff during field observations (top) and example data (bottom).

6 Simulation tools were configured with the field observations and applied.

Development of Data Collection Methodology: Field Observations – Human Behaviour

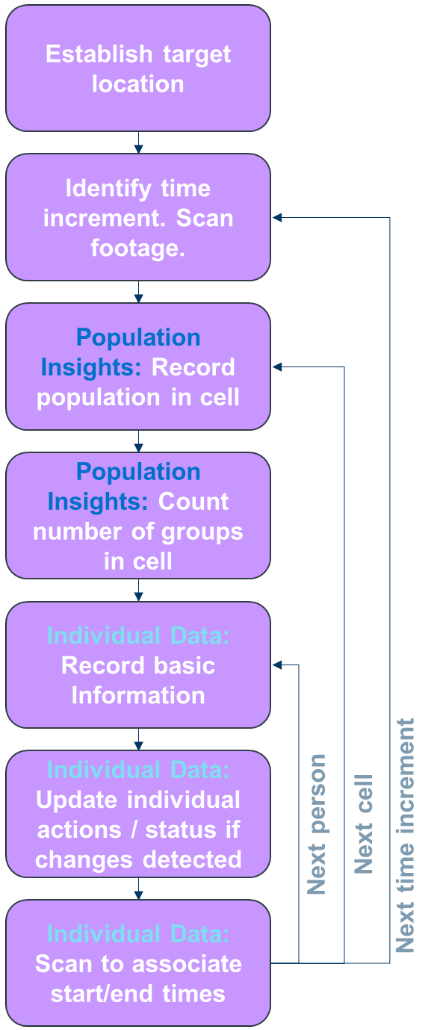
A set of behavioural metrics and a provisional protocol to capture data that reflected these metrics were produced. The metrics reflected the method used (i.e., manual observations or video extraction), where they might be applied (i.e., which dyad), the qualitative and quantitative data that might be captured, and the level of refinement (i.e., whether the data was at the individual or aggregate level, see 7).

7 *Example description of metrics at gate area*

Location	Qualitative	Aggregate Quant.	Individual Quant.
Gate: General Area	• General patterns of movement and behaviours across gate areas. • Pathways used (desire lines)	• Object touch points – number of times objects are touched (extracted from individual interactions with objects). • Occupancy over time. • Population distribution over time.	Number(#) & Delay (s): Direction / Standing / Action, filtered by sub-set of action / object combinations: • Touch - [Mobile_Device/Personal_Document/Luggage/FaceMask/Seat/Mobility_Aid/ Pushchair/Baby/Pax] • Hold (s) – [Luggage / Baby] • Speak (s) – [Staff/Crew/Pax/Mobile_Device] • Face – [Pax / Staff] • Sleep (s) / Eat (s) / Drink (s) • Cough / Sneeze / Yawn • Stand / Sit / Turn – [Direction Change]

This outlined what <u>might</u> be captured in these settings using the tools identified. From these initial estimates a baseline set of metrics (see B and C) has been established to take forward for subsequent workshop discussion in August 2023 with the client and stakeholders.

The provisional data collection protocol reflected observer field activities / supporting templates, along with analytical protocols for those extracting data from video footage captured from the field (see 8).



8 *Video data extraction logic*

Development of Data Collection Methodology: CATR – Human Behaviour

The protocol for the CATR experiments was developed from the field observations and tested across three return flights in May 2023. Initial insights and data collected were used to create the information proposed in this deliverable, including the scenario, method, tools and data list.

The collaborative workshop in August 2023 will be used to finalize the protocol in the CATR. This will enable the creation and submission of an ethics review for approval, conduct a pilot test in the CATR and then collect data across multiple trials.

The CATR facility includes a scaled gateway, jetway and cabin (see 9).

The scenario explored will be consistent with that outlined by the client in Phase I (i.e., late fall/winter, weekday, 0930, single-aisle, one class, short-haul, normal flight, carry-on luggage, service provided, etc.), but scaled for the capacity of the CATR facility – including 36 participants (scale 1:4.17) boarding in a single boarding zone. **1x pilot trial will be conducted and then 3 x trials (n=108) with 2 crew recruited.**

9 *CATR Facility*

Development of Data Collection Methodology: CATR – Human Behaviour

A protocol for CATR has been developed to capture passenger movement across the dyads. This has been designed both to supplement the gaps noted in the field observations (e.g., video footage onboard), and provide more control of the behaviours, environmental conditions and crew activities present.

This allows for a scenario to follow a stricter timeline of events – ensuring that data is collected on certain actions performed in know contexts (see 10).

It also allows for more control over the participant demographics and for more background information to be collected (e.g., age, gender, race, body scan dimensions, disability, grouping, assigned seat, air travel experience, etc., see 11).

Given that the scenario is more controlled than during the field observations, the protocol reflects the assumptions made and the 'choreographed' passenger experience – to reflect the expected narrative evident in the field observations.

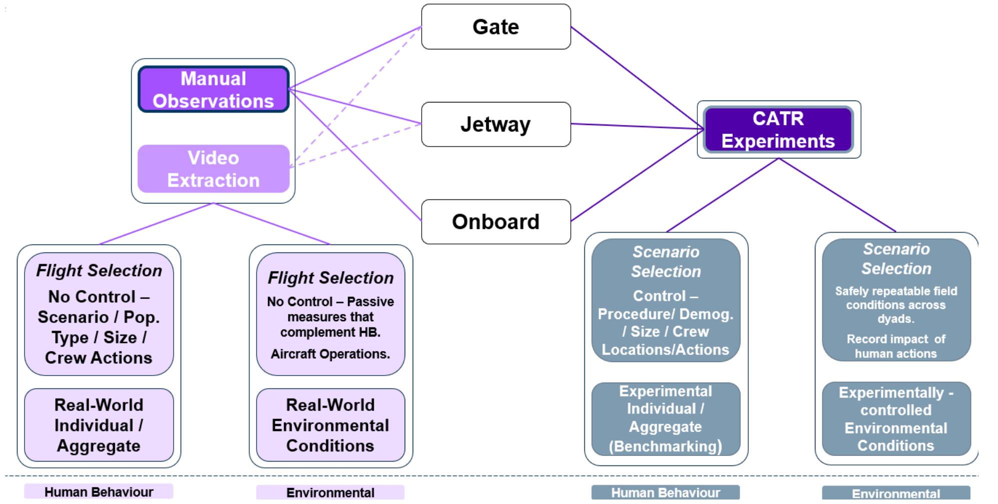
Time	Item	Activities
0800	Crew arrival	• Complete consent form • Provide pre-briefing • Complete demographic questionnaire • Body Scan
0830	Passenger arrival	• Complete consent form • Provide pre-briefing • Complete demographic questionnaire • Body Scan (Small % of selected participants) • Distribute boarding pass, carry-on luggage, event acting cards
0930	Gate - Start	• First participant enters the gate area ○ Data collection in the gate begins
1000	Jetbridge - Start	• First participant enters the jetbridge area ○ Data collection in the jetbridge begins

1030-1230	Flight – Start
	Flight - End
		• First participant enters the air cabin
		  ○ Data collection in the air cabin begins
		• Last participant exits the air cabin
		  ○ Data collection for air cabin ends

1230-1245	Jetbridge – End
	Gate - End
		• First participant enters the jetbridge area
		  ○ Data collection in the jetbridge begins
		• First participant enters the gate area
		  ○ Data collection in the gate area begins
		• Last participant departs the jetbridge area
		  ○ Data collection in the jetbridge ends
		• Last participant departs the gate area
		  ○ Data collection in the gate area ends

1230-1300	Passenger and crew debrief	• Post-briefing • Compensation

10 *CATR Scenario Timeline*



11 *Limitations of data collection methods*

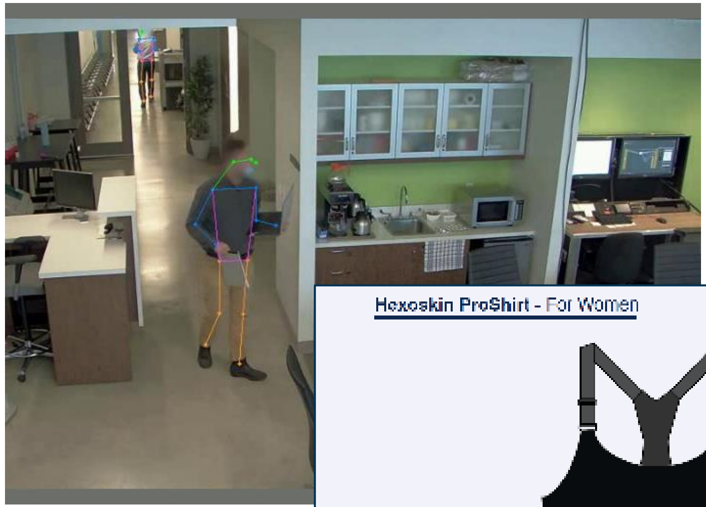
Development of Data Collection Methodology: CATR – Human Behaviour

Data will be collected using (see ●):

- 17 cameras located in the cabin and other cameras positioned around gate section and jetway (precise number determined during pilot).
- Development of data extraction system to automate locations and directions of detected participants.
- Instrumentation sensing object movement (e.g., door handles, flush, faucet, etc.)
- Glogerm / Blacklight to detect touch points.
- Hexoskin (for physiological measurements).
- AI-based diarization algorithm to detect speakers in multi-person space.

Data collected will include:

- Passenger / Crew movement; e.g., time spent in queue, etc.
- LAV use; e.g., frequency of use, time spent in queue, etc.
- Touch points; e.g., number of times locks, buttons, seats, galley items, tray tables, PSU touched, etc.
- Close contact; e.g., distance between individuals and time spent at this distance.
- Number of people speaking / Respiratory rates.



12 *CATR example means of data collection.*

Metric Summary: For Workshop Discussion

A baseline set of metrics have been produced for the environmental and behavioural data to be collected (see A, B and C). These have been derived from the field trials, from development of the data collection methodologies (and associated technology testing) and from discussions with client and stakeholders.

The lists presented here are intended to be described in detail at the planned August workshop. At that point, the lists will be finalized allowing the field and experimental protocols to be completed and final planning initiated

B indicates a sub-set of the behavioural metrics that might possibly be collected in the field, while C reflects metrics that might be informed by existing external sources. A modified version of these tables (derived from the workshop) is provided in Appendix 8.

A

PARAMETER	UNITS	METHOD	CATR	FIELD
Near Subject (cabin and airport only)				
CO2	ppm	UPAS	Seat back	Belt clip
Tdb	°C	UPAS	Seat back	Belt clip
RH	%	UPAS	Seat back	Belt clip
PPM2.5 (density)	µm/m³	UPAS	Seat back	Belt clip
PPM10 (density)	µm/m³	UPAS	Seat back	Belt clip
PPM2.5 (count)	#/cm³	UPAS	Seat back	Belt clip
PPM10 (count)	#/cm³	UPAS	Seat back	Belt clip
TVOC	Dimensionless	UPAS	Seat back	Belt clip
NOx	Dimensionless	UPAS	Seat back	Belt clip
Cabin				
CO2 (supply)	ppm	NDIR	Duct	
CO2 (return)	ppm	NDIR	Duct	
Tdb (supply)	°C	RTD	Duct	
Tdb (return)	°C	RTD	Duct	
Tdp (supply)	°C	Chilled Mirror	Duct	
Air Flow (supply)	kg/s	Station	Duct	
Air Flow (two sidewalls each)	kg/s	Hot-film	Tube	
Particle Size (supply)	µm/m³	TSI 3321	Duct	
Particle Size (supply)	#/cm³	TSI 3321	Duct	
Particle Size (return)[1]	µm/m³	TSI 3321	Duct	
Particle Size (return)[1]	#/cm³	TSI 3321	Duct	
Jet Bridge[2]				
CO2/Tdb/RH/PPM (entrance)	Varies	UPAS	Wall	Wall
CO2/Tdb/RH/PPM (20 mark)	Varies	UPAS	Wall	Wall
CO2/Tdb/RH/PPM (40 mark)	Varies	UPAS	Wall	Wall
CO2/Tdb/RH/PPM (exit)	Varies	UPAS	Wall	Wall
Airport				
CO2 (supply)	ppm	NDIR	Duct	
CO2 (return)	ppm	NDIR	Duct	
Tdb (supply)	°C	RTD	Duct	
Tdb (return)	°C	RTD	Duct	
Tdp (supply)	°C	Chilled Mirror	Duct	
Air Flow (supply)	kg/s	Station	Duct	
Air Flow (return)	kg/s	Hot-film	Tube	
Particle Size (supply)	µm/m³	TSI 3321	Duct	
Particle Size (supply)	#/cm³	TSI 3321	Duct	
Particle Size (return)[1]	µm/m³	TSI 3321	Duct	
Particle Size (return)[1]	#/cm³	TSI 3321	Duct	
CO2/Tdb/RH/PPM[3]	Varies	UPAS	Between seats	Between seats

B

	Units	Manual Observations (Gate / Jetway / Onboard)	Video Observations (Gate / Jetway)	CATR (Gate / Jetway / Onboard)
Gate Configuration / Dimensions	m	Measured / Plans	Measured / Plans	Measured / Plans
Jetway Configuration / Dimensions	m	Measured / Plans	Measured / Plans	Measured / Plans
Aircraft configuration / Dimensions	m	Measured / Plans	Measured / Plans	Measured / Plans
Boarding duration	s	Measured	Measured	Measured
Boarding queue length	#people or m	Measured (for observable area)	Measured	
Duration of aircraft states	s	Measured (door closed, taxi, climb, service)		
Person Type	Passenger / Crew / Staff	Estimated	Estimated	Survey Response
Sex	M/F/U	Estimated	Estimated	Survey Response
Age	Category / Yr	Estimated (Category - Child / Juvenile / Adult / Elderly)	Estimated (Category Child / Juvenile / Adult / Elderly))	Survey Response
Height / Seated Height	m			Measured
Width / Girth	m			Measured
Walking Speed	m/s		Observed (by location / impairment / encumbrance – e.g. across gate area)	Observed (by location / impairment / encumbrance – e.g. across gate area)
Flow (e.g. Desk / Jetway)	p/s OR p/m/s	Estimated (e.g. Desk / Jetway / Deplaning)	Observed (e.g. Desk / Jetway)	
Personal Space / Distance between people	m		Observed	Observed
Population Density	$\#/m^2$	Estimated according to grid	Observed (assuming coordinates established)	Observed (assuming coordinates established)

Face Touch Rate	# touch / min
	Pr.(touch)
		Observed (face / other)	Observed (face / other)	Observed (parts of head and face)

Surface Touch Rate	Person: # touch / min Person: Pr.(touch) Object: #touch	Estimated (given action OR location OR object AND Group)	Observed (given action OR location OR object AND Group)	Observed (given action OR location OR object AND Group)
Dwell time	s	Estimated (time for action OR location OR object)	Observed (time for action OR location OR object)	Observed (time for action OR location OR object)
Group Membership	Ingroup / Outgroup	Estimated	Observed	Observed
Pre Action Delay	s		Observed (e.g. time to initiate movement to desk once group called)	
Population Distribution	# / location		Observed (e.g. initial distribution at gate)	

C

	Units	Other Sources
Walking Speed	m/s	Distributions available for speeds and dwell times / delays (time top stow luggage) from article: Gwynne et al.
Compliance	Pr	Likelihood of someone following guidance. Derived from previous pandemic analysis carried out by MS.
Risk Averseness	Pr	Likelihood of taking safety actions when not required.

Next steps

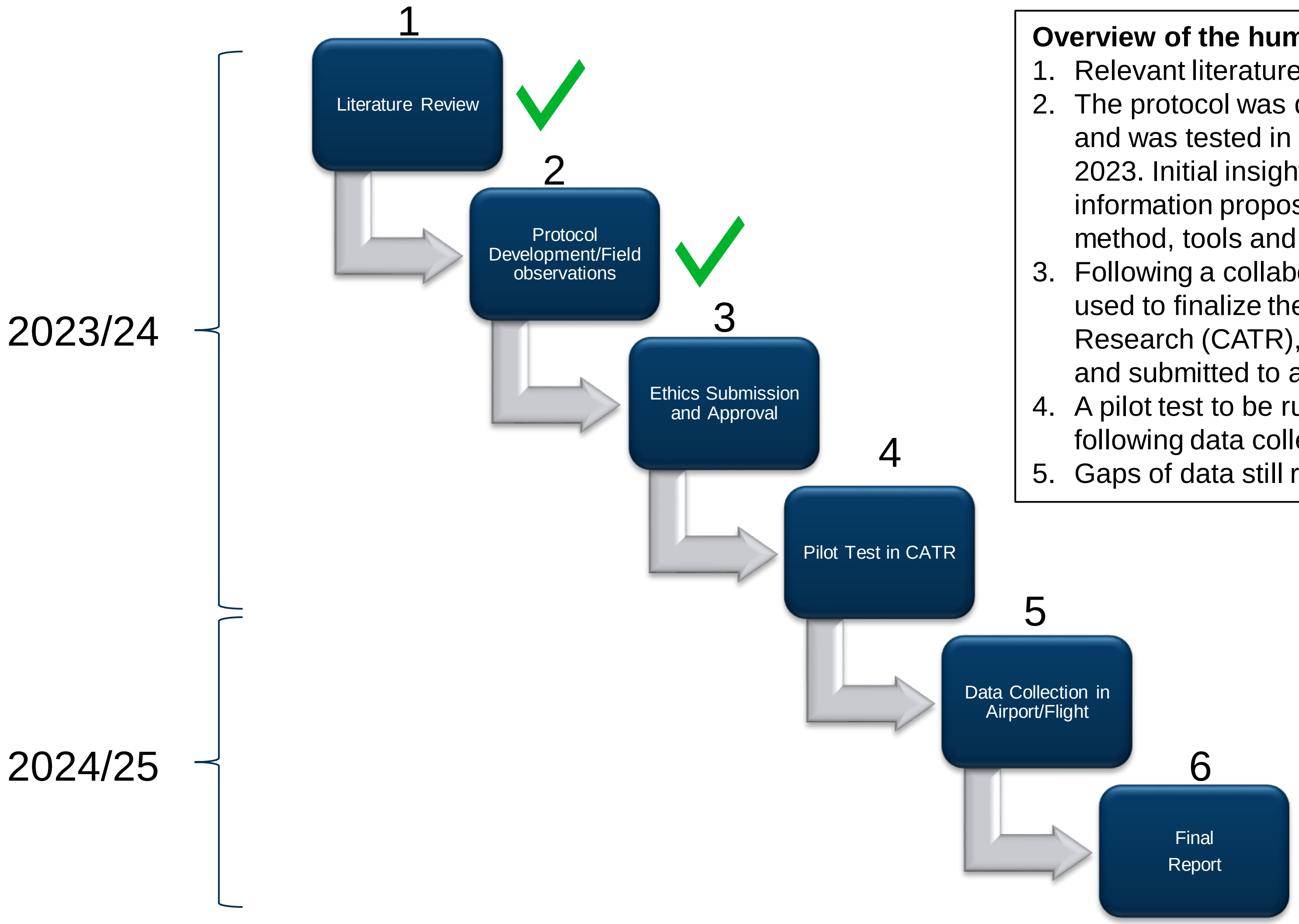
Submit findings from Phase I to August 2023 client / stakeholder workshop for review and feedback.

Modified methodology will then be trialled and applied in Phase II to capture field and experimental data and deliver the final methodology.

Communicable Disease Transmission in Air Travel: Human Behaviour

Shelley Roberts, PhD.
Shelley.roberts@nrc-cnrc.gc.ca

Human Behaviour: Project Plan and Milestones



Overview of the human behaviour data collection plan:

1. Relevant literature was reviewed and is presented in the report.
2. The protocol was developed based on the literature reviewed and was tested in the field across three return flights in May 2023. Initial insights and data collected was used to create the information proposed in this deliverable, including the scenario, method, tools and data list.
3. Following a collaborative workshop in August 2023, which is used to finalize the protocol in the Centre for Air Travel Research (CATR), the ethics review documentation is created and submitted to an NRC ethics review board for approval.
4. A pilot test to be run in the CATR is planned for Winter 2023 following data collection across 3 CATR trials.
5. Gaps of data still required are to be filled in-situ

Goal - CATR Simulation

- This observational study will collect data related to passenger behaviour and movement within the three environment types (gate, jetbridge and cabin).
- The observations and data collected will be used to provide benchmarking data for computational simulation tools.
- This study will supplement the data collected in the field at airports and aircraft.
- This deliverable contains the following sections to enable the reader to gain insight into the methodology and tools proposed to capture the data required (sections are hyperlinked):
  - Methodology
    - Video Capture
  - Physiology
  - Speech Detection

METHODOLOGY

Dr. Shelley Roberts

shelleyroberts@nrc-cnrc.gc.ca

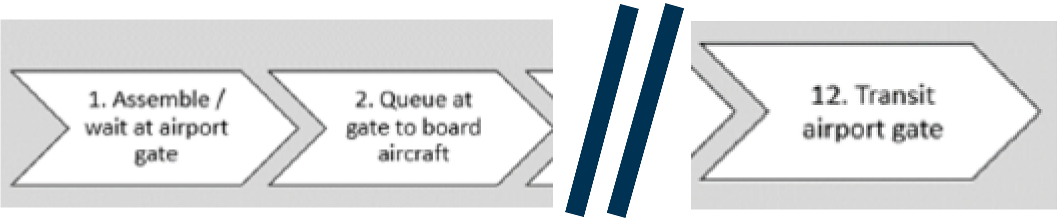
CATR (Centre for Air Travel Research)

This is the Centre for Air Travel Research located at the Ottawa International Airport in Ontario Canada. This is the simulation centre where we will be collecting the data.
Click here for a virtual tour: https://nrc.canada.ca/en/node/865

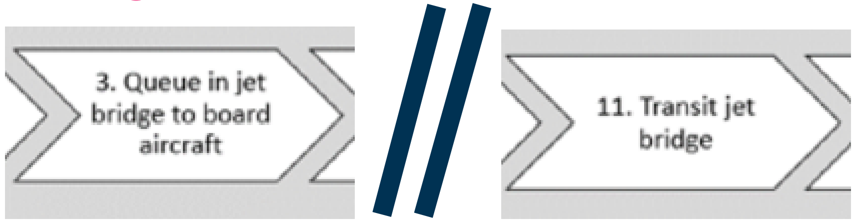
Scenario - CATR

Dyads/Environments to be included

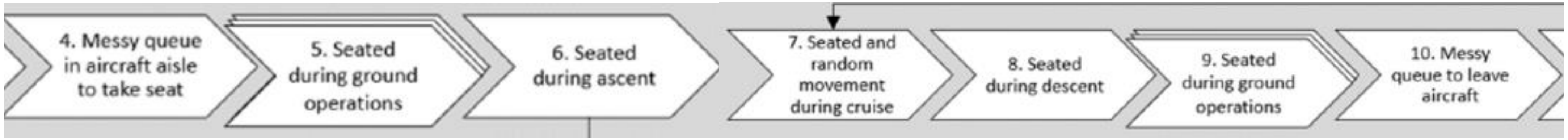
1. Gate



2. Jetbridge

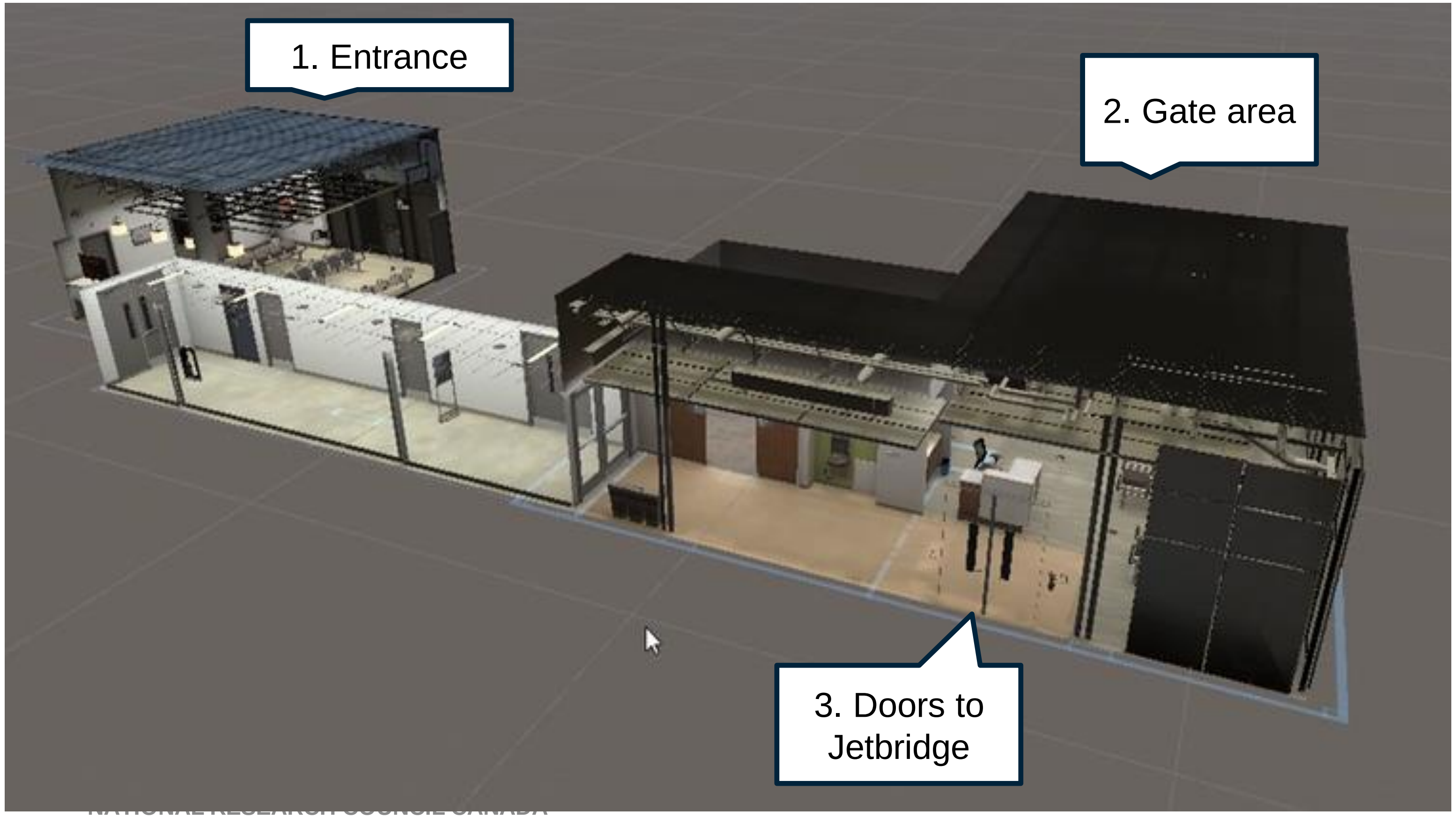


3. Cabin



CATR 3D Floor Plan

Within the Centre for Air Travel Research we will be using four main areas. At the entrance we will be welcoming the participants and providing them with a pre-briefing prior to study commencement. Once the study has started the participant make their way to the gate area, and then through the jetbridge doors when boarding is announced. The data in the cabin environment will be collected in the A320 simulator.



4. A320 Cabin

Use Case

A Boeing 737-Max8 engaged in scheduled part 121 operations, in single class configuration with 30-in seat pitch, boarding from front to back by zones with assigned seating, and using recirculation fans only at the gate during boarding, departs from Gate 25 at YOW in December, without needing deicing, for a 3 hour uneventful flight (no turbulence, etc.) to YWG inclusive of food service, where it arrives and deplanes at Gate 12 while using recirculation fans only at the gate. There is a risk of novel influenza and a single, unknown infectious individual; however, there are no enhanced disease transmission control measures* in place in the baseline case. Passengers are experienced business/leisure travelers, without mobility limitations, wearing face masks at their personal discretion. Some seat assignments are modified, and some luggage is checked at the gate during the pre-departure phase of the trip.

Scenario - CATR

The chosen scenario is based on project requirements, observations in the field and CATR constraints.

- **Timing:**
  - Time of year: Late fall, winter (passengers will bring outerwear)
  - Day of the week, time: Weekday, AM
  - Start time of the first dyad = 930; all other dyad start times are a function of respective previous durations.
- **Aircraft/Flight profile:**
  - A320, single aisle
  - One class (economy)
  - Type: short haul (2.5 hours); domestic
  - Booking: Full (36 passengers) = Ratio of 4.17 (A320 =150)
  - Seat pitch = 30”
  - Single boarding zone

Scenario - CATR

- **Normal flight**
  - No abnormal events to be expected
  - No turbulence
  - Constrained to single flight (not including between flights)
- **Baggage:**
  - Carry-on only; NRC to provide 1 carry-on luggage
  - Participants will bring up to 2 personal items to store
- **Service:**
  - One in-flight service provided (complimentary snacks, beverages)
- **Events may be added to create ecologically valid movement and actions**
  - Call to gate-side check luggage, seat change, luggage bins may be full and participants will need to search for a luggage bin

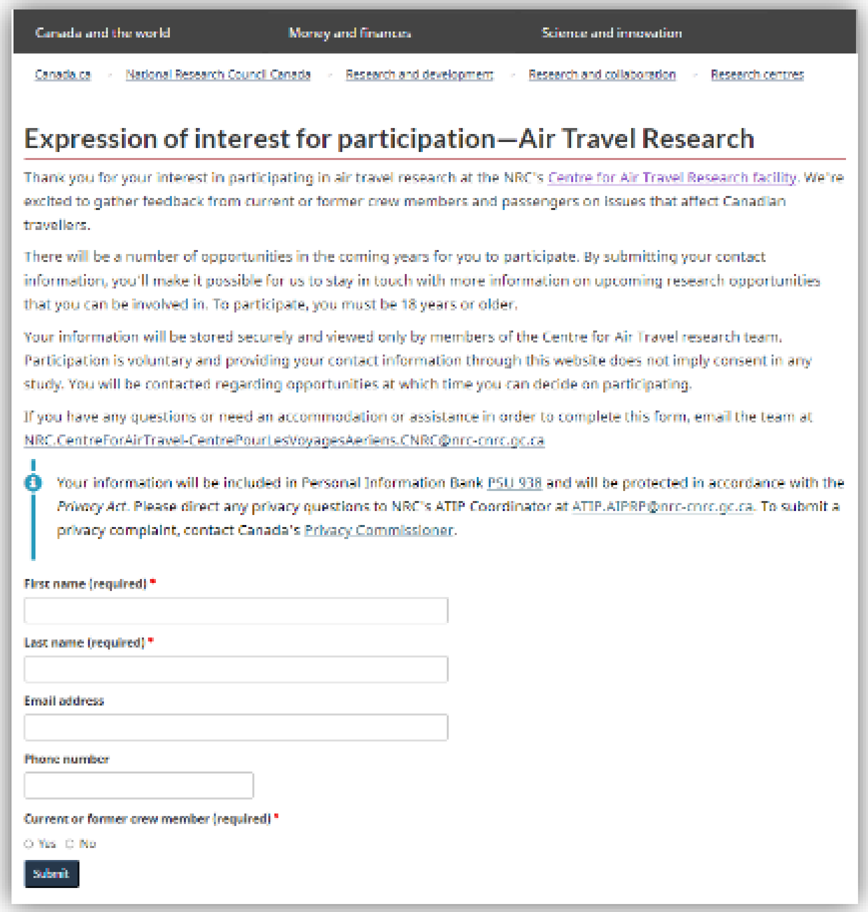
Participants

- **Passenger profile:**
  - 1 pilot study will be run to validate protocol
  - 3 trials, n=36 / trial (N=108)
  - Primarily business/leisure travelers (not a vacation flight/destination)
  - Age range: will try to recruit all ages, but for now assume 18+
  - Individual passengers and small groups of passengers will be recruited (or post-defined)
- **Crew profile:**
  - N=2
  - Canadian crew (former or current)
  - After recruitment – consent forms signed, pre-tour and training provided before trial day(s)

Recruitment

The NRC has created an expression of interest on the website. This has enabled the CATR to create a distribution list of potential participants (cabin crew and passengers) to recruit from for the trials.

- **Centre for Air Travel – EOI for participation**
  - > 330 Canadians have expressed interest
  - Use this database for recruitment
    - Passengers (377)
    - Crew (28)
  - NRC's communications department
    - Social media blasts closer to study to recruit locally
- **Recruitment notice to interested**
- **Follow-up with exclusion/Inclusion criteria interview**
- **Book 45 participants/day (need extra to account for no-shows)**


Canada and the world | Money and finances | Science and innovation

Canada.ca > National Research Council Canada > Research and development > Research and collaboration > Research centres

Expression of interest for participation—Air Travel Research

Thank you for your interest in participating in air travel research at the NRC's Centre for Air Travel Research facility. We're excited to gather feedback from current or former crew members and passengers on issues that affect Canadian travellers.

There will be a number of opportunities in the coming years for you to participate. By submitting your contact information, you'll make it possible for us to stay in touch with more information on upcoming research opportunities that you can be involved in. To participate, you must be 18 years or older.

Your information will be stored securely and viewed only by members of the Centre for Air Travel research team. Participation is voluntary and providing your contact information through this website does not imply consent in any study. You will be contacted regarding opportunities at which time you can decide on participating.

If you have any questions or need an accommodation or assistance in order to complete this form, email the team at NRC.CentreForAirTravel-CentrePourLesVoyagesAeriens.CNRC@nrc-cnrc.gc.ca

Your information will be included in Personal Information Bank PSU 938 and will be protected in accordance with the *Privacy Act*. Please direct any privacy questions to NRC's ATIP Coordinator at ATIP.AIPRP@nrc-cnrc.gc.ca. To submit a privacy complaint, contact Canada's Privacy Commissioner.

First name (required) *

Last name (required) *

Email address

Phone number

Current or former crew member (required) *

Yes No

Submit

Proposed Trial Timeline

Time	Item	Activities
0800	Crew arrival	• Complete consent form • Provide pre-briefing • Complete demographic questionnaire • Body Scan
0830	Passenger arrival	• Complete consent form • Provide pre-briefing • Complete demographic questionnaire • Body Scan (Small % of selected participants) • Distribute boarding pass, carry-on luggage, event acting cards
0930	Gate - Start	• First participant enters the gate area ○ Data collection in the gate begins
1000	Jetbridge - Start	• First participant enters the jetbridge area ○ Data collection in the jetbridge begins

1030-1230	Flight – Start
	
	Flight - End
		• First participant enters the air cabin
		  ○ Data collection in the air cabin begins
		• Last participant exits the air cabin
		  ○ Data collection for air cabin ends

1230-1245	Jetbridge – End
	
	Gate - End
		• First participant enters the jetbridge area
		  ○ Data collection in the jetbridge begins
		• First participant enters the gate area
		  ○ Data collection in the gate area begins
		• Last participant departs the jetbridge area
		  ○ Data collection in the jetbridge ends
		• Last participant departs the gate area
		  ○ Data collection in the gate area ends

1230-1300	Passenger and crew debrief	• Post-briefing • Compensation

A proposed trial timeline. There will be a total of one pilot trial and 3 trials.

Demographics collected

Demographics will be collected from each participant to understand the population being sampled.

- Age
- Gender
- Race
- Body Scan dimensions
  - Height
  - Weight
- Disability
- Grouping
- Assigned seat
- Air Travel experience/Years of cabin crew experience

Size stream – used to collect body dimensions.

GATE

As the participants enter the gate area data collection activities will commence. Listed on this and the next 2 slides are assumptions, start/stop timeline, and type of data collected. Please see the excel file in the associated folder for exhaustive list of proposed data.

Assumptions

- All participants have boarding passes and will enter the gate seating area after instructions are given and as they arrive on site (on-board individually/small groups)

Timeline:

- Departure: 1st participant enters Gate to last participant enters Jetbridge
- Arrival: 1st participant enters Gate to last participant exits Gate
- Estimated time spent at gate: 30-60min

Data Collected / Method

- Actions (frequencies, types)
- Touchpoints (location, frequencies)
- Movement (location, duration, distance)

Jetbridge

Assumptions
- Jet bridge does not need to be extended or retracted
- Jet bridge can accommodate passengers with reduced mobility

Timeline
- Departure: 1st participant enters Jetbridge to last participant in Cabin
- Arrival: 1st participant enters Jetbridge to last participant in Gate
- Estimated time spent in jetbridge: 30min

Data Collected
- Actions (frequencies, types)
- Touchpoints (location, frequencies)
- Movement (location, duration, distance)

Adobe stock image: jetbridge search

Cabin

Assumptions

- Passengers can walk around the cabin
- Forward lavatory operational
- Forward galley installed
- Actions led by crew/captain announcements

Timeline

- Begin: 1st passenger in cabin
- End: Last passenger out of cabin
- Estimated time spend in cabin: 120min

Data Collected

- Actions (frequencies, types)
- Touchpoints (location, frequencies)
- Movement (location, duration, distance)

Methodology to Collect Data

Prior to data collection a pilot study will be conducted to ensure data is collected appropriately, the method is valid and the researchers are able to practice employing the methodology. Within the pilot study it is imperative to collect and validate touch points within each environment that are frequent and shared across participants. This will enable the team to ensure that there are no missing variables to be collected. This information will be shared with project stakeholders to reprioritize the data list if required.

Two main methods of data extraction are relied on: video and instrumentation.

1. Video – the CATR can be instrumented with approximately 100 video cameras to collect the data. Two ways to extract and analyze the data will be manually or using machine learning and AI (for more details please see section labeled “Video Capture”).

2. Instrumentation – within some data collection activities, such as the lavatory, it may be more beneficial to collect the data using sensors. The exact data to be collected using this method will be determined in the August 2023 workshop.

Method of Data Collection

Identify High Frequency Touch Points

- Pilot simulation
- Glogerm + Blacklight

https://thekidshouldseethis.com/post/see-germs-spread-mark-rober

Two methods

- Extract with video
  - Approx. 17 cameras in cabin,
    - 1/monument (x12), 1 by lavatory, 1 in galley, 1 by forward door, 2 down aisle
  - TBD in jetbridge and gate
  - Manual data analysis (worst case)
  - Machine learning with bounding boxes of interest to analyze behaviour (best case)
    - This method of analysis was determined by Phase 1 observations.
- Instrumentation
  - LAV instrumented for data collection
    - Doorknobs/locks, flush, faucet (output is time stamped)

Data (V= video, I= instrumentation)

An overview of the type of data that is to be collected includes movement, lavatory use, touch, close contact, events, speech and physiology. Please see excel file for exhaustive list of data.

Movement

- E.g. time spent in queue (V)

LAV use

- E.g. frequency of use, queue length and time, time spent (V)

Touch

- LAV (I): external door knob, internal door knob/lock, flush button, faucet, toilet seat lid
- Galley items (V)
- Tray table, seat back, PSU, seat pouch, overhead bin, seatbelt, armrest, barriers (V, I)

Data (V= video, I= instrumentation)

Close Contact

- Duration of crew to crew contact, duration of crew to pax contact, number of contacts that came into contact that is seated beyond 1m (V)

Events (scenario specific)

  - Length of service, length of boarding time, length of deboarding time

Speech

  - Speakers
    - Speaker diarization procedure for accurate multiple speaker speech time stamps generation

Physiology

  - Proposed Hexoskin (TBD)
  - Or re-use previously collected data

Proposed Data Collected at Gate, Jetbridge and Cabin

Human Behaviour Data in CATR

- Gate: A list of 31 proposed behaviours can be found in appendices
- Jetbridge: A list of 22 proposed behaviours can be found in appendices
- Cabin: A list of 55 proposed behaviours can be found in appendices

NOTE: Final data list for CATR submitted after August, 2023 workshop can be found in Appendix 8

VIDEO CAPTURE:
COMPUTER VISION AND AI TECHNIQUES TO EXTRACT HEAD POSITION AND BODY POSE DATA FROM VIDEO

Ryszard Dabkowski

Ryszard.Dabkowski@nrc-cnrc.gc.ca

Using Computer Vision and AI Techniques to Extract Head Position and Body Pose Data from Video

Requirements:

- Minimal impact on behaviour of subjects
- Avoid if possible external marker systems etc
- Try to keep deployable in future field studies if at all possible
- Maintain privacy -build in an anonymization plan
- Streamlined to be easily usable with ‘manual’ video annotation techniques

Current working plan:

- Use AI-based pose determination algorithms to locate head position and orientation
- Currently using Yolov7 pose in Python to extract locations of test subject from video
  - Need single-stage processing
  - Need multi-person tracking
  - This can be changed to different algorithm if needed
- All video to be post-processed so computation does not need to be real-time and we can accept some longer post-processing time
  - Can be run in real-time depending on video quality input and graphics card used, but there is no benefit
- Use stereoscopic cameras to capture 3D positions in hold-room and jet-bridge environments where freedom of movement of subjects requires 3D posture measurement
- Use 2D cameras to capture behaviour inside cabin where location of subjects is much more constrained and environment is much more complex
- Add additional AI-based behaviour monitoring if possible in the future based on classification and body posture data – overlay onto manual annotation system before human review
- Focus on custom-designed video annotation system to manually annotate from synchronized video streams with overlaid posture/head position data
- Manual annotation allows us to ensure all required behaviours are captured and provides 100% built-in quality check

Using Computer Vision and AI Techniques to Extract Head Position and Body Pose Data from Video

Requirements:

- Minimal impact on behaviour of subjects
- Avoid if possible external marker systems etc
- Try to keep deployable in future field studies if at all possible
- Maintain privacy - build in an anonymization plan
- Streamlined to be easily usable with ‘manual’ video annotation techniques

General Plan:

- **Participant Position and Head Orientation:** Evaluate use of stereoscopic cameras throughout the CATR facility to extract positions and head orientation of participants throughout each dyad. If used, adapt similar skeleton model approach used in existing work, but in 3D. Key information extracted with this technique is limited to head position and orientation.
- **Other behaviours:** Manually annotated using 2D video streams. Develop annotation system to be able to concurrently label behaviours on multiple synchronized video streams to provide full visibility of dyad area. Explore use of AI algorithms to reduce manual work load for video annotation. AI-flagged events will be overlaid on 2D video stream prior to manual review

Current Working Plan

Use AI-based pose determination algorithms to locate head position and orientation in 3D using stereoscopic cameras

- If reliability of this system is not high enough, an automated 2D-based system using a gridding approach will be used to determine participant location with facial recognition to determine head orientation
- Stereoscopic cameras are planned to be used in hold-room and jet-bridge environments where freedom of movement of subjects requires 3D posture measurement
- 2D cameras (or combined 3D and 2D system) to capture behaviour inside cabin where location of subjects is much more constrained and environment is more dense and complex. Separate 2D head or facial tracking will be developed to track head direction and separation in seats.

Currently using Yolov7-pose in Python to extract locations of test subject from video

- Need single-stage processing
- Need multi-person tracking
- This can be changed to different algorithm if needed

All video to be post-processed so computation does not need to be real-time and we can accept some longer post-processing time

- Can be run in real-time depending on video quality input and graphics card used, but there is no benefit to this

Add additional AI-based behaviour monitoring if possible in the future based on classification and body posture data – overlay onto manual annotation system before human review during manual video annotation

- Position/head orientation is prioritized since these are continuous measurements which are known to be critical and are very tedious and time consuming to manually track
- Automation of other behaviours may be added if project resources allow, behaviour choices will be based on readiness of existing models and potential reliability of AI methods weighed against time/effort saved in manual annotation work

Focus on custom-designed video annotation system to manually annotate from synchronized video streams with overlaid posture/head position data

- Custom designed or custom-adapted system to make the annotation process as easy as possible
- Certain times such as boarding queue, boarding/disembarking, jet-bridge will be quite busy so a relatively user-friendly system is required
- Will significantly reduce person-hours required per minute of video, allowing more video to be analyzed with given project resources
- Will reduce potential for notation errors, researcher fatigue – minimize potential errors

Develop system with anonymization plan built in which keeps all relevant extracted data – not required for internal CATR use

- Allow for potential deployment for field studies

Manual annotation allows us to ensure all required complex behaviours are captured and provides 100% built-in quality check

Example Screenshot

Example screenshot from fully automated data extraction process thus fa

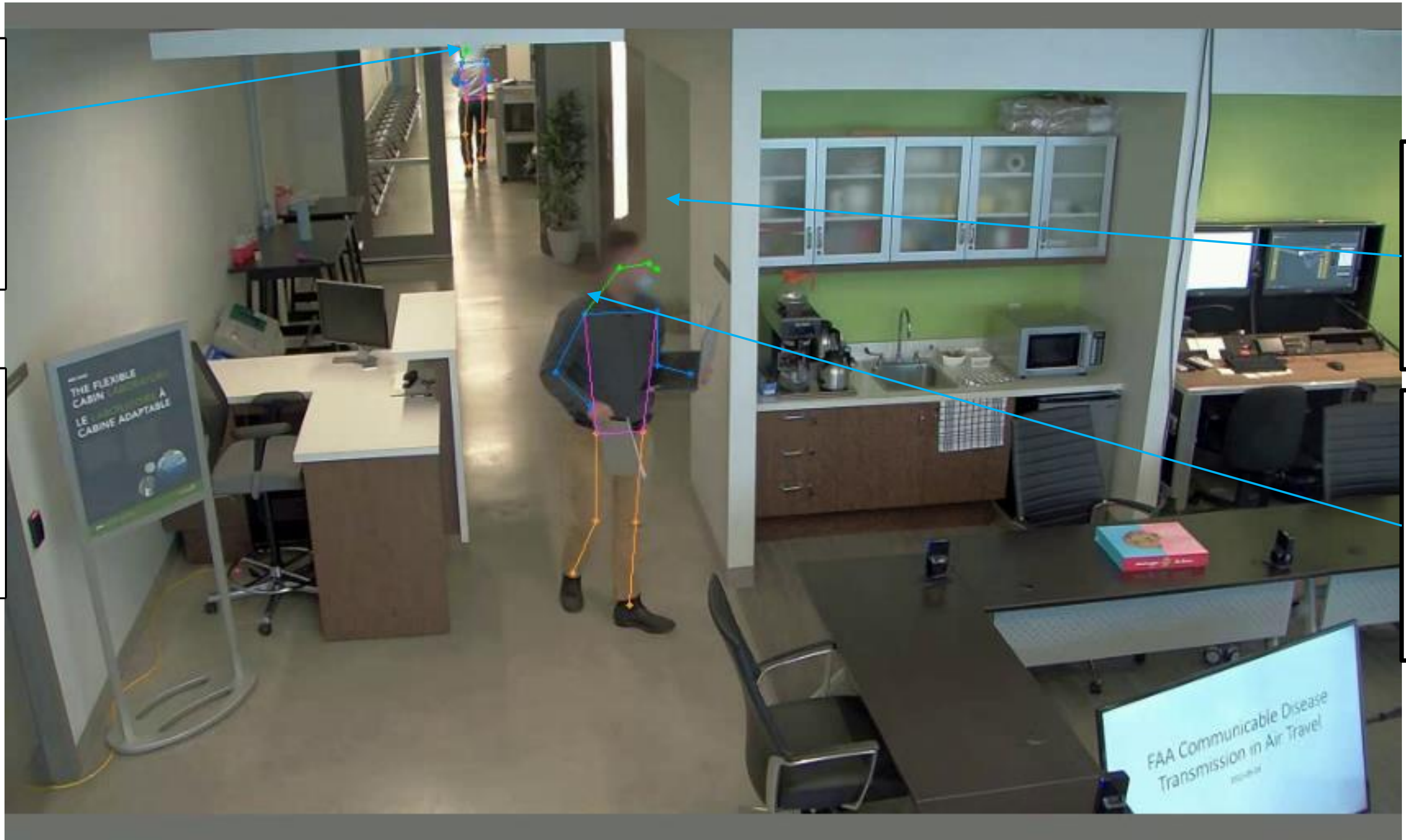
Some level of inference of position of occluded areas

18 point skeleton model (can be expanded, but higher computational load)

Reliable, fully automated facial blurring based on facial key-points extracted from full skeleton model with custom pre/post processing routines

Location and orientation of head is determined from raw video and overlaid over auto-anonymized video to allow future annotation of video without ethics/privacy concerns

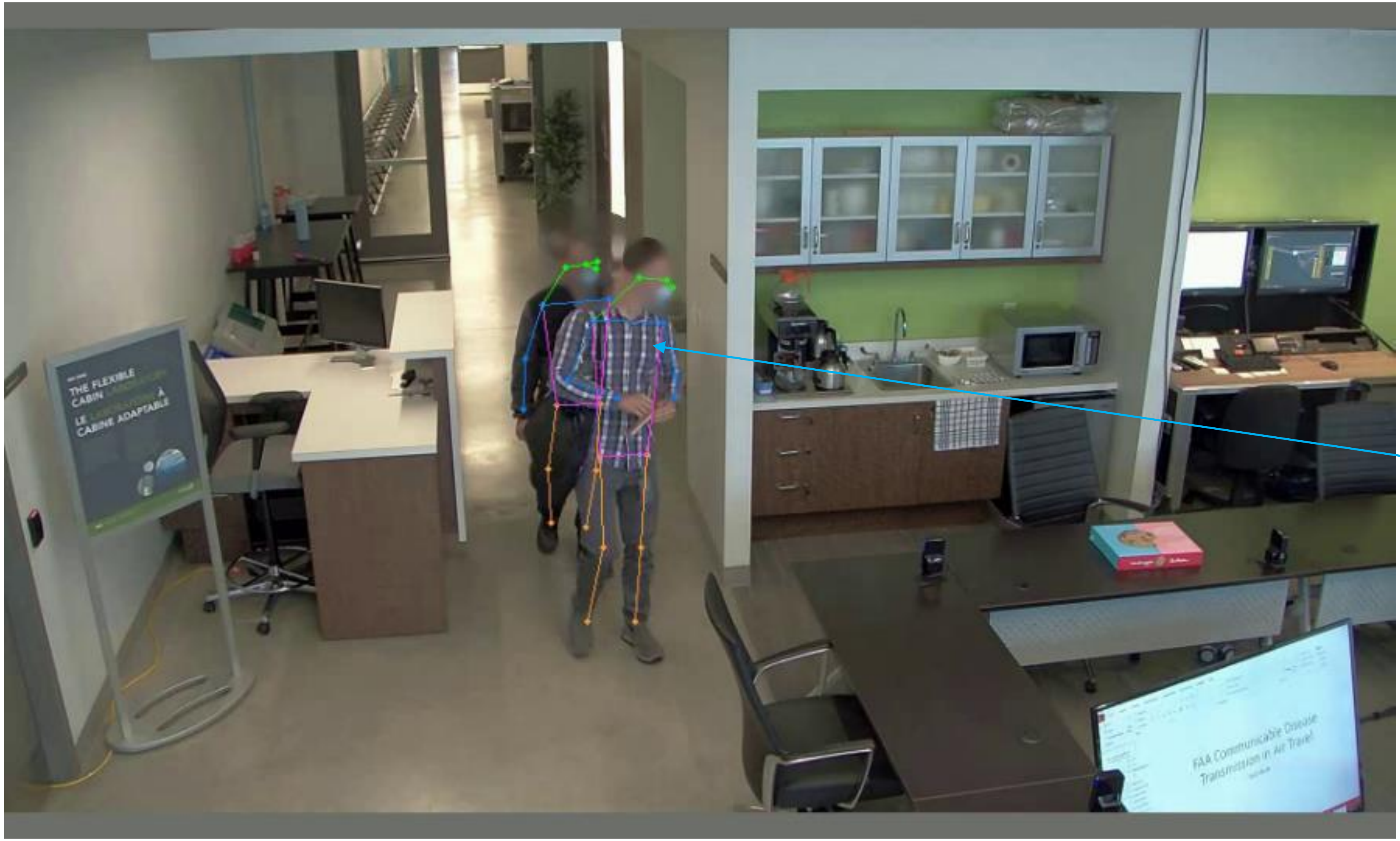
Example Screenshot #2



Full body-based facial/head position works reliably with and without mask-wearing

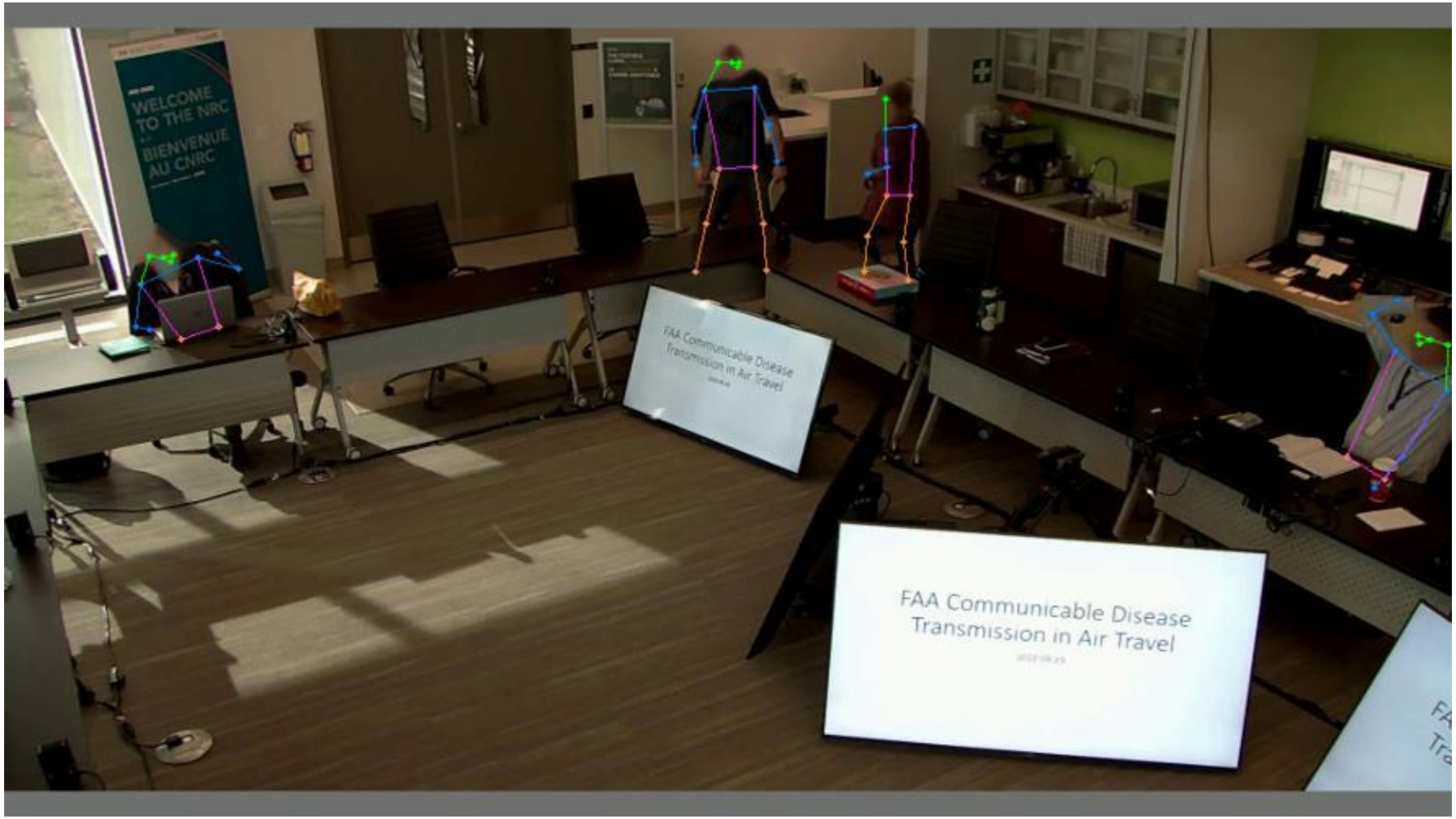
Reliable full body position including hands allows for potential automation of specific behaviour detection

Example Screenshot #3



Works well with multiple subjects at once even when subjects occlude one another

Example Screenshot #4



Works well with seated and standing postures

Remaining Challenges and Future Evaluations

Validation of existing algorithms/systems in CATR environment including tightly packed cabin

Development of stereoscopic camera based positioning algorithm and adaptation of existing work using stereoscopic cameras – evaluation of reliability of measurements

Development of relative head distance and orientation measurements from 2D cameras in cabin environment

Scaling to multi-camera systems allowing full coverage of whole experimental area

Creation of custom hybrid manual/automatic video annotation software

Evaluation of re-recognition algorithms for tracking individuals over long-term to establish in-group/out-group behaviours

Development of automatic detection/highlighting of other behaviours, contact between people, contact between objects, etc.

PHYSIOLOGY: MINUTE VENTILATION

Dr. Andrew Law

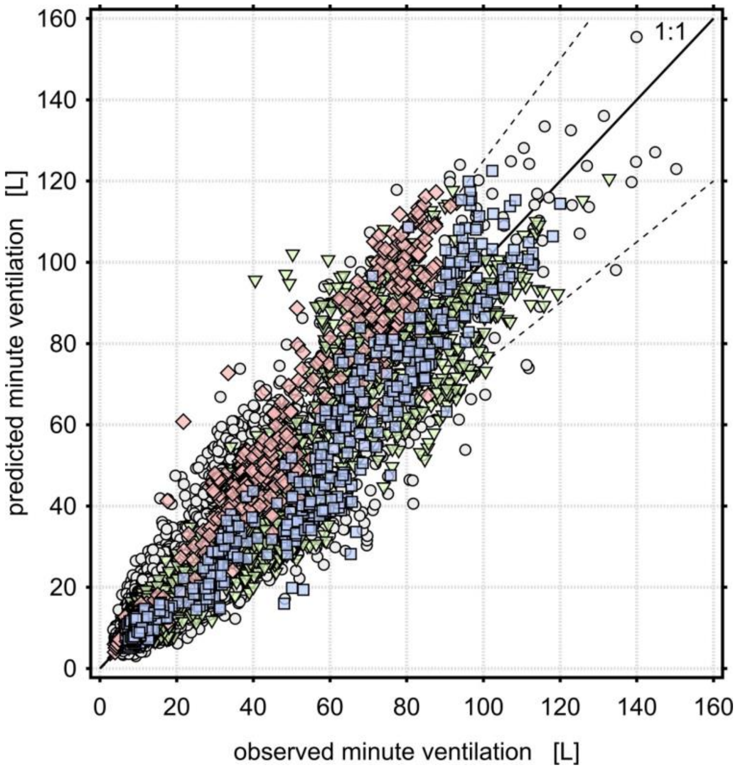
Andrew.law@nrc-cnrc.gc.ca

Effects of demographics and physical activity on minute ventilation

- Minute ventilation can be estimated from heart rate (HR), respiration rate (f_B), age, sex, and forced vital capacity (FVC)

$$V_E = e^{-8.57} HR^{1.72} f_B^{0.611} age^{0.298} sex^{-0.206} FVC^{0.614}$$

Greenwald, Roby, et al. "Estimating minute ventilation and air pollution inhaled dose using heart rate, breath frequency, age, sex and forced vital capacity: A pooled-data analysis." *PLoS One* 14.7 (2019): e0218673.



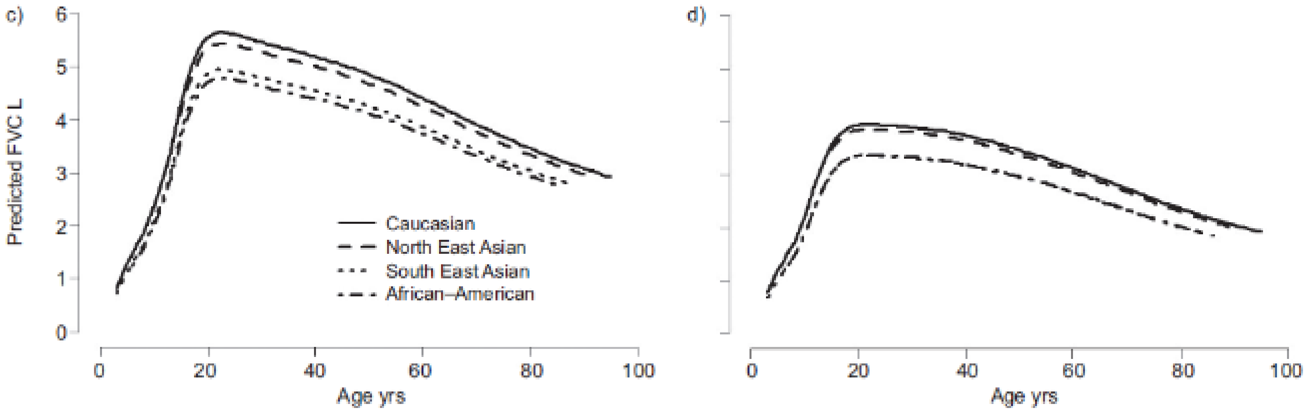
Circles are persons without an FVC measurement; triangles are persons with measured FVC = 85–115% of the predicted value; diamonds are persons with measured FVC < 85% predicted, and squares are persons with measured FVC > 115% predicted.

- Forced vital capacity (FVC) can be predicted based on age, sex, ethnicity, and body size

Quanjer, Philip H., et al. "Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations." (2012): 1324-1343.

Males

Females



Effects of cabin pressure and hypoxia on minute ventilation

- Minute ventilation increases with hypoxic ventilatory response to reduced oxygen pressure in cabin

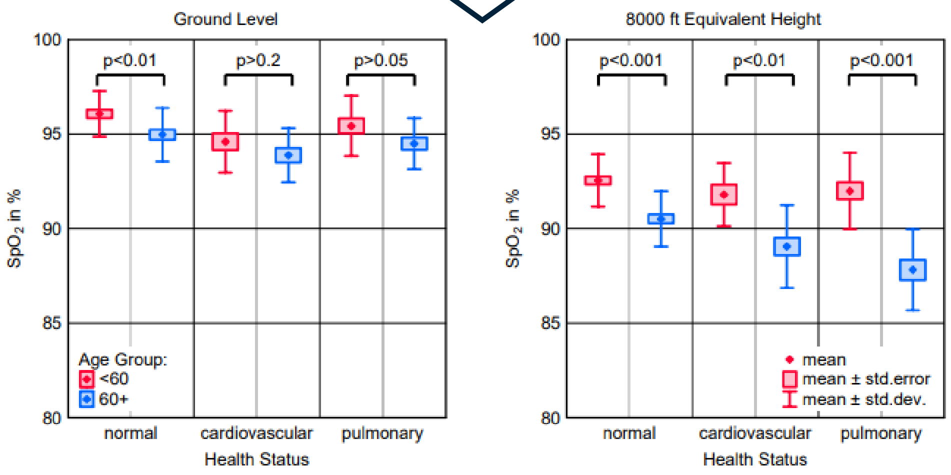
McNeely, Eileen, John Spengler, and Jean Watson. "Health effects of aircraft cabin pressure in older and vulnerable passengers." *Report No. RITE-ACER-CoE-2011-1. National Air Transportation Center of Excellence for Research in the Intermodal Transport Environment (RITE)* (2011).

Table 5. Breathing and Heart Rate Measures – Chamber Study.

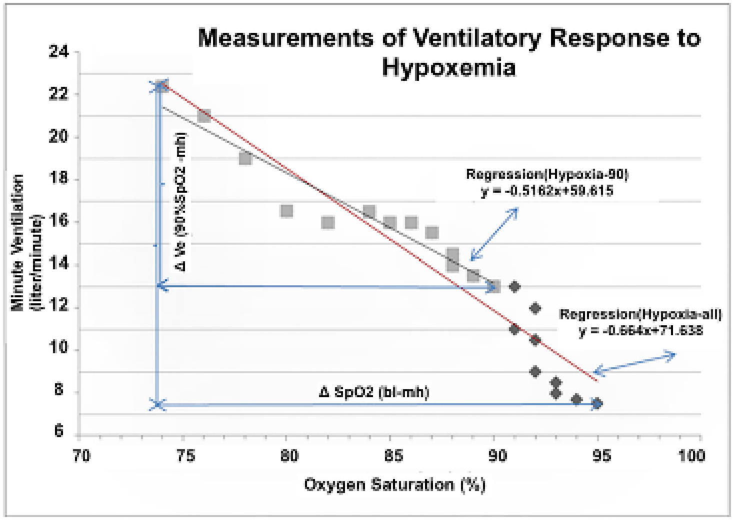
Period/group	Control Days Subjects (N)	Control Days Mean(SD); Range	Flight Days Subjects(N)	Flight Days Mean (SD); Range
Minute ventilation (L/min)				
Overall	40 (2289)	13.5 (7.6); 0.9, 68.1	41 (2334)	15.8 (8.6); 3.4, 79.2
Healthy	14 (682)	12.6 (5.4); 2.4, 37.3	14 (696)	14.4 (7.7); 3.4, 78.9
Cardiac disease	12 (748)	14.5 (8.4); 3.0, 57.1	13 (798)	16.4 (9.9); 3.4, 67.4
Smoker	14 (859)	13.3 (28.9); 0.8, 296.1	14 (840)	16.5 (7.9); 5.5, 79.2
Baseline SaO2 ≥96%	34 (1954)	13.5 (7.8); 0.9, 68.1	35 (2021)	16.2 (8.4); 3.9, 79.2
Baseline SaO2 <96%	6 (335)	13.3 (6.4); 4.3, 52.9	6 (313)	13.2 (9.2); 3.4, 78.9
Age <65y	23 (1345)	13.1 (8.3); 0.9, 64.6	24 (1378)	16.2 (9.6); 3.4, 78.9
Age ≥65y	17 (944)	14.0 (6.3); 4.3, 68.1	17 (956)	15.3 (6.9); 5.2, 79.2

- Effects of cabin pressure on blood oxygen saturation (SpO_2) and minute ventilation depend on multiple factors, including age and health status

Grün, Gunnar, et al. "Impact of cabin pressure on aspects of the well-being of aircraft passengers–a laboratory study." *Proceedings of 26th ICAS Congress, Anchorage, Alaska, USA*. 2008.



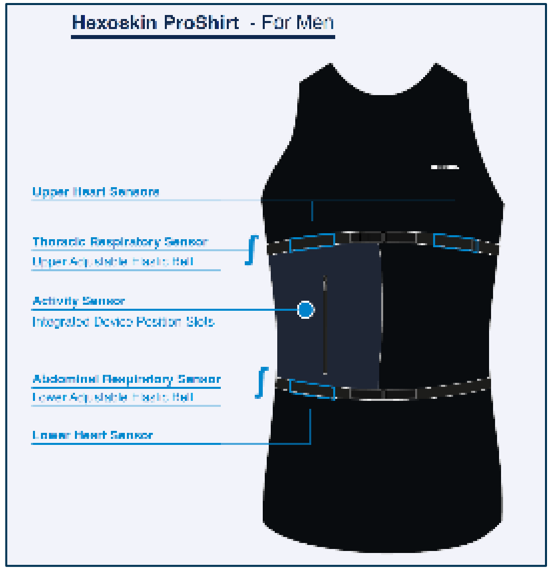
Goldberg, Shmuel, et al. "Analysis of hypoxic and hypercapnic ventilatory response in healthy volunteers." *PLoS One* 12.1 (2017): e0168930.

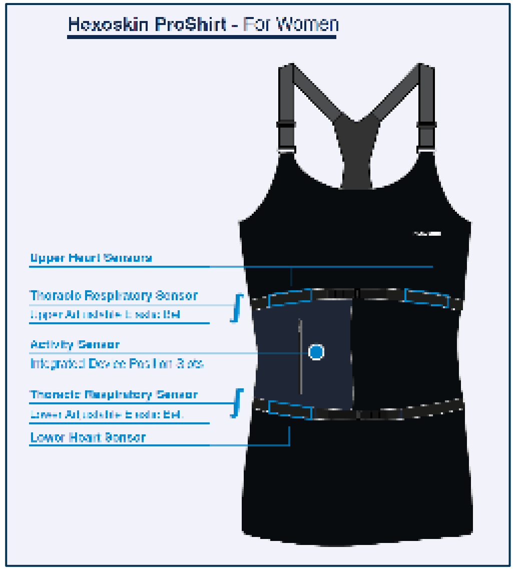


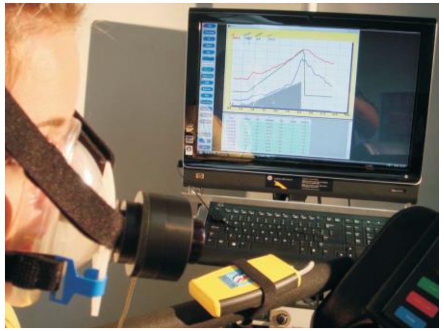
Proposed method for measuring minute ventilation (CATR or in-flight)

- The Hexoskin ProShirt provides continuous monitoring of ECG, respiration rate, tidal volume, and minute ventilation

- Hexoskin tidal volume measurements require initial calibration with a respirometer



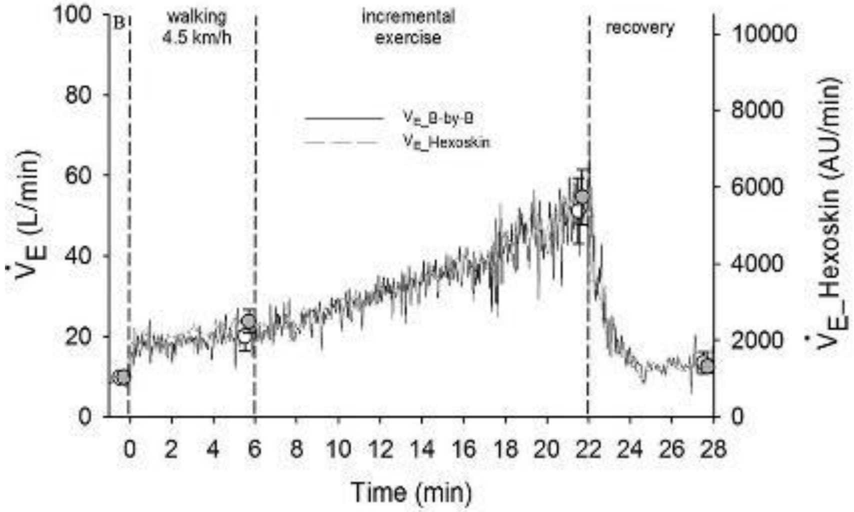




Vacumed 17130 Spiro Flow-Volume Module

- Hexoskin measures have been validated across different postures and activities of daily living

Villar, Rodrigo, Thomas Beltrame, and Richard L. Hughson. "Validation of the Hexoskin wearable vest during lying, sitting, standing, and walking activities." *Applied Physiology, Nutrition, and Metabolism* 40.10 (2015): 1019-1024.



Physiology

Please see the word document in the associated folder

AI based speech detection algorithms development

Sebastian Ghinet, Charly Tenon Kone, Ryszard Dabkowski, Dana Sayed Ahmed, Anant Grewal

Sebastian.Ghinet@nrc-cnrc.gc.ca

Speech Detection

- **Context:** AI technology is thought for this application to identify and capture the duration of an individual's speech in a conversation with others without capturing the content of the speech. This application will extract the required features from the participant speech to allow for the calculation of their speech duration. These speech durations will later be used to calculate the potential risk of viral contaminants spread during an individual's speaking activity in a multi-participant speaker environment within an aircraft cabin or an airport space. Therefore, the accurate speech detection/identification characteristics in noisy environments is of outmost importance.
- **Objective:** The main objective of this task is to advance the development of a portable device that each participant can wear, or a device that could be mounted onboard an aircraft within the seat backrest in front of each participant.
- The developed device will analyze the acoustic data acquired using an integrated electret microphone and will only provide as output, information on the speaker anonymous identification and the GPS time when the their speech started and ended for each sentence during a conversation such as:

Speech Sequence ID #	Speaker ID#	Start time (HH:MM:SS)	End time (HH:MM:SS)
1	Speaker 1	10:16:22	10:17:31
2	Speaker 2	10:17:45	10:18:53
...			

Speech Detection

Plan:

- Open-source artificial Intelligence based Speaker Diarization algorithms such as PyAnnote will be integrated into the developed device.
- The algorithms will only be used to accurately detect the speech signal present in the aircraft/airport noisy environment and extract the information required for this project.
- In order to comply with the privacy requirements of this project, no speech will be recorded and no audio files of any participants speech will be saved/exported on any storage support.
- Instead, some features of a speaker diarization algorithm will be used to accurately identify and time stamp the beginning and the end of the sentences corresponding to each speaker detected by the algorithms integrated in the portable device.
- All portable devices will be GPS time synchronized for a global identification of various participants interactions during each experiment.

Speech Detection

Progress:

- Literature review completed to identify present applications of speech recognition system development and integration for aerospace applications such as aircraft cockpit and cabin.
- Literature review completed to identify available open source artificial Intelligence based Speaker Diarization algorithms.
- Multiple algorithms were identified and the team decided to further develop the Speech Detection Algorithms for this project based on PyAnnote algorithms.
- PyAnnote was installed on a NRC server and the following work is in progress:
  - Literature review of user manuals and research articles on PyAnnote algorithms;
  - Compile the Python scripts and run validation/verification application cases for speech detection;

Future work:

- Starting in September: algorithms tailoring and optimization for speech detection task.

Speech Detection

Conclusion:

- The algorithm proposed for this project will only be used to identify the time stamps corresponding to the beginning and the end of the sentences accurately associated with each speaker.
- This information will allow to accurately determine for how long each participant talked with other participants to calculate the viral contaminants spreading risk due to each individual speaking activity

Speech Detection

Proposed Speaker Diarization procedure for accurate multiple speaker speech time stamps generation:

- Step 1: **Speech Detection**: Specific algorithms are employed to differentiate speech from background noise in the audio signal.
- Step 2: **Speech Segmentation**: This step entails extracting small segments from the audio file, typically of approximately one second long. Each segment is associated with a particular speaker, ensuring isolation of individual speakers within the audio signal.
- Step 3: **Embedding Extraction**: At this stage, all the embedded speech segments generated and gathered in Step 2 are consolidated. These segments are then utilized to create a neural network specifically designed for speaker embeddings. These embeddings will next be utilized within a deep learning framework.
- Step 4: **Clustering**: Once the speaker embeddings are derived in step three, the subsequent step involves clustering these embeddings that exhibit similar characteristics or belong to the same speaker, to enable effective organization of the speech segments.
- Step 5: **Labeling Clusters**: Following the clustering process, the resulting clusters are labeled, typically indicating the number of speakers present within each cluster. This labeling step helps in identifying and distinguishing different speakers within the audio recording**.**

Speech Detection

Please see the word document in the associated folder

GHD Advisory

Safety Risk Assessment of Communicable Disease Transmission in Air Travel: Development of Field Data Methodology

→ Movement Strategies & National Research Council Canada

Steve Gwynne, Shelley Roberts, Paul Lebbin, Steve Hunt, Ailsa Hamilton-Smith, Russ Thomas, Ryszard Dabkowski, Hui Xie, & Kasper Pannell

METADATA

Title	Safety Risk Assessment of Communicable Disease Transmission in Air Travel
Abstract	Development of a methodology to be employed in Phase II of the project. Includes development and application of field observations techniques.
Client	Federal Aviation Administration
Filename	FAA Phase I Report - Field Observations FINAL.pptx
Version / Status	V8
Author	Steve Gwynne, Shelley Roberts, Paul Lebbin, Steve Hunt, Ailsa Hamilton-Smith, Russ Thomas, Ryszard Dabkowski, Hui Xie, & Kasper Pannell
Reviewer	Simon Owen (GHD Section), Steve Gwynne (NRC Section)
Date	21/09/2023

General Approach

The National Research Council Canada (NRC) and Movement Strategies (MS, a GHD company) were asked by the FAA to collect field and experimental data in support of the FAA modelling of passenger / environment interactions across the dyads shown in **Figure 1**. The scenario suggested by the FAA was:

- A single-aisle commercial aircraft (e.g., A320 / B737) engaged in scheduled part 121 operations, in single class configuration, and using its auxiliary power unit at the gate during boarding, departs from a gate at Airport#1 in December for a 3-hour uneventful flight (no turbulence, etc.) to Airport#2, where it arrives and deplanes at a gate while use a ground cart for air supply. There are no enhanced disease transmission control measures in place in the baseline case.

MS was brought into the project to support NRC given their experience in the following areas:

- Conducting field observations/experiments across the passenger timeline in different scenarios. This includes experience in data collection on pedestrian performance during the pandemic.
- Experience in applying/testing different data collection techniques/technologies.
- Using empirical data in simulation models to explore different scenarios and to dig down into underlying dynamics.

These aligned with the requirements of this phase of work, given the scenario outlined, namely:

- The compilation of the current understanding of passenger behaviour across the dyads of interest such that a broad picture of passenger actions can be developed – specifically those actions that might increase passenger exposure to a viral outbreak.
- The description of these actions such that they can be captured via a set of data collection activities.
- The design and application of a field observation methodology enabling a sub-set of these actions to be explored.
- The development of a refined version of this methodology and data collection metrics for review by the client and stakeholders later in 2023.
- Support for the development of a methodology for experimental trials to be conducted at NRC facilities later in the project.

This report outlines the work conducted by MS and NRC in successfully meeting these objectives: the development and testing of field observations, focusing on the passenger performance and the metrics that might be captured. A description of the experimental trial methodology is outlined in the accompanying Phase I report. The parallel environmental work conducted by NRC is delivered separately, although is referenced at numerous points in this report for context.

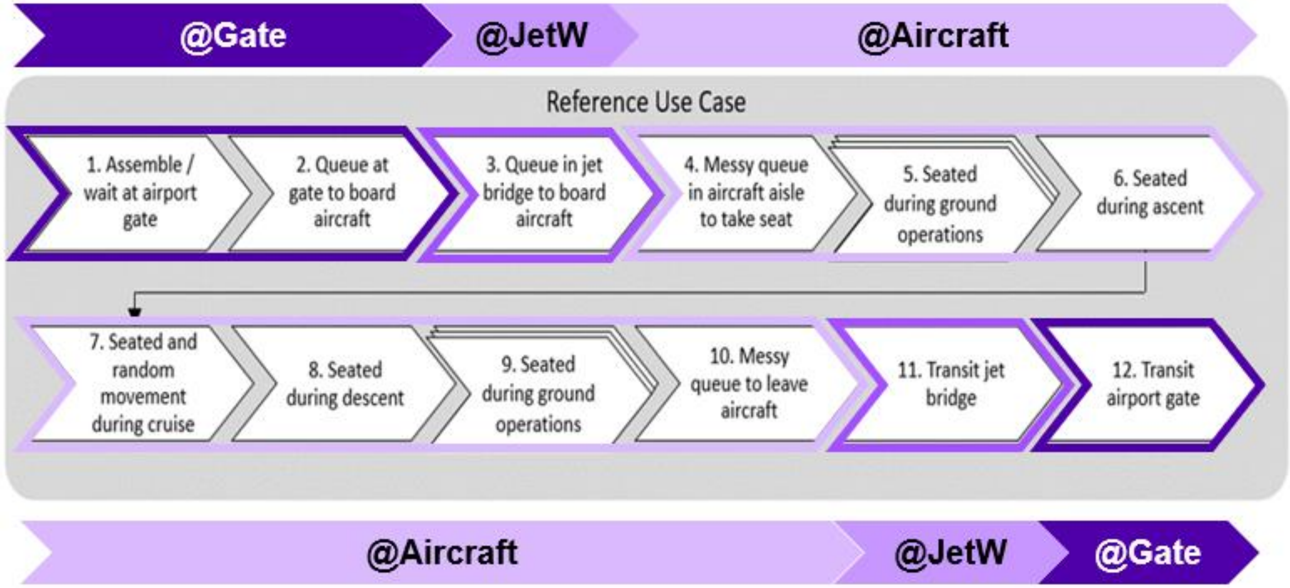


Figure 1: Dyad locations of interest.

General Approach

Phase I of the project includes three primary stages (see **Figure 2**):

❶ **Compile current understanding**:

- Review existing material to identify data that might be used, methods for data collection and factors / passenger actions that should be examined as part of Phase II data collection efforts (see **Appendices 1A – 1B**).
- Receive feedback from clients and stakeholders during biweekly meetings and periodic workshops conducted during Phase I.
- Review of tools currently available to establish passenger counts (from video data) (see **Appendix 2**).

❷ **Data collection activities:**

- **Develop a simple conceptual model of passenger behaviour** reflecting best understanding of the actions and interactions that might be expected during the use case.
- **Develop and execute a plan for field observations** (see **Appendices 3A – 3C**).
- **Identify lessons learned** from these field observations and establish the types of data that could be captured from these activities.
- **Establish a template for data extraction from video footage** (used both in relation to CCTV cameras at the airport and supporting coverage of the CATR facility during the planned experiments (see **Appendices 4 – 7**).

❸ **Looking forward:**

- **Develop a data collection plan for future field observations**.
- **Develop a data collection plan for the CATR trials**.

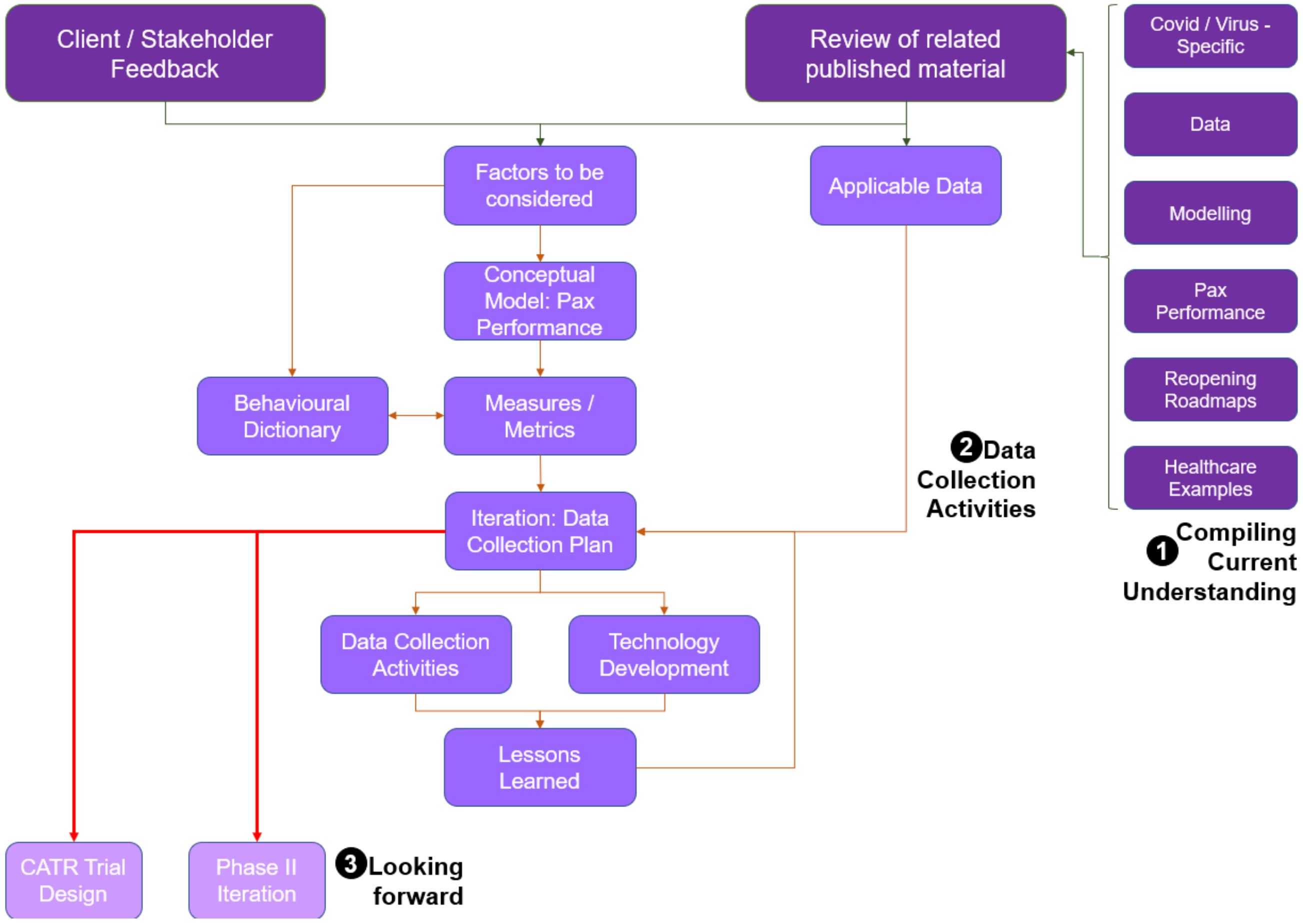


Figure 2: Key stages of Phase I of the project.

These tasks form a basis for Phase II data collection and modelling methodology. Key contributions to the development of the methodology are briefly described in the follow pages, along with the assumptions and limitations associated with the manual observations and extraction from video footage for the scenario examined (described overleaf).

General Approach:Assumptions and Limitations

	Assumptions	Limitations
General	• Selected flights are representative of the scenario conditions. • Data timings capture key periods – including peak times given the additional potential for interaction. • Data produced is consistent across the various data collection methods and can be synchronised to a single timeline. • Presence of observers/technology do not affect behaviours observed. • Identity of the public will be protected and (1) no effort will be made to deliberately identify members of the public and (2) every effort will be made to not accidently allow for this identity to be revealed. These two points underly the method developed. • Refinement of behavioural dictionary does not exclude behaviours that significantly affect the conclusions drawn.	• Actions are represented in a reductionist form – broken down into basic constituent parts. In addition, they will be analysed independently of an individual – such that an individual's narrative (sequence of actions) across their travel will not be maintained. This is a limitation, but also an additional protection of passenger anonymity.
Manual Observations	• Sampled areas at gate / onboard are representative of similar locations at other airports or on comparable single-aisle aircrafts. • Refinement of behavioural dictionary does not exclude behaviours that significantly affect the conclusions drawn. • The visual catchment area of the observers at the gate and onboard allow for key data to be collected.	• The ad hoc nature of the qualitative observations at the gate; i.e., that the observer (albeit an expert observer) notices key movement characteristics. • Actions are assigned on an individual basis. In reality, multiple actions are performed simultaneously. The approach adopted will report actions as a sequence of composite tasks. • Observers may vary in the way in which they compile data. Measures will be taken to minimize this (e.g., template development, training, testing, etc.); however, some variation is expected. • Timing will be based on observer recognition and recording the event type.
Data Extraction	• Data timings capture key periods – including peak times given the additional potential for interaction. • Sampled areas at gate / onboard are representative of similar locations at other airports or on comparable single-aisle aircrafts. • Sufficient data will be captured to compensate for gaps in the manual observations (e.g., the production of more refined value distributions, etc.). • The visual catchment area of the camera and the quality of the images produced (at the gate / jetway) will allow for key data to be collected.	• Actions are assigned on an individual basis. In reality, multiple actions are performed simultaneously. The approach adopted will report actions as a sequence of composite tasks. However, attempts will be made to identify passengers in adjacent time increments where possible. • The cameras are fixed in position, although it may be possible to rotate them in some instances. This provides a limited capacity to adapt to changing passenger conditions (e.g., plane comes into to a different gate, local incident means certain seats are not used, etc.). • Passenger actions may be lost if they are continually facing away from the camera.

Compiling Current Understanding

Compiling Understanding

The authors were tasked with capturing passenger behaviour across the set of dyads[1] shown in **Figure 3**. This is in conjunction with data on the environmental conditions – such that the conditions faced can be coupled to the extent that potential exposure might be assessed.

The goal was then to establish the types of behaviours that might reasonably be expected (and which are deemed to influence exposure) and then determine how data might be captured to quantify these behaviours; i.e., define a data collection methodology.

The first stage of this was to identify current understanding - the types of behaviours that passengers might perform and the degree to which these are understood to affect exposure.

Material was compiled by reviewing literature from several different subject areas (see ❶ in **Figure 2**):

- Covid-19 specific material
- Data collection related to the outbreak
- Attempts to model exposure / human activities
- Passenger performance (especially related to the outbreak)
- Reopening roadmaps & healthcare activities.

This involved a review of 160+ articles. This was not exhaustive – but focused on articles published in English, within 20 years of the pandemic, and in publicly accessible research.

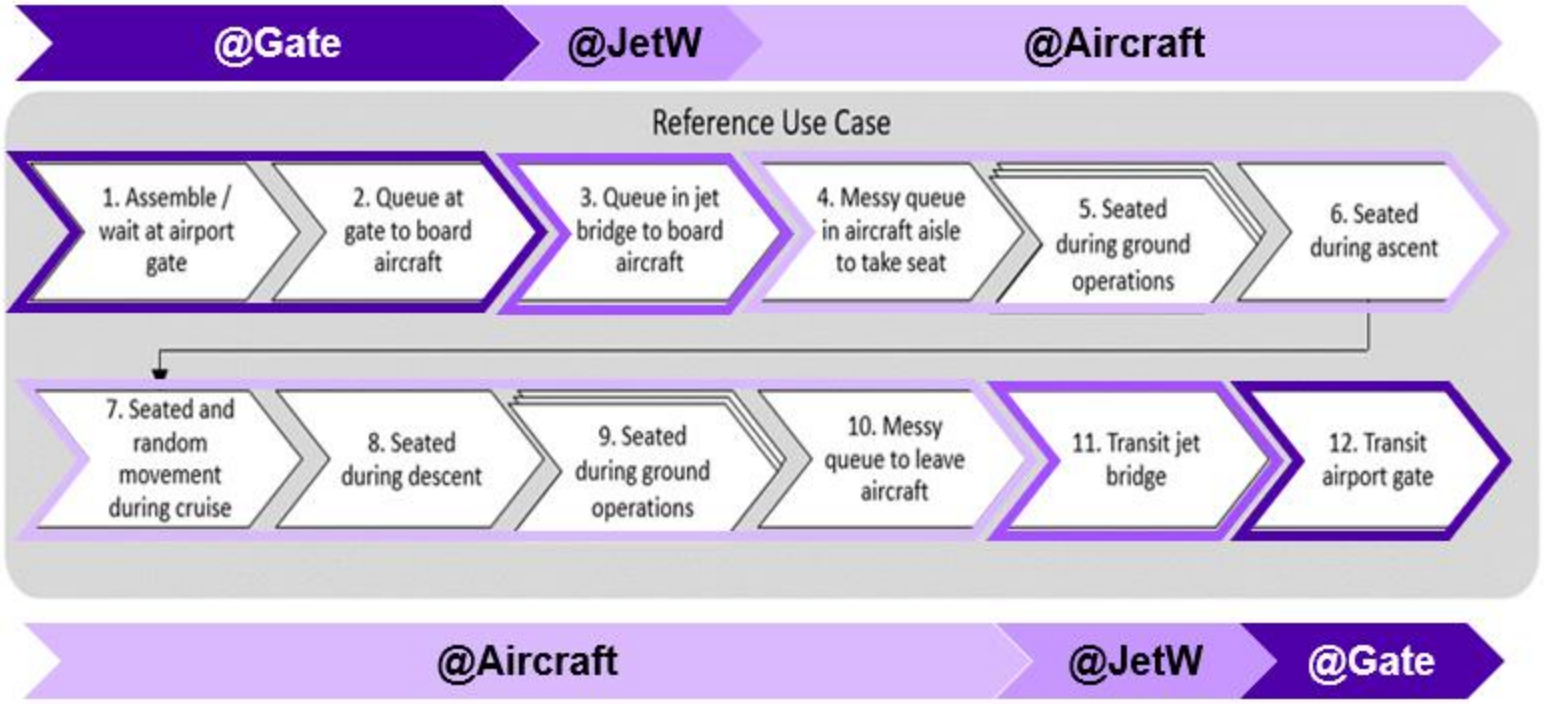


Figure 3: Dyad locations of interest.

[1] Defined by the actions performed and environmental conditions present given the time and location.

Compiling Understanding: Passenger Actions

The goal of this compilation was to learn methodological lessons and also to identify data that might be employed by models in assessing passenger exposure. The general findings are reported **in Appendix 1A**, with sources deemed to be of particular empirical or methodological value described in **Appendix 1B**.

A model was extracted from the reviewed content by identifying several sets of factors:

- Agent Attributes / Agent Actions,
- External Objects with which actions might interact,
- Output types that might be produced by agent/object interactions and then through compiling examples in the aggregate.

This model is descriptive and is an aid to the elements that might be of interest in our future data collection efforts. It should also be noted that the version of this model shown in **Figure 4** does not represent the full set of actions and objects identified from the literature review. This set has been reduced – both given the relevance of factors to the work being conducted and also given the lessons learned from the field observations. As such, this iteration of the model is a pragmatic take on the factors that might affect passenger performance in the dyads identified, and that might reasonably be modelled.

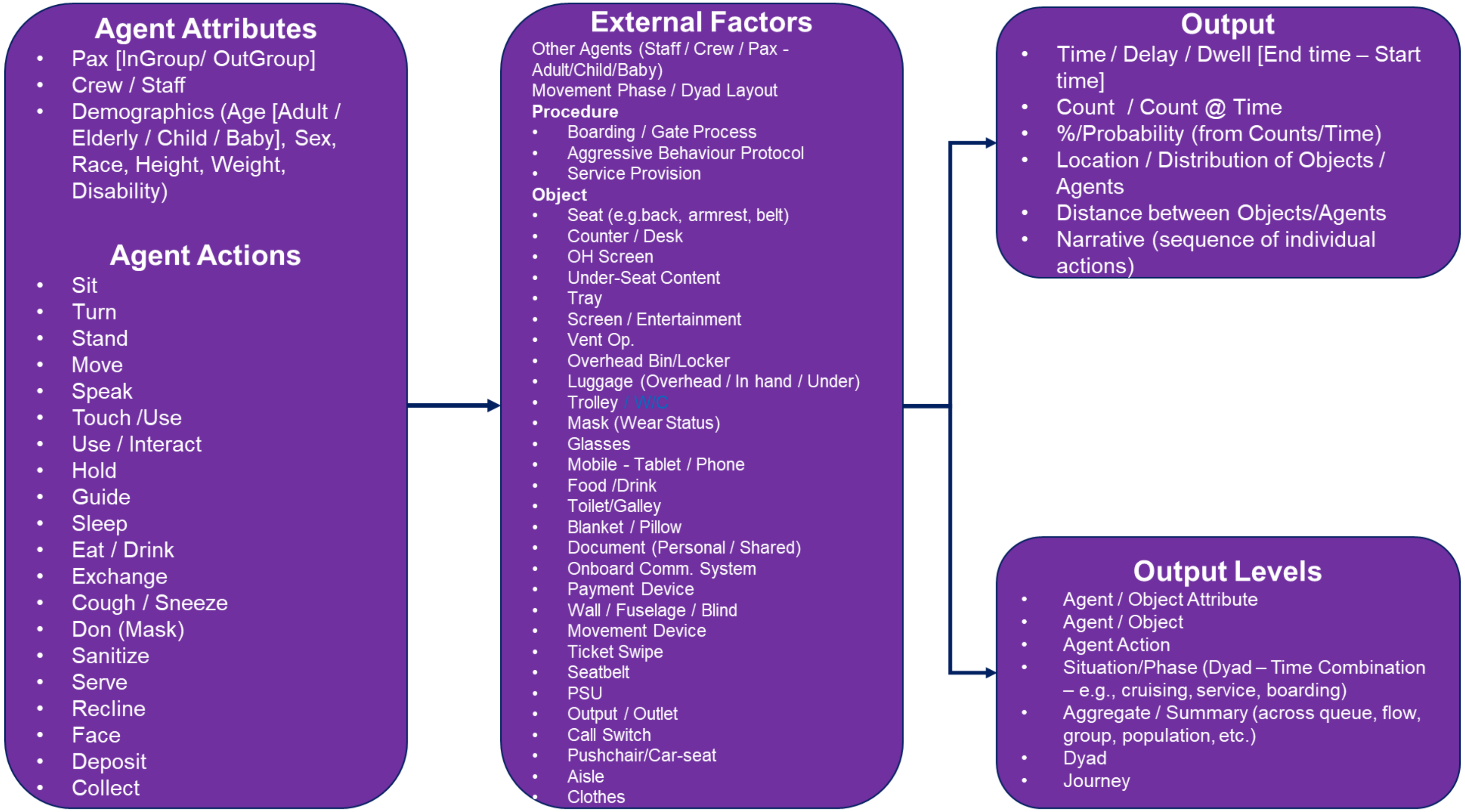


Figure 4: Expected passenger actions and interactions.

Modelling Strategies

As stated, our objectives are threefold:

- To generate data that reflects passenger behaviour that might affect their exposure to viruses present in the dyads of interest.
- To generate a methodology for collecting such data in the field and in experimental settings representing those dyads.
- In doing so, support the development of models to reflect passenger behaviour and its relationship with environmental conditions present in those dyads.

Reflecting on this last point, it is worth noting that there are broadly three approaches to model such relationships:

- Microscopic (representing humans as individual agents moving within the locations within a dyad).
- Macroscopic (representing population activities given a particular dyad).
- Statistical (representing factors and their impact on dependent outcomes).

The first two represent deliberate attempts to reflect passenger performance, albeit at different levels of granularity (see **Figure 5**). As is apparent, the approaches require different inputs and produce outputs at different levels.

This means they are capable of producing different types of insights and can be similarly subjected to different levels of testing. Such testing will inform the validity of the approaches but also the benefits of employing them; e.g., how much confidence do we have with microscopic predictions verses macroscopic predictions across the dyads in which we are interested?

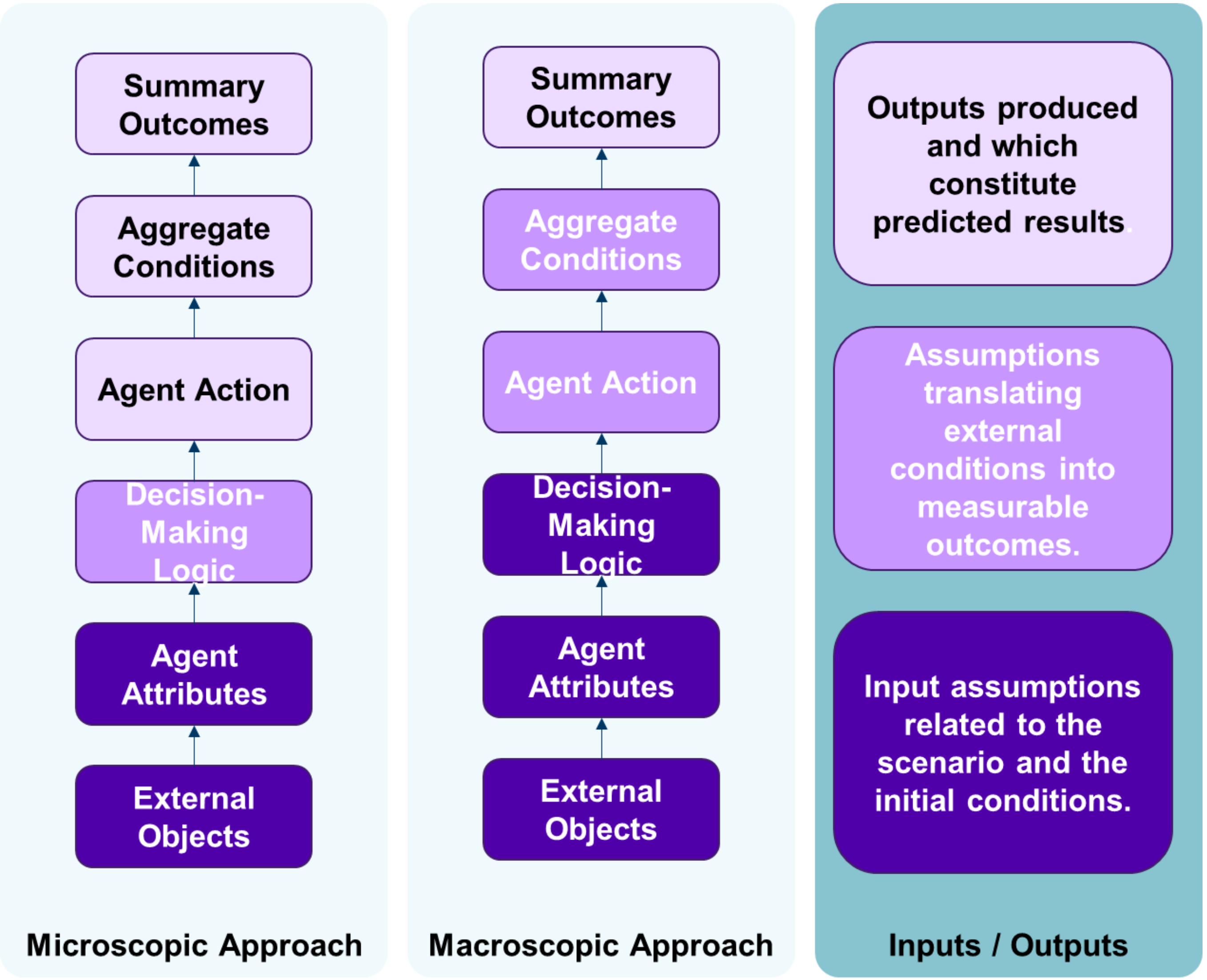


Figure 5: Model granularity and its impact on inputs and outputs. *(Derived from: Gwynne,S.M.V., Hunt,A.L.E., Why model evacuee decision-making?, Safety Science 110 (2018) 457–466.)*

Data Collection Activities

Field Observations

Trial field observations were conducted in Canada in April/May 2023 (see ❷ in Figure 2). **The objective of these trials was to test the effectiveness of the provisional plans developed, the technology employed, and the assumptions made to ensure that the data collected met the needs of this work (i.e., could be applied within the FAA models).** These trials are described in more detail in **Appendix 3A**. These trials included:

- Overnight visit to Airport#1 (25/4/23)*. Establish camera positions, grid locations of interest.
- Overnight trip to Airport#2 via Airline#1 to test data collection approach and prototype iPad app design (30/4 - 1/5/23)*.
- Debrief on data collection efforts with NRC staff (2/5/23) *. Update app design / simplify data collection activity. Return trip to Airport#2 via Airline#2 (3/5/23)*.
- Visit to the CATR facility and debrief on data collection efforts with NRC staff (4/5/23)*. The goal here was to update app design and simplify data collection activity.

*UK Date formats used here

Figure 6: Pre-trial preparation during overnight visit.

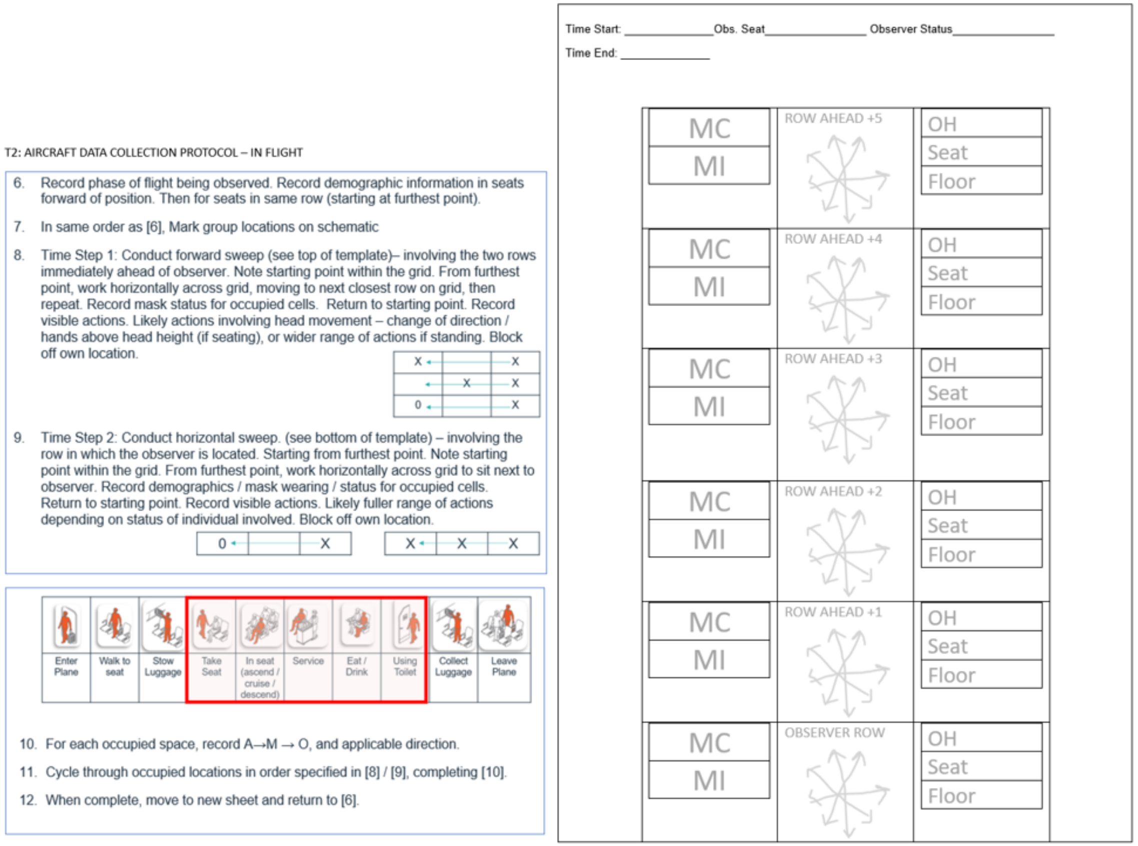


Figure 7: Later iteration of template for onboard data collection.

The work conducted during the field observations was to try out the approaches developed and learn methodological, logistical and procedural lessons to enhance the scope and content of the data collected in Phase II (see Figure 6 and Figure 7) – ensuring that it better meets the end users' needs (e.g., FAA modellers).

It also allowed data to be captured. The team analysed this data (again trialling the analytical approaches developed), primarily to determine the types of data that might be generated (format and content) and the effort required to do so.

Field Observations: Data Analysis

A sample of the data collected during the Phase I field observations of passenger movement has been examined. The data collected and the implication for the Phase II field observations are presented in **Appendix 3C**. The objective of the Phase I field observations as a pilot study is not to produce a representative data-set for practical use. Instead, the aim is to identify:

- the types of data that might reasonably be collected through manual observations,
- limitations in the data collection method,
- the limits to what might be expected of observers in the field,
- the gaps that cannot be filled by manual observation, thus informing the requirements of the video and experimental data collection.

The data analyzed represents approximately 10% of the manual observations during the Phase I field observations. However, it represents a range of locations, observers, attributes/action types (i.e., content types), data formats, and data from different levels (e.g., individual, population, aggregate, etc.). As such, it provides an overview of the passenger behavioural data that can be collected through manual observations.

Object	Touch		Use	
	Frequency	Time (s)	Frequency	Time (s)
Luggage	0 (0%)	-	0 (0%)	-
Document	8 (20.5%)	24.8 ± 4.6	15 (38.5%)	21.5 ± 11.3
Mobile device	**19 (48.7%)**	21.0 ± 10.6	4 (10.3%)	22.5 ± 0.9
None	12 (30.8%)	21.1 ± 7.1	**20 (51.3%)**	21.9 ± 7.1
All	39 (100%)	21.8 ± 8.7	39 (100%)	21.8 ± 8.7

Figure 8: Frequency / time of touching and using objects.

The data analysis conducted was designed to explore a range of different situations, events/actions, levels and formats – to determine whether the extraction of such data is possible (see **Table 1** and **Figure 8 – Figure 9**).

Table 1: Aggregated flow rates.

	Flow rate (pers/min)		
	Weighted average	Min	Max
Boarding	6.1	5.5	9.1
Deplaning	9.9	6.6	12.0

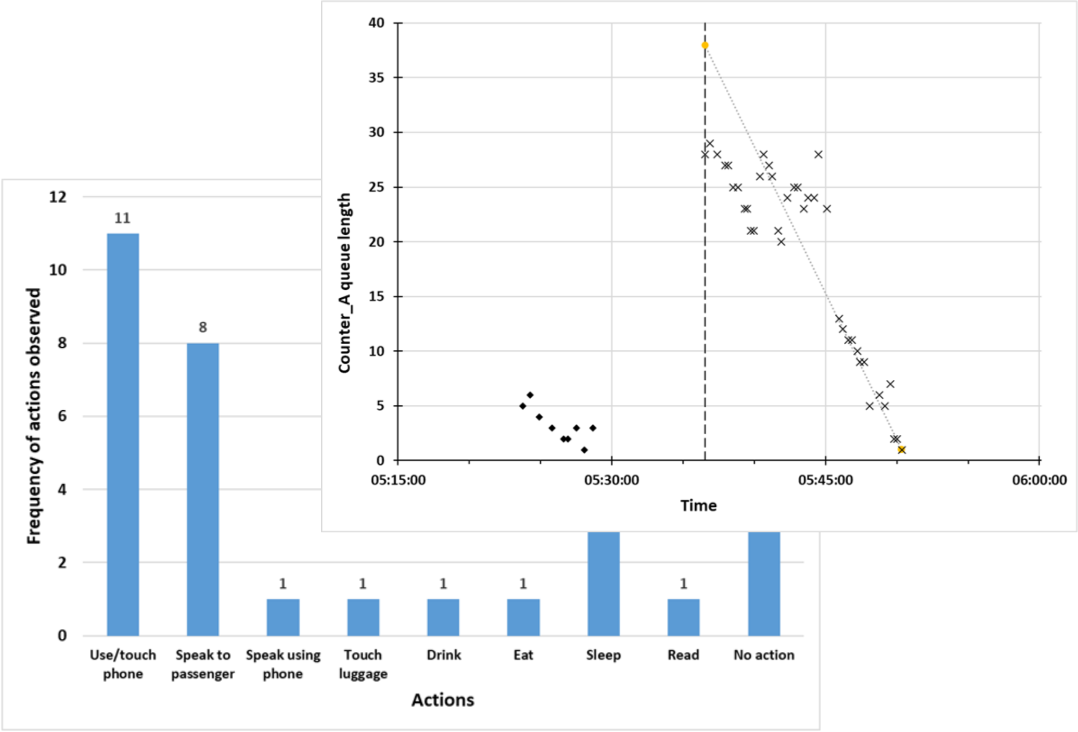


Figure 9: Frequency of actions and queue length.

Field Observations: Data Analysis

The data collection exercises, and the video extraction, have demonstrated that several data types can be produced. These are defined as the follows:

- Time period (by Factor) [End time – Start time]
- Count Total (by Factor / Location)
- Count (by Factor / Location) vs Time
- Average Measure (by Factor/Level) [accompanied by range or SD]
- Frequency Distribution (by Factor)
- Speed (m/s) (by Factor)
- Flow (p/s) (by Location / Factor)
- % Population (by Factor)
- Probability of Occurrence (by Level/Factor)
- Location / Distribution of Objects / Agents (vs Time)
- Derived Population Density / Distance between Objects/Agents
- Narrative (sequence of events / actions / locations) by Level.

One or more of these might be used for each of the data types described later in relation to the three modes of data collection (field observations, video footage extraction and experiments at the CATR facility).

The precise data types available will be dependent on the Factors and Levels. In this context, Factor refers to the attribute, action, or condition being represented; e.g., time spent speaking, etc. Level refers to the granularity of the data produced – or at least that used in the production of the data type in question.

There are several different degrees of refinement:

- Agent Attribute (e.g., by Age) or Object Attribute
- Agent or Object (e.g., Touch / Seat)
- Agent Action (e.g., Move)
- Situation (Dyad – Time Combination) (e.g., During Service)
- Aggregate / Summary (e.g., across queue, flow, group, population)
- Dyad (e.g., during boarding)
- Journey (e.g., between gate to gate)

It is apparent that some of these relate to physical entities (e.g., agent or object), some represent a procedure or event (e.g., when service was being conducted), while the others are a composite at the individual level (e.g., journey from gate to get – see **Figure 10**) or aggregate level (e.g., queue development – see **Figure 11**).

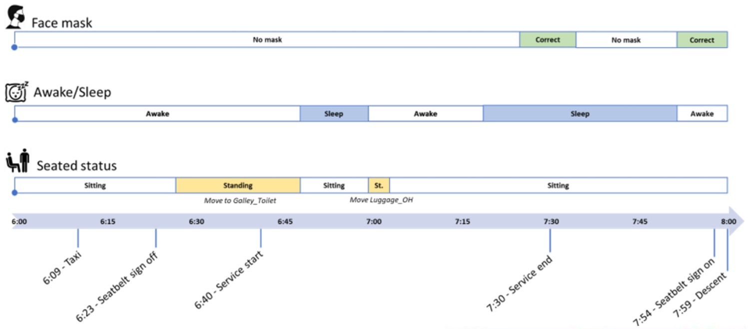


Figure 10: Individual narrative.

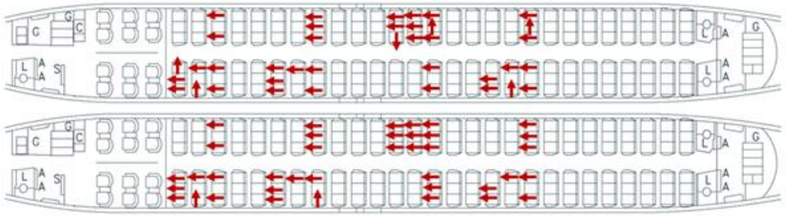


Figure 11: Map of passenger direction over time.

Video Data Analysis from Comparable Settings

A provisional template was developed and applied to a comparable people movement scenario to determine its applicability and capacity to produce useful data (see ❷ in Figure 2)**.** This work paralleled effort to design a procedure for field observations given the overlap in the data collected.

- GHD staff previously recorded people movement during their attendance of 21 large-scale public events held in the UK during the pandemic.
- These government-sanctioned pilot events (including theatrical, sports, music, business events) were held to explore the impact of specific capacity levels and non-pharmaceutical interventions to reduce covid transmission (e.g., mask wearing, social distancing, etc.) on the crowd behaviour and aggregate conditions produced.
- They were part of the UK Government's effort to assess the potential impact of reopening public events upon the spread of covid virus.
- Video footage from one of the events was deemed suitable having identified conditions that approximated the those in the gate area (see Figure 12).
- For instance, the public has access to seating areas, services, and were exposed to scheduled events that they wanted to attend.

This led to them waiting, interacting with other seated members of the public, circulating through the space and tidal flows reflecting motivated movements to/from events.

The goal here was not to generate data representative insights into passenger behaviour at gate areas, but to test a template design to see if data reflecting key elements of their behaviour and identify enhancements might be captured (see Table 2).

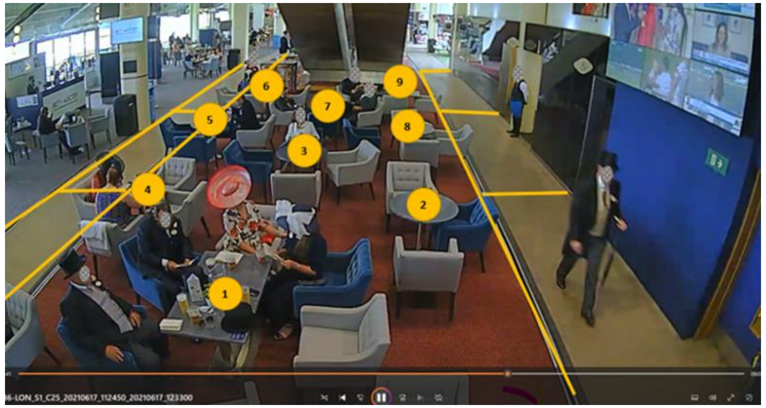


Figure 12: Trial Data Extraction from video footage.

The assumption made was that the application of the template to this footage provided useful insights into its application to gate footage. A time was selected when the area was busy to maximize the data collection opportunity.

A detailed description of this effort is presented in **Appendix 3B**.

Table 2 : Example output from data extraction.

Person	Previous Alias?	Previous Alias? (2)	Loc	Mask	Direction	Status	Action (1)	Modifier (1)	Action (2)	Modifier (2)	Action (3)	Modifier (3)
G4_01_00			G4	N	In	Sit	Speak	In	Touch	Device		
G4_02_00			G4	N	In	Sit	Speak	In	Touch	Device		
G5_01_00			G5	N	In	Sit	Speak	In				
G5_02_00			G5	N	In	Sit	Speak	In				
G5_03_00			G5	N	In	Sit	Speak	In				
G6_01_00			G6	N	In	Sit						
G7_01_00			G7	N	In	Sit	Speak	In				

Translating to Model Inputs

- The output produced from the field observations might inform model application in several ways. This impact will depend on whether the model is microscopic (representing humans as individual agents moving within the locations within a dyad) or macroscopic (representing population activities given a particular dyad).
  - **Qualifying individual performance.** Identifying the types of actions performed (e.g., carry baby), the conditions under which they are performed (e.g., during boarding) and the other objects and actors involved (e.g., path selected and the delaying of others moving behind them given their slow movement).
    - For **microscopic** models, this will inform the agent set of actions to be represented and the potential impacts that might need to be represented.
    - This might inform the description of situations represented within **macroscopic** models. For instance, a collection of individual acts might combine to produce an episode to which aggregate conditions are assigned in a macroscopic model.
  - **Qualifying aggregate conditions.** Identifying the situations when/where certain conditions might emerge and outlining their impact. For instance, where do queues occur and what is their footprint, etc.
    - This will be a benchmark of comparison for **microscopic** models. For instance, the paths adopted, or location of merging flows might be compared.
    - In a **macroscopic** mode, this will be an input describing the nature of a particular emergent condition. It might confine the condition. For instance, the queue footprint might affect the space available for other aggregate conditions in the dyad.
  - **Quantifying an element of individual performance.** For instance, the time an individual spent at the desk. This is assigned per individual once they encounter a desk object and might be sensitive to the precise action performed (e.g., used mobile phone to board) and attributes associated with that individual (e.g., elderly).
    - For **microscopic** models, these would be inputs that set the behavioural performance of the agents. This might be set (to reflect a specific scenario) or randomised (to perturb conditions within a known set of boundary conditions). This would determine the impact of the action on the agent's movement.
    - This would not be relevant for **macroscopic** models.
  - **Quantifying the probability of the individual act occurring.** This would likely be done by developing an average value or a distribution.
    - For **microscopic** models, a set of probabilities would be interrogated when a certain situation was detected or would be driven to 'script' the response. This would determine the likelihood of an act occurring.
    - This would not be relevant for **macroscopic** models.
- **Quantifying aggregate performance.** For instance, the flow produced leaving the jetway, the queue length, the population density of people across an area. These rely on the actions and interactions of many individuals to produce the emergent condition.
  - For **macroscopic** models, this would be an input to determine the performance of the sub-population in a particular dyad given a condition faced.
  - For **microscopic** models, this would typically be a benchmark against which performance might be compared.

Simulation - Gate: Queuing at Desk

- Basic tests were conducted to explore the data collection procedure and the potential application of the data to agent-based modelling tasks. Namely:
  - Can the individual data collected regarding delays at the desk in the gate area be used to configure the agent-based tool? Is it the appropriate type of data and format to be employed?
  - What queuing is predicted by the agent-based tool?
  - Do the predicted queue lengths compare favourably with the aggregate queue length data collected at the gate?
- This examines the model's capability to generate reasonable results, but also the consistency between two distinct data collection efforts: the recording of individual delays at the desk and the queue lengths recorded during the same time period.
- Simulations were conducted using Pathfinder. It is intended that this model (along with the EXODUS model) will be used to simulate various passenger movement scenarios during Phase II.

Table 3: Example service times.

Service time (m)	Percentage
0.1	5.26%
0.3	63.16%
0.5	23.68%
0.7	5.26%
0.9	2.63%

- The model was configured using the observed service time delays at the airport desk - delay (in sec) per person. This was converted into a simple distribution experienced at gate. Initial performance was examined to ensure the movement was representative (see **Table 3** and **Figure 13**). A single queue was examined for simplicity. The simulated results were then compared against queue lengths observed.
- There was a simplification of grouping and demands – it was assumed that people crowding around queue when called and that movement to desk is negligible.

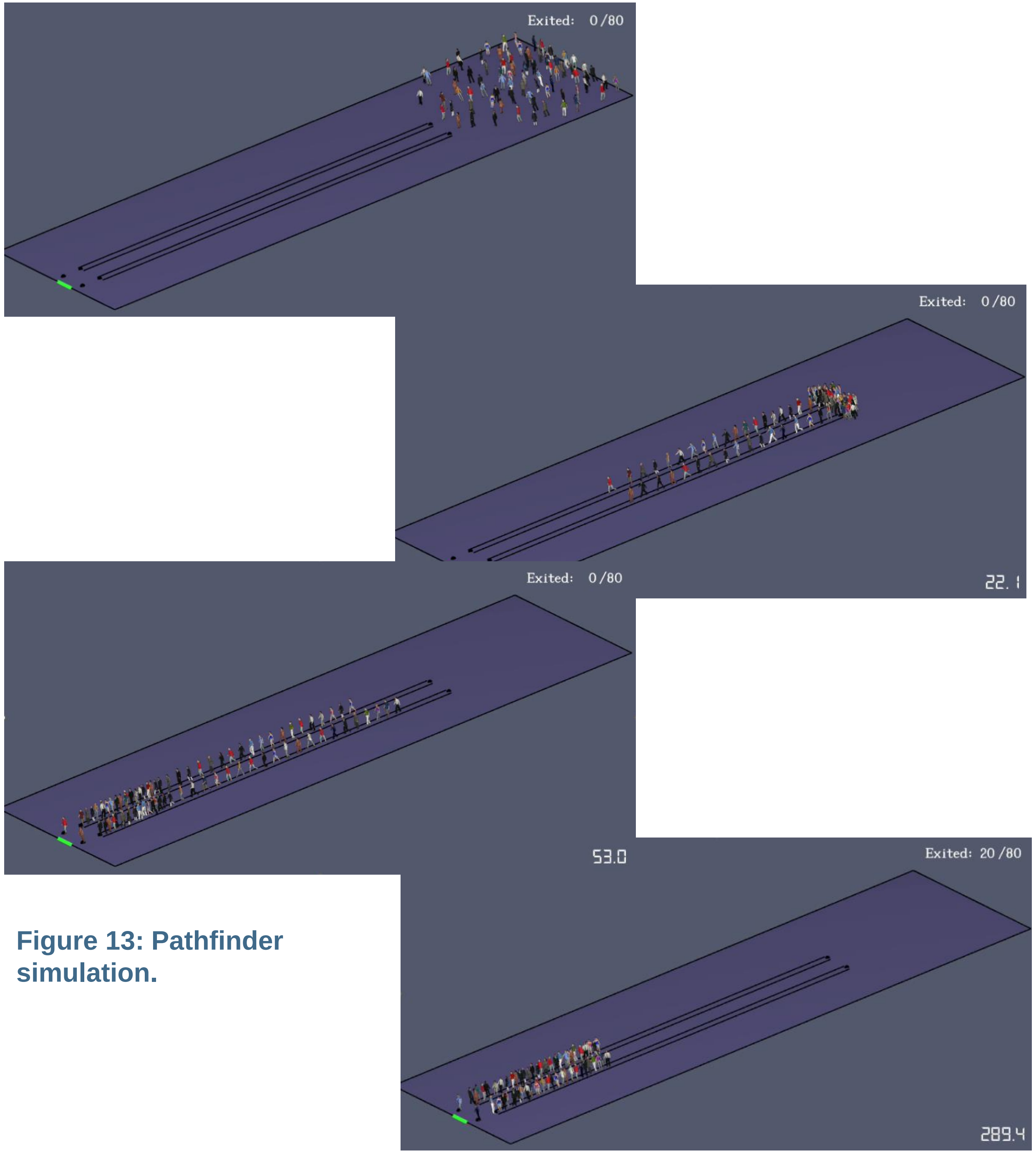


Figure 13: Pathfinder simulation.

Simulation - Gate: Queuing at Desk

- The queuing observations are shown in **Figure 14**. Nine queue observations were made before boarding was called (at approximately 05:37). At this point, the first group was called, and queuing continued throughout the rest of boarding. The data shown in **Figure 14** reflects the observed length of a single queue.
- **Figure 15** compares the observed data with the data generated through the Pathfinder simulation and through engineering calculations. In each case the queue length per time increment is shown.
- It is apparent that the engineering calculation closely approximates the observed data. The engineering calculation applied service times at the desk derived from the distribution of observed times. However, it did not represent the movement required to traverse the queue line. As such it was a simplification.
- The simulated output closely approximated both the engineering calculations and the observed data. The simulated data represented the distribution of movement speeds typically seen in an ambulant population and the distribution of service time delays. The simulated results also closely reflect the observations. This result suggests that simulation does not introduce variation that leads to the results deviating significantly from the simple engineering analysis (i.e., is not overly complex) and captures sufficient underlying dynamics to produce the observed aggregate conditions given the observed individual delays.
- Perhaps more importantly, both the simulated and engineering calculations suggest that the two data collection efforts (individual delays and aggregate queue length) are a reasonable reflection of the relationship between these two levels of activity.
- This suggests that the simulation tool might prove a useful means to augment the data collection and be used as part of the data collection planning. This might include:
  - Simulating the experimental design prior to execution in order to test the experimental protocol, subsequent participant movement, and data collection sources to ensure that the conditions produced are as expected and captured.
  - Simulating the experimental scenario after perturbing specific parameters (e.g., participant order, etc.) to generate a distribution of results – in the hope of producing more robust findings.
  - Simulating variants of the experimental scenario to test the stability of the scenario results; i.e., whether it is an outlier whose results drastically change given modest changes in the scenario condition (e.g., 5% increase in service time produces 100% increase in queue length, etc.).

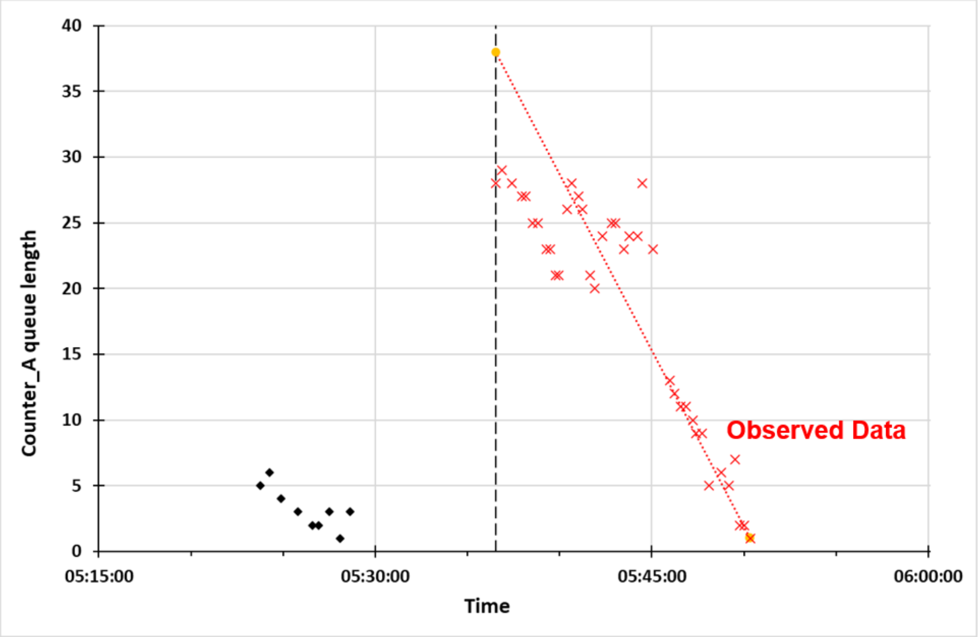


Figure 14: Observed queue lengths verses time.

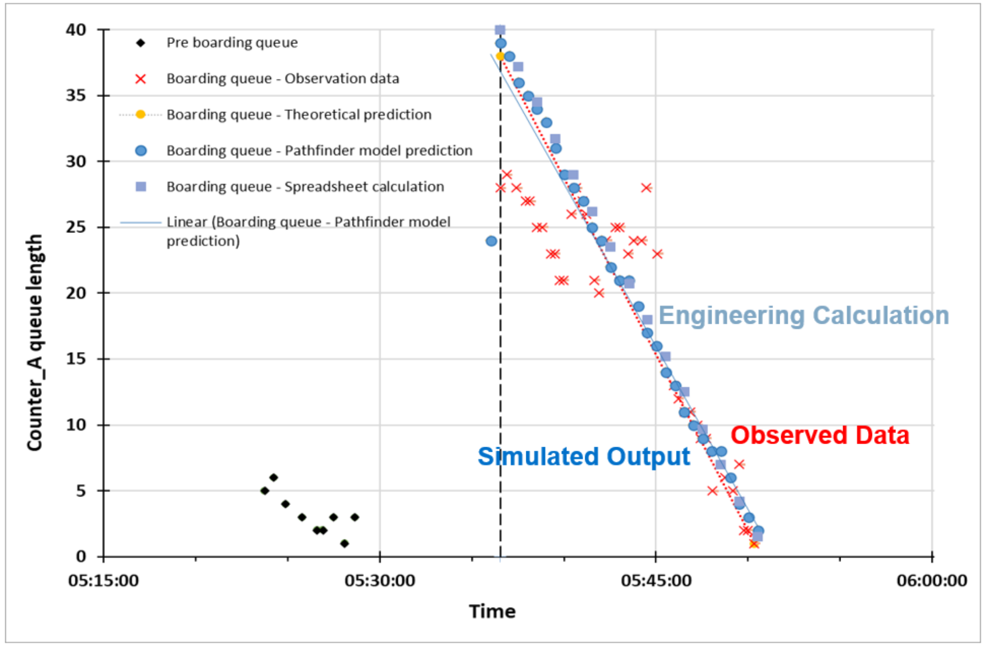


Figure 15: Observed/Simulated/Calculated queue lengths verses time.

Observation, Experimentation and Simulation

- The previous 'abductive' simulation use (bridging between individual and aggregate data) provides some confidence that the Phase I observation data might be used to configure such tools, albeit in a simple situation. Given the objective of Phase II (the creation of a data-set suitable for modelling), this is a positive finding.
- **Figure 16** shows the anticipated data generation and use in Phase II.
- The conceptual model will be used to inform the manual observation and video analysis methodologies – identifying what factors should be examined given practical limitations.
- Data will be produced from these activities. The stability of this data will be examined using the 'abductive' simulation bridging shown previously – ensuring that different data collection activities make sense within the same dyad context. The stability of the data will be similarly tested.
- This will inform the development of the final CATR scenarios and methodology. Both will be simulated to identify critical locations, unintended situations of interest, gaps in data coverage, and order of magnitude estimates for the results.
- The initial conditions in the CATR trials will be perturbed and the scenarios simulated to increase confidence in the robustness of the original findings.
- The model will also be used to reproduce the CATR results – allowing the conditions produced to be communicated in detail – in a naturalistic way – whilst maintaining the anonymity of those involved (see **Figure 17**).

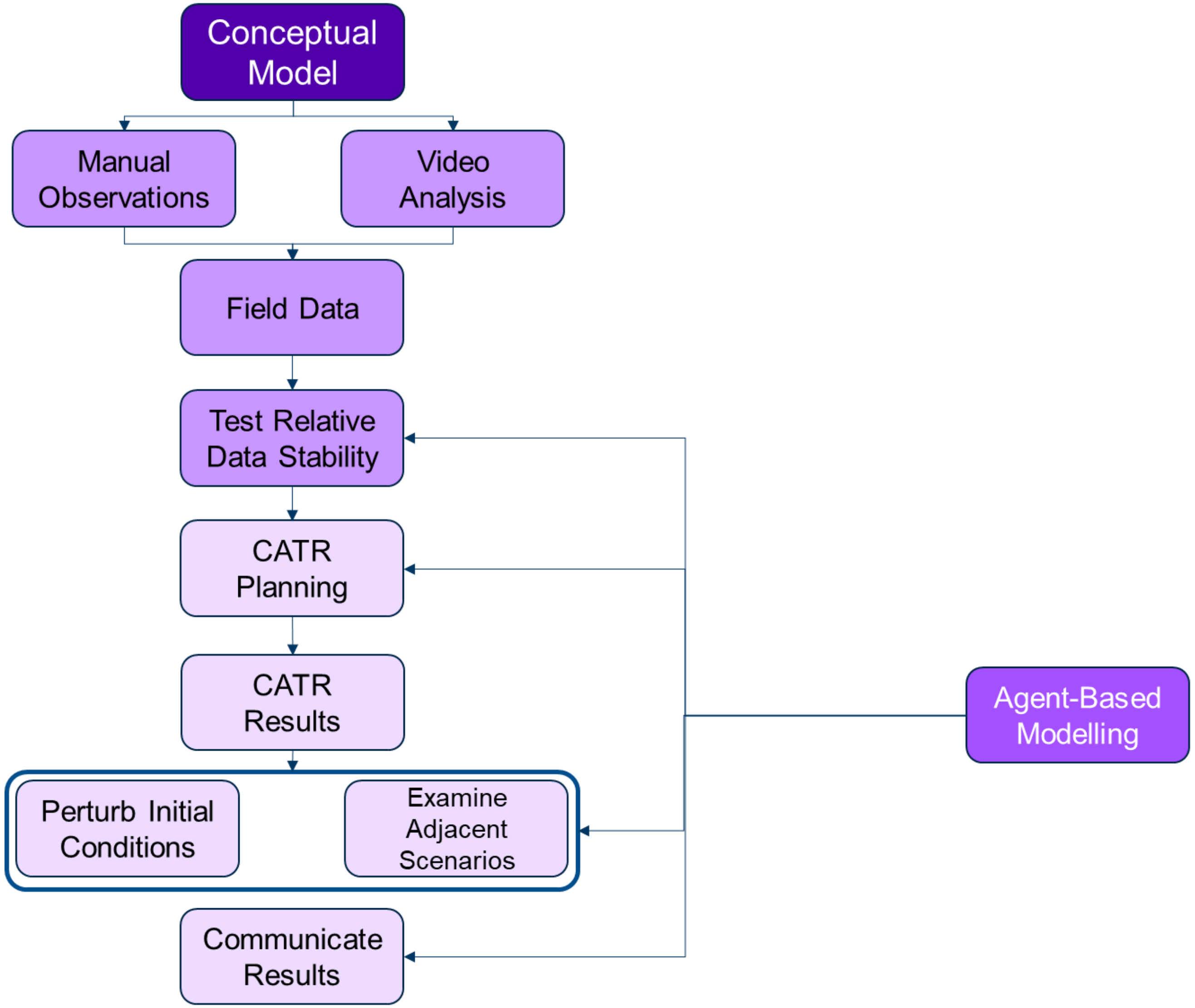


Figure 16: Use of agent-based simulation throughout Phase II.

Figure 17: Use of agent-based simulation to recreate experimental conditions.

Looking Forward

Looking Forward: Observation Methodology

An observation methodology is required (see ❸ in Figure 2). Three modes of data collection are available: manual field observations, video extraction from CCTV footage, and trial data from the CATR facility. These provide different coverage and different levels of detail in terms of the data that might be collected (see Figure 18).

These clearly provide access to different parts of the dyad timeline and different types of data – made more complicated by the fact that the CATR experiments will be a scaled version of the Gate/Aircraft environment making direct comparison between aggregate results more challenging.

Clearly:

- **Onboard observations do not include video cameras. Onboard manual observations are limited** (especially seat activities) by observer view and capacity to record rapid activities. This places extra emphasis on the CATR onboard trials.
- The CATR trials focus on conditions within each dyad, rather than the continuity of passenger experience across the dyads. In addition, CATR is a scaled version of the conditions experienced onboard. As such, aggregate conditions in the CATR facility will primarily act as a means of comparison (between data-sets and against modelling efforts).
- **Field observation only provides control over the flights being observed** (via manual observations of video extraction)**.** We have no control over the passenger demographics, population size, specific crew actions, the precise timing of boarding / onboard procedures, environmental conditions or gate allocations (these may be switched). There is some potential for switching between video footage of different flights (with comparable scenarios); however, although this would minimize any significant data omissions, it is likely to be a relatively costly endeavour.

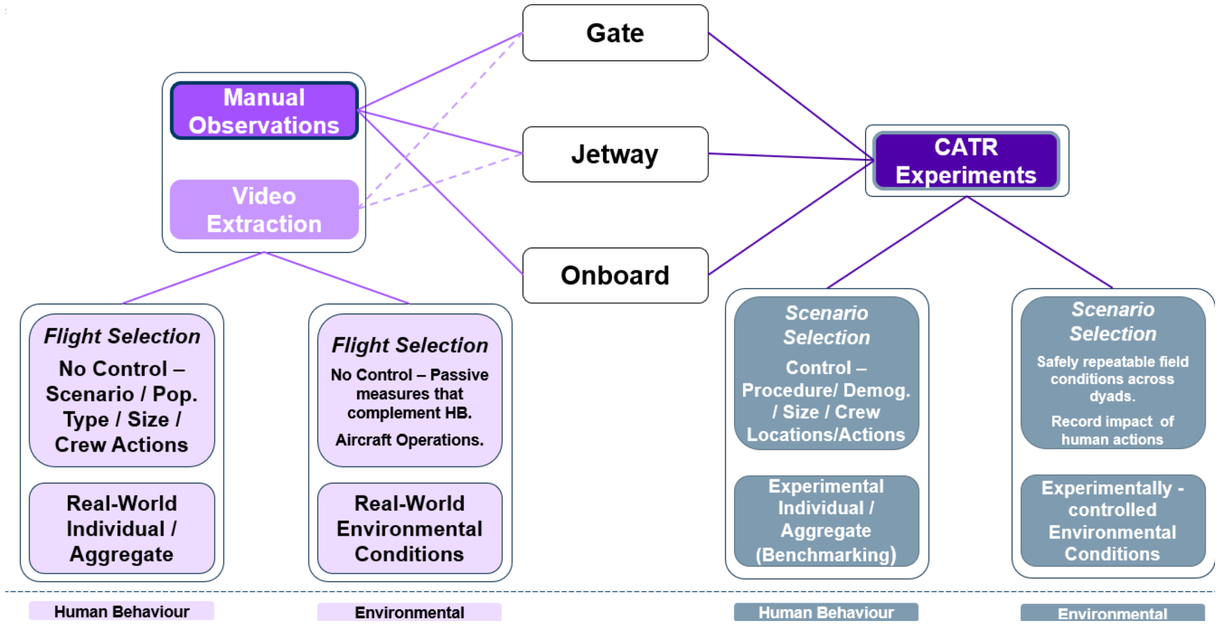


Figure 18: Data Coverage by dyad and source.

- **Experimental observation provides more significant control** over the passenger demographics, population size, scripted crew actions, the precise timing of boarding / onboard procedures, environmental conditions and gate allocation.

A set of *potential* data types (arranged by data collection method, dyad and level of refinement) are presented in **Appendix 7**.

Field Observations: Metrics By Dyad

- The set of metrics that might be captured across the Gate, Jetway and Aircraft dyads (see **Figure 19**) are described overleaf. A more complete list of these terms and basic definitions are presented in **Appendix 6**. This has been refined here reflecting lessons learned during the field observations and an initial prioritisation of data to be collected.
- This assumes the use of manual observations and/or data extracted from video footage.
- The set of metrics shown is not a suggestion of what **should** be captured, but what **might** be captured, and therefore requires prioritization.
- The data is described using four columns (see **Figure 20**):
  - Location: in which location within a dyad the data is being collected.
  - Qualitative: descriptive data outlining the types of conditions and performance observed.
  - Aggregate Quantitative: Metrics that relate to the performance across populations, locations or time periods. It should be noted that the individual quantitative metrics can be compiled and summarised to reflect additional aggregate conditions.
  - Individual Quantitative: Metrics that relate to the performance of individual passenger or crew actions. These relate to counts (‘#’) or timings. Specific metrics are identified along with a set of action/object combinations that all involve counts while some also involve a time (indicated by the inclusion of an ‘(s)’ in the table entries overleaf). These allow the general timings/counts to be filtered by different actions or attributes. Counts allow for the probability of actions to be established, while the delay allows the dwell time (i.e., duration of activity) to be established – both filtered by location / objects / attributes, according to the circumstance.
- **Black text** indicates that the metrics can be captured using manual observations. **Blue text** indicates that additional data is available from video footage.
- The data include qualitative and quantitative evidence at individual and aggregate levels. This allows a degree of flexibility to account for the different modelling approaches that might be applied (e.g., microscopic or macroscopic) and for model configuration and benchmarking.
- A modified version of these tables (derived from the workshop) is provided in **Appendix 8**.

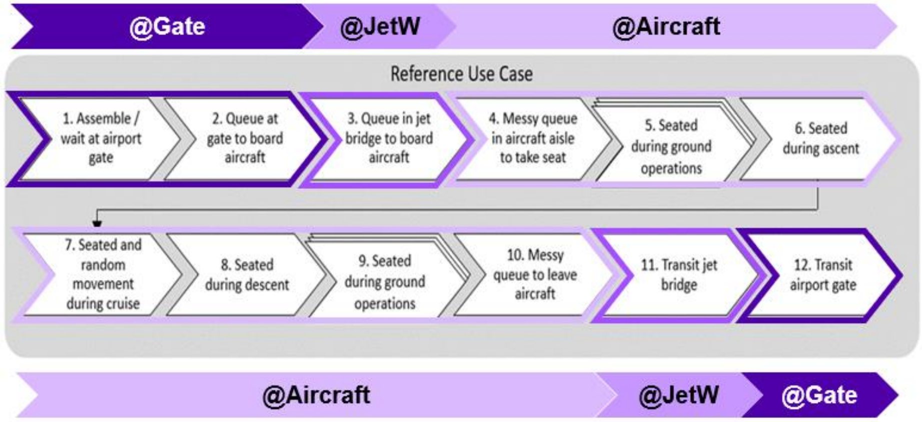


Figure 19: Dyads of interest.

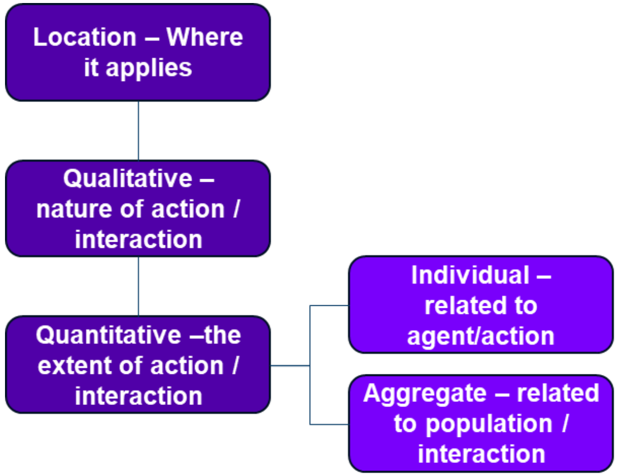


Figure 20: Metric definitions.

Field Observations: Metrics By Dyad

Location	Qualitative	Aggregate Quant.	Individual Quant.
Gate: General Area	• General patterns of movement and behaviours across gate areas. • Pathways used (desire lines).	• Object touch points – number of times objects are touched (extracted from individual interactions with objects). • Occupancy over time. • Population distribution over time.	Number(#) & Delay (s): Direction / Standing / Action, filtered by sub-set of action / object combinations: • Touch - [Mobile_Device/Personal_Document/Luggage/FaceMask/Seat/Mobility_Aid/ Pushchair/Baby/Pax] • Hold (s) – [Luggage / Baby] • Speak (s) – [Staff/Crew/Pax/Mobile_Device] • Face – [Pax / Staff] • Sleep (s) / Eat (s) / Drink (s) • Cough / Sneeze / Yawn • Stand / Sit / Turn – [Direction Change]
Gate: Desk	• Action selection of first person in queue / type of queue structure. • Narrative of actions of 1st person in queue.	• Aggregate of individual data summarised during post-observation analysis. • Queue length over time in gridded area (#). • Queue processing time (s). • Map – Direction / Action– Object-Person-Group over time. • Frequency of items/objects touched (by individual). • Densities/contact distance (ppm^2) of those in queue (i.e., along length of queue). • Map – Direction / Action– Object-Person-Group over time. • Object touch points – number of times objects are touched (extracted from individual interactions with objects) • Time pax spend in queue.	Time spent at desk (s) by 1st person filtered by sub-set of action / object: • Touch – [Mobile_Device / Personal_Document / Luggage / FaceMask/MobilityAid/Desk/TicketSwipe/Pax/Staff] • Hold – [Luggage / Baby] • Speak – [Staff/Pax/Mobile_Device] • Cough / Sneeze / Yawn • Turn – [Direction Change] • Time spent at desk (s) for 1st person and actions for entire queue filtered by sub-set of action / object: • Touch – [Mobile_Device/Personal_Document/Luggage/FaceMask/Mobility_Aid/Desk/TicketSwipe/ Pax/Staff] • Hold – [Luggage / Baby] • Speak – [Staff / Speak/Pax / Mobile_Device] • Cough / Sneeze / Yawn • Turn – [Direction Change]
Gate: Seat	• Direction / Actions performed by those in seats. • Grouping of people in seats. • Profile of those in seats (demographic, mask status, etc.).	• Aggregate of individual data summarised during post-observation analysis. • Object touch points – number of times objects are touched (extracted from individual interactions with objects) • Total number of people seating / standing – over time. • Total time people standing/seated. • Occupied % - over time. • Avg. Dwell Time (s) – time pax in seating area. • Frequency of items/objects touched. • Densities/contact distance (ppm^2).	Travel speed (m/s). Number(#) & Delay(s): Direction / Standing / Action, filtered by sub-set of action / object: • Touch (s) - [Mobile_Device / Personal_Document /Luggage/ FaceMask/ Seat/Mobility_Aid/ Pushchair/Baby/Pax] • Hold (s) – [Luggage / Baby] • Speak (s) – [Staff/Crew/Pax/Mobile_Device] • Face (s) – [Pax / Staff] • Sleep (s) / Eat (s) / Drink (s) • Cough / Sneeze / Yawn • Stand / Sit / • Turn (s) – [Direction Change]

Field Observations: Metrics By Dyad

Location	Qualitative	Aggregate Quant.	Individual Quant.
Jetway	• Passenger actions at front of queue (deposit /collect luggage). • Ground staff actions at front of queue (deposit / collect luggage). • Grouping of passengers in queue.	• Flow Rate (p/s). • Number of luggage present over time. • Object touch points (extracted from individual interactions with objects). • Densities/contact distance (p/m^2) in observable area. • Queue length in observable area. • Number of bags removed by crew (vs. time). • Time to remove bags / crew. • Number of bags deposited by pax (vs. time) • Time to deposit bags / pax.	1st Person Delay time at aircraft exit (s). • Deposit – Luggage Actions / Delay@Exit / Luggage Deposit Delay / Number of bags left by each pax (by action / object - filtered by sub-set of action / object: • Collect (s) – [Luggage/Mobility_Aid/Pushchair/Car-Seat] • Deposit (s) – [Mobility_Aid//Pushchair/Car-Seat] • Touch (s) - Mobile_Device • Touch – [Personal_Document / Luggage/FaceMask/Mobility_Aid /Pushchair/Car-Seat/Pax/ Crew/ Fuselage] • Hold (s) – [Luggage /Baby (s)] • Speak (s) – [Crew/ Pax /Mobile_Device] • Face (s) – [Pax/Crew] • Eat (s) / Drink (s) • Cough/Sneeze/ Yawn • Turn – [Direction Change]

Field Observations: Metrics By Dyad

Location	Qualitative	Aggregate Quant.	Individual Quant.
Onboard - Seat	• Direction / Actions performed by those in seat rows by groups. • Narrative view of pax. actions – by a sample of those in particular seats with actions sequenced over time. • Map – Direction / Action–Object-Person-Group over time.	• % of pax seating/standing v time. • % of pax facing a direction v time. • % of pax eating/sleeping/ speaking. • #Object touch points (extracted from individual interactions with objects). • % of pax engaging in specific action.	Number(#) / Time(s): Location / Direction / Direction Changes / Actions / Actions – Object-Group v Time filtered by • Move (s) • Touch – [Armrest/ Seatbelt / Tray / SeatBack / Blind / PSU /Overhead_Locker/ Pay_Device / Pax /Crew /Mobile_Device /Personal_Documen/Luggage/FaceMask] • Hold (s) – [Luggage/Baby] • Speak – [Crew/Pax/Mobile_Device] • Face (s) – [Crew / Pax] • Sleep / Eat / Drink • Cough / Sneeze / Yawn • Stand / Sit / Recline– [Status Change] • Turn – [Direction Change]
Onboard – Aisle/Cruising	• Crew activities in aisle during cruise/service. • Pax activities in aisle during cruise.	• Number of crew in aisle v time. • Number of crew serving v time. • Service time window. • Avg.Crew Time in Aisle. • Avg.Crew Time Serving. • Number of pax in aisle v time. • Avg.Pax Time in Aisle.	Number(#) and Time(s) Direction / Direction Changes / Actions / Actions – Object-Group v Time filtered by Move/Aisle (s) filtered by • Hold/Baby (s) • Touch – [Overhead_Locker/SeatBack/Pax/Crew/FaceMask/Mobile_Device] • Speak – [Crew /Pax] • Face – [Crew /Pax] • Cough / Sneeze / Yawn • Move (s) - [Galley/Toilet] • Collect – [Overhead_Locker] • Deposit – [Overhead_Locker] • Wait (s) • Turn – [Change Direction] • (Crew) Serve (s)

Field Observations: Metrics By Dyad

Location	Qualitative	Aggregate Quant.	Individual Quant.
Onboard - Between Seat & Target	• Narrative – paths / movement of pax from seat to toilet/galley via aisle.	• Map - Paths adopted from seats to aisle / galley. • Number of pax moving between seat / toilet – seat/galley. • Pax time out of seat/in aisle. • % Population out of seat. • #Object touch points (extracted from individual interactions with objects).	• Probability of a passenger leaving seat per unit time. • Number of actions per passenger (e.g., number of times pax visits toilet). Number(#)/ Time (s): Actions / Actions – Object v Time filtered by sub-set of • Move (s) – [Aisle/Galley/Toilet] • Hold (s) – [Baby] • Touch – [Overhead_Locker / SeatBack/ Pax /Crew /FaceMask/Mobile_Device • Speak –[Crew/Pax] • Face – [Pax /Crew] • Cough/Sneeze/Yawn • Collect- [Overhead_Locker] • Deposit – [Overhead_Locker] • Turn – [Change Direction] • Stand - [Change Status] • Sit - [Change Status]
Onboard - Aisle During Boarding / Deplaning		• Flow during boarding/ deplaning (Number of pax passing at time increment). • Number of pax present in aisle section vs. time.	Number(#)/ Actions / Actions – Object v Time, filtered by Touch – [Overhead_Locker / SeatBack] Turn – [Change Direction] Sit – [Change Status] Stand – [Change Status] (Crew Action pre-board) Sanitize (Crew Action pre-board)) Touch/Galley
Toilet/Galley	• Activities adopted in and around toilet. • Footprint occupied.	• Pax queue length vs time. • Pax number in galley vs. time. • Number of crew in galley v time. • # Crew Actions.	• Time pax spent waiting for toilet. • Time pax spent in toilet. • Time pax spent in galley. • Crew Time in Galley Number(#)/ Actions / Actions – Object v Time, filtered by • Touch – [Mobility_Aid /Pax/ Crew/Toilet (Door)/Galley] • Hold – (s) [Baby] • Speak (s) – [Crew/Pax] • Face (s) – [Pax/ Staff] • Cough / Sneeze/ Yawn • Turn – [Change Direction]

Field Observations: Roles and Movement

- The method for the manual observations involved assigning each observer a role and then choreographing their movement (within each dyad) in order to execute their responsibilities (see Table 4). This identifies the six observers allocated for field observations, their task in each of the dyads, and timing of their movement.
- The movement and activities of the observers are outlined in more detail in Figure 21- Figure 25 which show the primary actions of the observers over time.
- These roles will be fleshed out to the same extent as conducted in the field observations. The guidance provided during this initial effort is shown **Appendix 3A: Supplementary Material.** The role responsibilities and choreographed movement will be finalized once the metrics have been agreed and the data collected approach signed off.

Table 4: Data collection roles for the manual observers.

	At Airport		In Aircraft		
Observer	Gate	Jetway	Boarding	In flight	Deplaning
1	**Monitor desk.** Board at end of boarding.			Allocated Seat for entire flight. **Monitor adjacent seats.**	**Monitor adjacent aisle.** Leave last.
2	**Monitor desk.** Board at end of boarding.			Allocated Seat for entire flight. **Monitor adjacent seats**	**Monitor adjacent aisle.** Leave last.
3	**Monitor seat.** Board at end of boarding.			Allocated Seat for entire flight. **Monitor adjacent seats.**	**Monitor adjacent aisle.** Leave last.
4	**Monitor seat.** Board at end of first boarding group.		**Monitor flow of passengers from assigned seat**	Allocated Seat at front. **Monitor adjacent seats.**	**Monitor flow off** Leave last.
5		Move directly to jetway before boarding. **Monitor flow and ground staff activities until all boarded.** Move to aircraft after passengers.		Allocated seat for entire flight at rear of craft. **Monitor movement between seat – aisle / galley**	Leave first. Return to position on jetway. **Monitor flow and ground staff activities until all deplaned.**
6	**General observations at Gate area.** Board at end of first boarding group.	-	**Monitor crew activities from assigned seat at rear of craft.**	Allocated Seat at rear. **Observe crew/pax aisle activities. Observe galley/toilet area.**	**Monitor adjacent aisle. Monitor crew activities.** Leave last.

Manual Observation: Storyboard – Example (1)

BC – 1 week

1 **Preparation**

BC - 90 mins

2 **Onsite Preparation**

BC - 30 mins

3 **Commence Observation**

First Call

4 **Gate Observations**

Last Pax Leaves Gate

5 **Jetway Observations**

Last Pax Clears Jetway

1

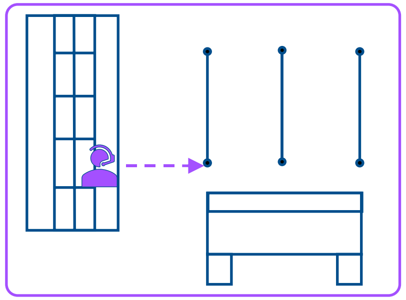
- Create 1m x 1m grid before arrival. No bigger than 2x2 grids. Used in floor overlay – primarily to simplify counts and determine population densities.
- Conduct overnight site visit.
- Identify observer locations – seats/counter/ jetway/general observations.

- Establish sample areas.
- Capture view at multiple airport gates – account for relocations. Identify observer positions.
- Measure landmarks/paths/fixtures/dimensions & distances
- Visit Control Room. Get stills of cam views (capturing gridding) / camera angle / position.
- Choreograph movement times of observers between gate area and aircraft – given their roles and responsibilities – relative to stage of aircraft boarding.
- Ensure device times are aligned with each other and with environmental sensors.
- Finalise roles and responsibilities of observer team, confirm their familiarity with them, and finalise movement of observers between locations at gate and onboard.

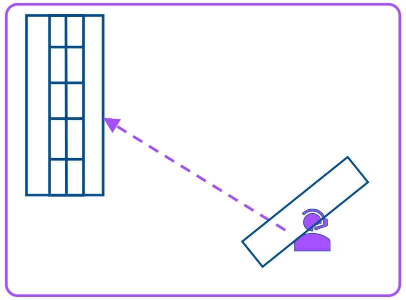
Outcome: Complete preparations for data collection

2

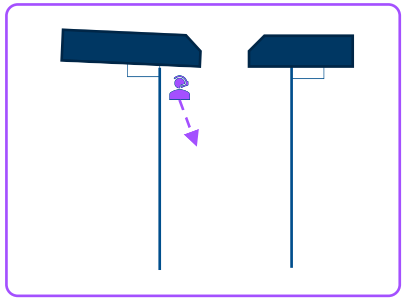
- Observers sent to assigned locations-**90mins before boarding**.



Desk Observer (x2) [Ob1, Ob2]: Ensure observer is perpendicular to the start of the desk queue.



Seat Observer (x2) [Ob3, Ob4]: Ensure observer has elevated view (i.e., standing) and can see bank of assigned seats.



Jetway Observer (x1) [Ob5]: Ensure observer can see first person in queue and ground crew activities (i.e., luggage), without obstructing boarding. Move directly to location.

- Observers conduct tests on iPad app (see **Figure 21**) – confirming equivalence of view-point with gridded locations.

Figure 21: Observer activities.

Manual Observations: Guidance and Technology

- Each observer will be assigned an iPad with a dedicated application – designed to simplify data collection (see **Figure 22**).
- This was designed (MS and NRC staff) and developed (NRC staff) during the field observations conducted in April 2023.
- The goal was to simplify the data collection process, make the data captured more consistent and easier to analyse and aid observers attract less attention while in the field.
- Different versions of the application have been produced for passenger observations, flow logging, and qualitative observations. These will certainly evolve in Phase II to reflect data collection needs. A number of lessons were documented from the field observations (see **Table 4** in **Appendix 3A**).
- Instructions have been developed for each of the roles identified. These will be finalised after the Phase II August workshop – when the set of metrics to be collected have been agreed.
- A script has been developed for each observer role – to ensure a consistent response to passenger questions. However, the use of the iPad application has been demonstrated as attracting few if any queries during the data collection – given the prevalence of passengers using mobile devices.
- Paper templates will be produced as back-up for the iPad application, should technical issues arise.

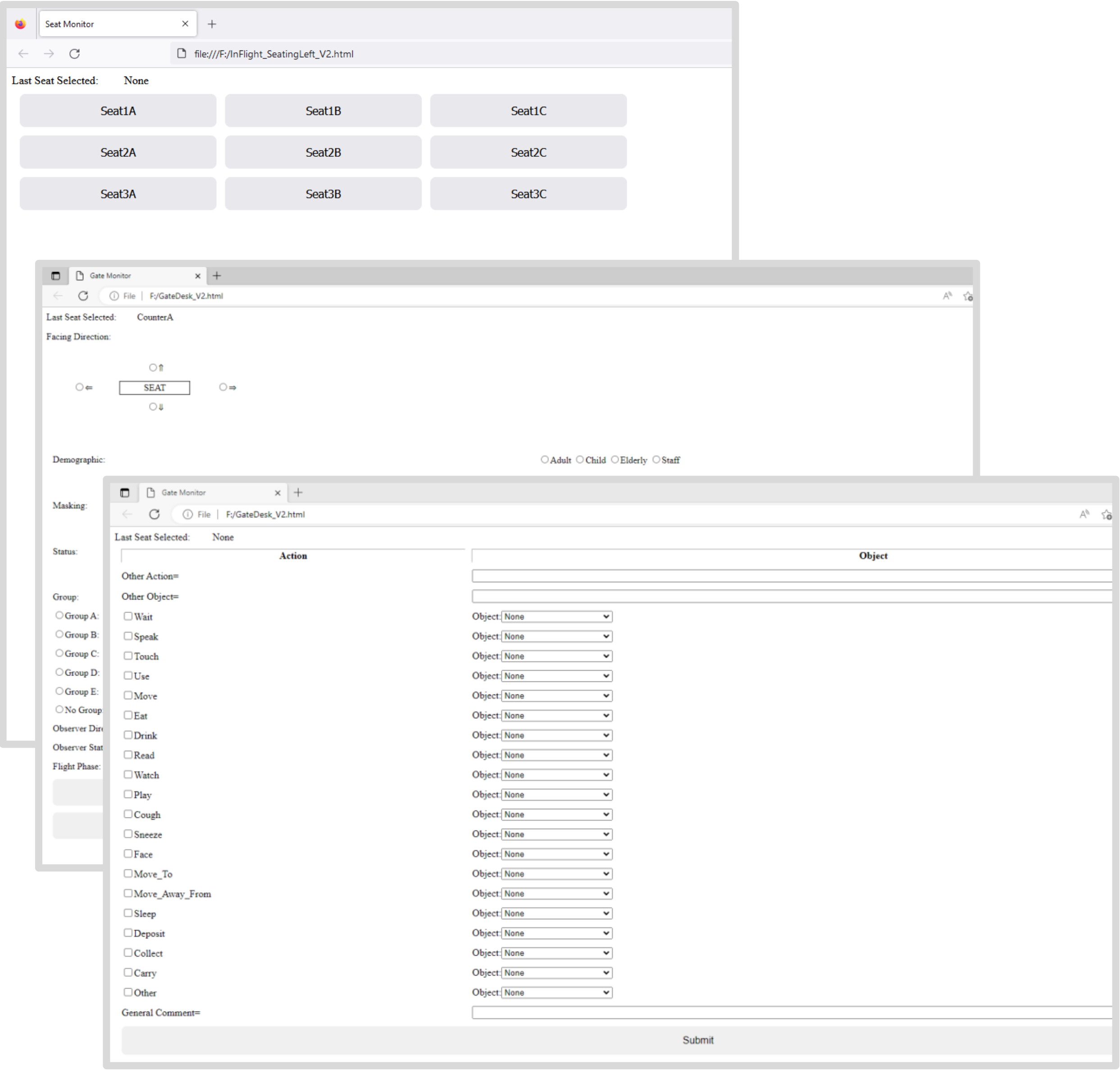


Figure 22: iPad app interface.

Manual Observation: Storyboard – Example (2)

BC – 1 week

1 **Preparation**

BC - 90 mins

2 **Onsite Preparation**

BC - 30 mins

3 **Commence Observation**

First Call

4 **Gate Observations**

Last Pax Leaves Gate

5 **Jetway Observations**

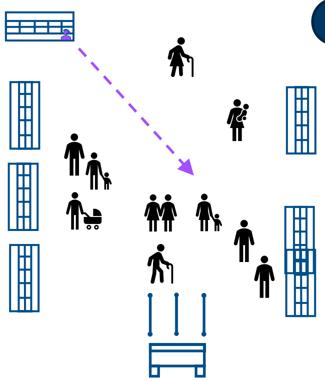
Last Pax Clears Jetway

6 **Boarding Observations**

2

General Gate Observer [Ob6]

- Ensure observer can see general movement at gate to capture aggregate conditions and make qualitative observations.
- Needs access to early boarding allowing them to get onboard and be in position for crew activities and first passengers.



Outcome: Complete preparations for gate locations

3

Commence Gate Observation [Ob1-4,6] – 30 mins before boarding.

- Start observing designated locations / recording in iPad app observations according to guidance.

4

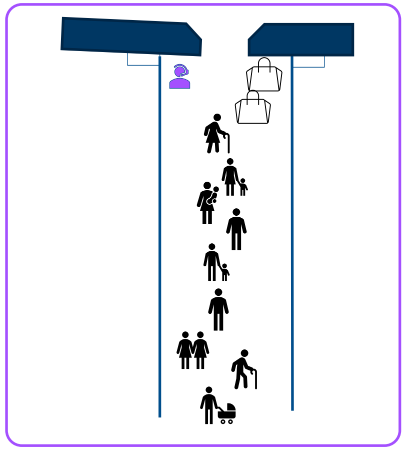
Gate Observation by location

- **Desk [Ob1, Ob2] –** Actions/Interactions of first pax in queue / Queue length. Record data @ new pax at desk.
- **Seat [Ob3,Ob4]** – Changes to Actions/Interactions of those seated. Record when change in pax act/situation.
- **[Ob1, Ob2] / [Ob3] - Board after all pax. [Ob4] - Board after 1st Group.**

5

Commence Jetway Observations [Ob5] – Immediately after first arrival.

- Record time of first arrival.
- Record number of articles remaining next to exit.
- Continue until all passengers are boarded.
- Move to assigned seat.

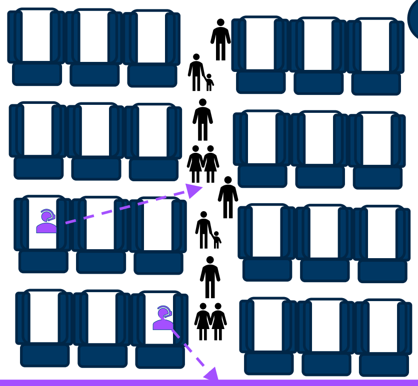


Outcome: Complete observations outside of aircraft

6

Boarding / Deplaning Observations [Ob4+Ob6]

- **[Ob6]** seated at rear. Tracks crew actions in preparation for boarding and during deplaning.
- **[Ob4]** observes behaviours of those in pre-determined aisle section.



Outcome: Complete boarding observations

Figure 23: Observer activities.

Manual Observation: Storyboard – Example (3)

Ascent Completed
Seat belt sign off

7 In Flight

Seat belt sign on
Descent Initiated

8 Crew Preparation

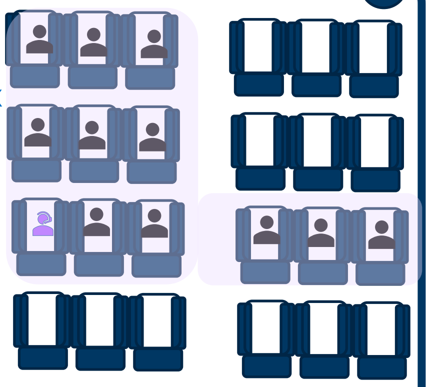
Seat belt sign off
taxiing

9 Commence Deplaning

Passengers
leave aircraft

10 Jetway Observations

Seat Activities [Ob1-4] (7)

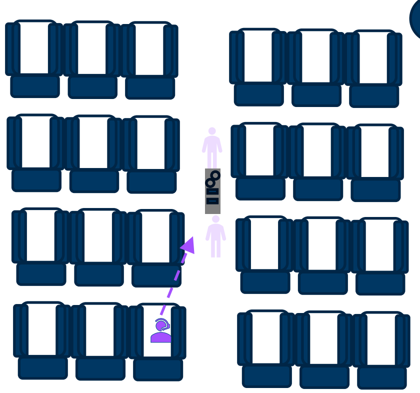


- Responsible for monitoring passengers in same row and six seats ahead of observer across two rows.
- Observer works in 10-minute cycles: 30% looking forward, 50% looking along row, 20% resting. Row bias given that it provides more on pax actions.
- Observer scans areas in same order (e.g., right to left, etc.).
- Event-based - Records times of changes in status or action. Times are automatically recorded by app. Estimate of action / state timings therefore recorded. Combination of time-based and event-based approaches produces a sample of actions with reasonably precise times and count sizes.

Movement from seat to toilet/galley/seat [Ob5] (7)

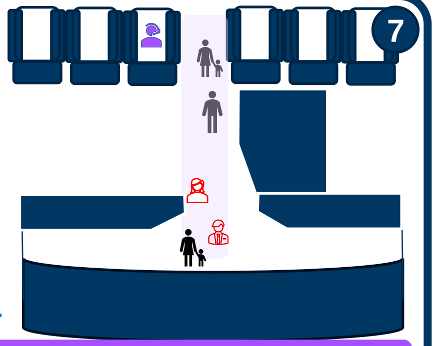
- Observer positioned scan block of seats during cruising.
- Record time when person leaves seat, seat location, the time the aisle reached, the time aisle left, the goal (e.g., toilet, seat), and the time of arrival. Additional actions recorded during movement (e.g., speak to person) and on their arrival (e.g., touch overhead, touch toilet, etc.).

Aisle Monitoring [Ob6] (7)



- Event-based monitoring of crew and pax in the aisle.
- Scan for movement of passengers and crew in aisle. Note time pax/crew in aisle, actions performed, total number of people in aisle, along with service window.
- **[Ob6]** will switch between galley observations and aisle observations. Focus on aisle during service; attention split between aisle and toilets during rest of cruising period, with data recorded based on passenger activity.

Toilet/Galley Activities [Ob6] (7)

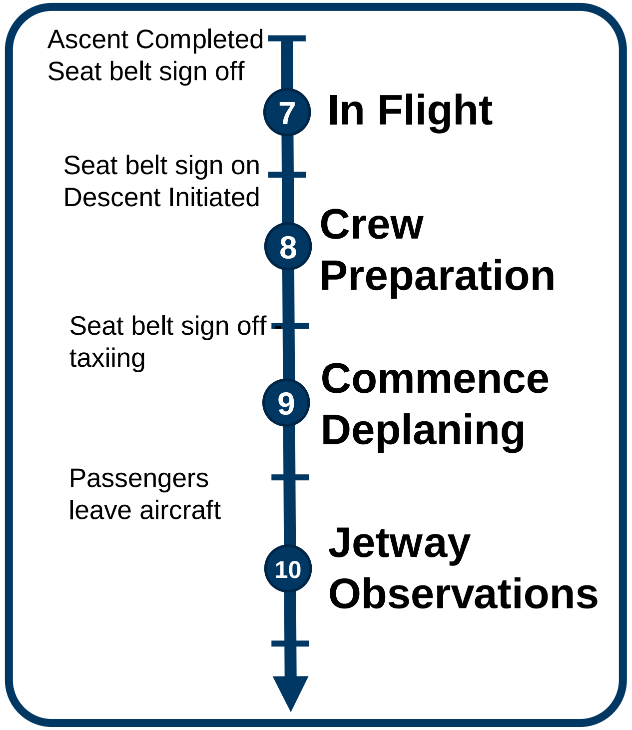


- **[Ob6]** monitors passenger bathroom use (actions, objects touched, etc.) and the queue lengths produced. Also monitor passenger / crew activities in galley along with recording number present and dwell times.

Outcome: Complete cruising observations

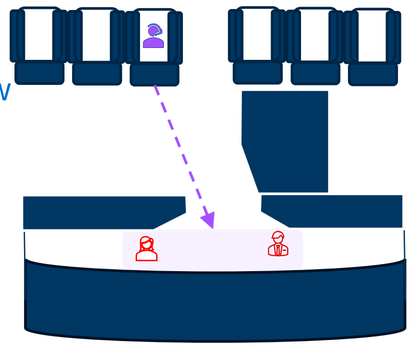
Figure 24: Observer activities.

Manual Observation: Storyboard – Example (4)



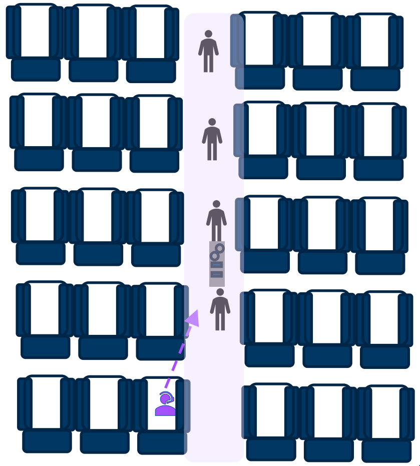
8 Crew Activities [Ob6]

- **[Ob6]** remains at the rear seat during deplaning.
- Observe the actions of the crew in and around the galley and toilet making preparations.
- Event-based observations of crew actions and interactions with objects and other crew (proximity, conversations, etc.)



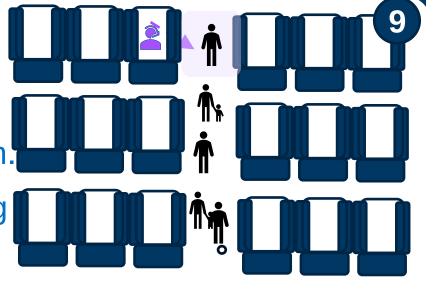
9 Commence Deplaning[Ob1-4]

- Passengers get out of seats and start to collect belongings from under seat and OH belongings.
- **[Ob1-4]** remain in seats and monitor conditions in designated aisle locations – five rows adjacent to their assigned seating.
- Identify #people, direction faced and interactions at OH or seat level.



9 Deplaning Flow[Ob5]

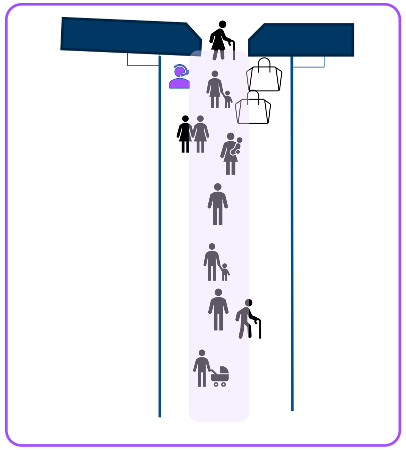
- **[Ob5]** remains at forward seat during deplaning and logs the number of people passing them.
- Event-based observations – log arrival of individual at Ob5 location with time of event automatically recorded.



Outcome: Complete onboard observations

10 Jetway Observations [Ob6]

- Move from seat when seatbelt sign is off.
- Move to previous location (see 5) on jetway – to log movement.
- Log each arrival using app and record number of articles remaining next to exit.
- Continue until all passengers deplaned.



Outcome: Complete observations

Figure 25: Observer activities.

Looking Forward: CCTV Extraction Methodology

Access to airport coverage is expected for Phase II of this work. This access will allow manual observations but will also allow video footage of passenger movement to be examined. This will be derived from airport CCTV cameras or installed cameras (likely attached to or adjacent to existing CCTV cameras). In either circumstance, measures will be taken to respect the privacy and anonymity of passengers at the airport as per agreements with the airport. The precise source of the footage will have implications on the data extraction methods (see **Appendix 2**). This will relate to the gate and possibly the jetway locations.

If third-party footage is available, then all locations / actions / group membership will be manually extracted by the operator. If bespoke (stereoscopic) cameras can be installed this will locate (identify coordinates for each person in the frame), assign a direction, and timestamp the event. All other passenger attributes and actions will likely still need to be manually extracted – as such the automated extraction reduces effort for a portion of the data extraction process.

Camera locations will have been previously examined to determine their catchment areas and overall coverage of the gate area. Similarly, analysts will be selected who have examined all relevant guidance, reviewed the location, are familiar with the behaviours being examined and the goals of the project. The data extraction is reliant on a number of preparatory tasks that are outlined in **Appendices 4 and 5**.

A set of templates have been developed to allow the analyst to review the video material and generate records for each observed action. The analyst will scan the entire video footage (see **Figure 26**). The timeline for data capture will follow the timings associated with the manual field observations; for instance, starting 60 minutes prior to boarding until the gate area is clear. As with the manual observations, the analyst will focus on one particular location; e.g., seating, desk, general movement. The scan of the video will allow time increments to be established. This increment will determine the time when comparison is made with the previous step allowing changes in situation and actions to be recorded. From previous analysis, this will likely be either 30s or 60s. The time-step only reflects the sampling rate, rather than the times recorded, as will be explained below. In all instances, the identity of the extractor will be recorded to allow inter rater comparisons to be made in the quality assessment process. Previously, 10% of data extraction was duplicated allowing data to be assessed for accuracy and consistency.

The data collection is categorised into **General Population Insights** and **Individual Data**; the former relate to the aggregate conditions present, while the latter relates to actions associated to individual passengers. At each time increment, information on the distribution of the population will be recorded (the column headings for this template are shown in **Figure 27**).

Time	Groups Present	Pop Size – Loc G1	Pop Size – Loc G2	Pop Size – Loc G3	Pop Size – Loc G4	Pop Size – Loc G5	Pop Size – Loc G6	Pop Size – Loc G7	Pop Size – Loc G8

Figure 27: General Population Insights template column headers (see Appendix 5).

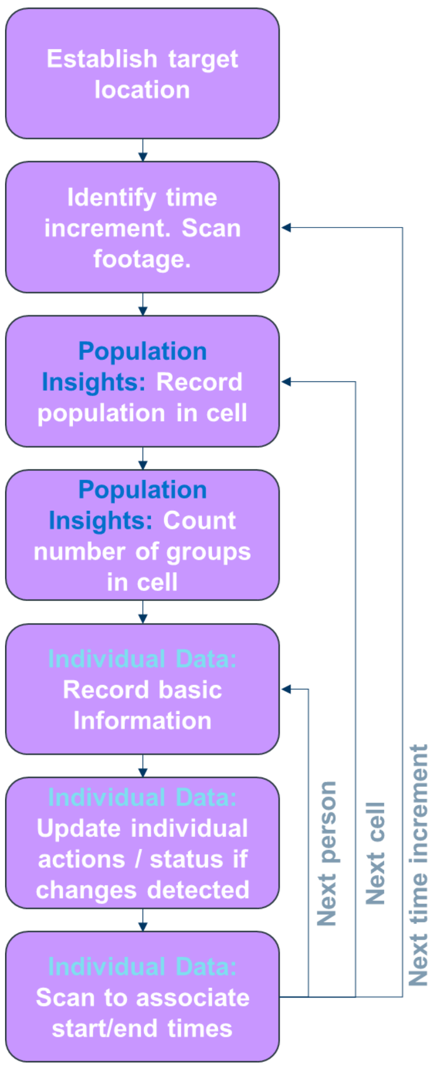


Figure 26: Extraction logic.

Looking Forward: CCTV Extraction Methodology

The people counts relate to the numbers recorded in pre-determined areas around the gate area. This may be manually determined (counting the number located in the gridded spaces) or automatically derived (positions extracted automatically from the video footage). In the latter case, this template will be auto-populated by the data generated. Manually observed densities allow average distances to be derived; automatically extracted data allow the distances to be recorded and then the densities to be established. The gridded locations will also be scanned to determine the number of groups present in accordance with the definitions used in the manual observations. This will be recorded for each time-step.

The second step relates to recording **Individual Data (see Figure 28)**. These tasks refer to each individual observed for that time increment and relate to their activities. Cell location within the grid or definable location will still be recorded to enable densities to be easily established and provide an easy means to track data extraction; however, an option for automatically extracted coordinates is also included. An individual record is established for the individuals in view for each defined area. This includes a unique identifier, direction faced and coordinates. The unique ID includes reference to the time increment and the grid location. If automated data is available, the precise co-ordinates will be recorded. Some effort will be made to record whether the individual has appeared in previous time increments. If so, their prior ID will be recorded using Aliases. This may not always be possible. The individual will also be assigned to one of the previously identified groups (if appropriate).

A set of other attributes are then collected – comparable to those collected in the manual data collection effort; e.g., whether they are passenger or crew, demographic information, whether they are wearing a mask, standing or sitting, and the actions being performed/ how they are being performed, and the objects affected. The individual's action, direction and status will only be recorded in a new record if it is deemed different from the equivalent attribute in the previous time increment. This is to make the extraction process more efficient, generate more refined assessment of the times where necessary, and also to provide two levels to the timing: the time increment and the specific start-end time associated with the action/status change. At that point, the video will be scanned to determine the precise start and end point of the previous action and then recorded.

If movement is detected and co-ordinates are automatically extracted, then the distance traversed by an individual in the same time increment can be established and then the speed derived.

Time	Area	Observer	Event Phase

Person ID	Direction	X Coord	Y Coord	Previous Alias?	Previous Alias? (2)	Person Type	Demographic	Mask	Status	Action (1)	Modifier (1)

Object (1)	Action (2)	Modifier (2)	Object (2)	Action (3)	Modifier (3)	Object (3)	Group Identity	Updated Start Time	End Time	End X	End Y	Distance (m)	Speed (m/s)

Figure 28: Individual Data template column headers (see Appendix 5).

Looking Forward: Summary

The work presented here outlines planning for future field observations. This involved

- Reviewing existing knowledge to develop a conceptual model of passenger behaviour,
- Developing and applying a data collection methodology,
- Interrogating a sub-set of the data produced to establish the consistency and viability of the data collection methods,
- Simulating some of the field conditions to examined the performance of the different methods employed,
- Refining the data collection methods and identifying a baseline set of metrics for review.

This work has been completed and a methodology and set of metrics produced for refinement (as presented in the Executive Summary of this work) and eventual assessment during the August 2023 client and stakeholder workshop.

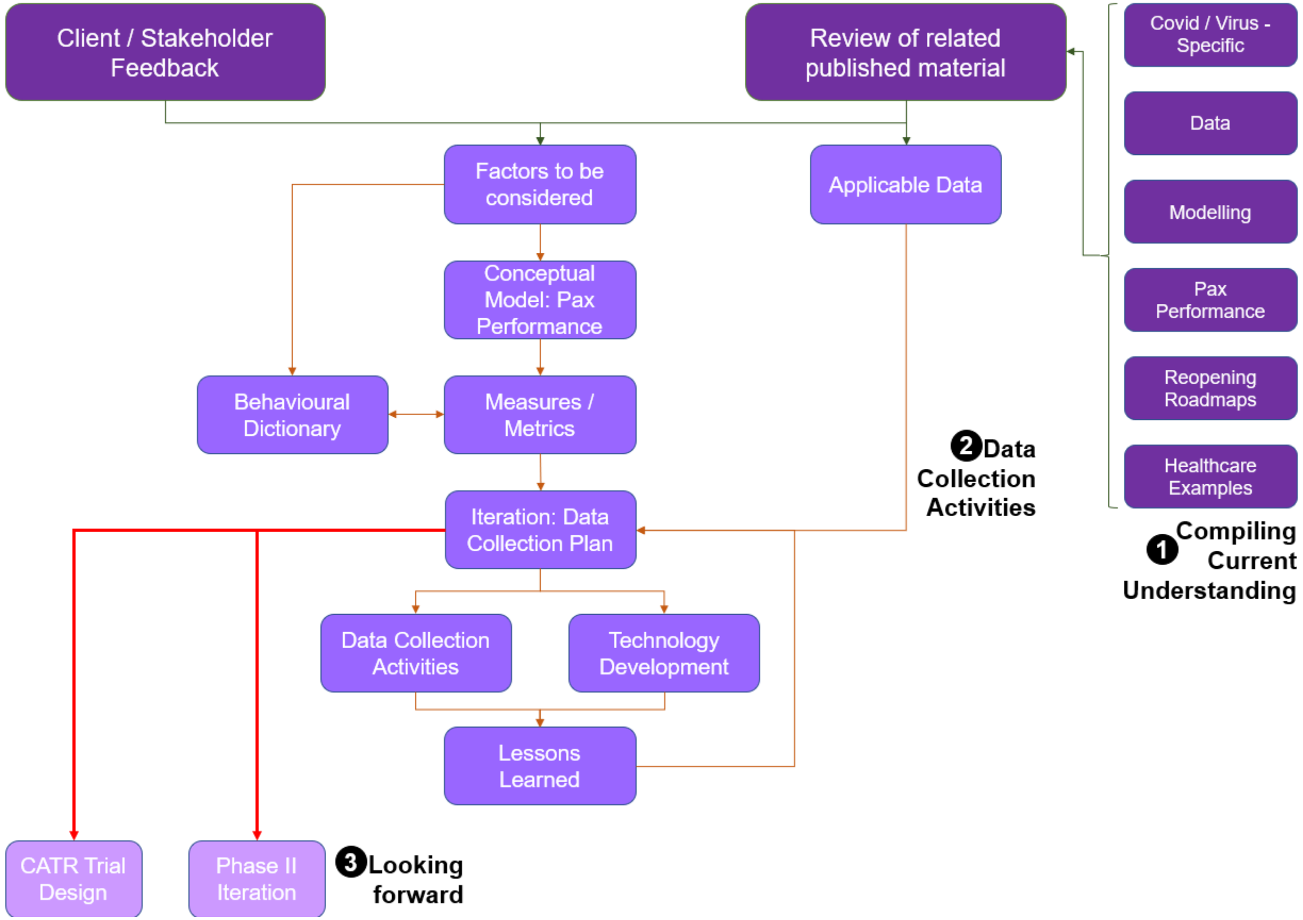


Figure 29: Key stages of Phase I.

GHD Advisory

*Thank You

→ ghd.com/advisory

Appendix 1A: Literature Review

Material was reviewed from several different subject areas:

- Data collection related to the outbreak
- Attempts to model exposure / human activities
- Passenger performance (especially related to the outbreak)
- Reopening roadmaps
- Healthcare modelling activities
- Covid-19-specific material.

The main findings from these documents are reported in the sections below. Greater emphasis is placed on the first three areas – given their direct relevance to the work conducted here (and therefore more usable findings).

Data: 26 studies in total, 15 studies summarised. The summaries focus on data collection method and key results, especially what has been examined regarding passenger behaviours/actions/scenarios in airports and similar environments.

- Toffoluti et al collected data from a survey with 15,147 respondents from over 28 European countries. The dependent variable was mental well-being (MWB), which was assessed using the WHO-5 Index, MWB score attributed to non-pharmaceutical interventions. The following scenarios were considered – closure of services/workplaces, confinement in home. Results gathered on MWB suggest restriction on international travel, private gatherings, and contact tracing, (workplace closure) were negatively (positively) associated with MWB by about, respectively, - 0.63, - 0.24, - 0.22, (0.29) [Data3].
- Lordo et al collected data from a survey of passengers and crew from 130 flights. Environmental measurements were collected from a total of 80 flights, with flight factors also considered. Logistic regression analysis performed to assess how specific health outcomes are associated with environmental measures in the cabin. Significant evidence for positive correlation between the number of air exchanges (ACH) and the likelihood of back pain/stiffness, ear pain/pressure, and itchy/irritated eyes and between cabin temperature and the likelihood of each of the top ten reported health outcomes (except for runny nose/sneezing and for dry/irritated/sore throat, where negative correlations were noted). For passengers: pain/stiffness in the back and neck, as well as dry mouth and lips, were higher in 747 aircraft; ear pain, pressure, and blockages were higher in 737 and 767 aircraft; itchy or irritated eyes were lower in A340 aircraft versus all other types; longer flights tended to have passengers who were more likely to report dry eyes, mouth, and lips, as well as back pain, but who were less likely to report ear pain and pressure. For crew: the lowest odds of reporting these health outcomes occurred in flights on 777 aircraft, and to a lesser extent, flights on 767s; Lower odds were noted with short flights and flights with no more than one time zone crossed; Flights that were exclusively in the southern hemisphere were associated with lower odds of reporting pain in the neck and shoulders by cabin crew. [Data10]
- All of the Echeverría-Huarte et al experiments were recorded by a camera at 25 fps with a 4 K (i.e., 3840×2160 pixels) resolution. It was hung at a height of 12 m. from the floor pointing downwards. All participants wore a red hat which was tracked generating exposure times and persistence of movement direction. Distributions recorded such as exposure time periods (*texp*) during which two pedestrians are uninterruptedly closer than 1.5 m. Probability density functions (PDFs) of *texp* when the prescribed safety distance is 2 m and 1.5 m for different densities. Number of times that a pedestrian is uninterruptedly closer than 1.5 m to another during a *texp* greater or equal to 2 s, as a function of density. Average of these distributions was calculated for different values of the time lag τ. This is used to show that fast speeds lead to quicker decays than slower ones. Data can be rescaled multiplying τ by the average velocity of the volunteers in each case. All curves collapse reaching ‹O›=0) for a characteristic length of about 4.5 m, which is about half of the room size. This suggests that people when moving inside the arena, mainly follow a fixed direction until they approach to any of the walls. Also indicates that people avoid collisions with others by modifying movement direction, as might be expected behaviour in real life. Also

observed that the density should not be higher than 0.16 pedestrians per square meter in order to guarantee an interpersonal distance of 1 m. [Data13]

- Budzyn et al used case study data from schools (from between July 1–September 4, 2021), 520 US counties with a school start date, known and uniform mask requirement, across 3 weeks with 7 full days of case data. For counties with multiple school districts, the median school start date was used. County-specific paediatric COVID-19 rates from CDC's COVID Data Tracker were tabulated and aggregated by school start week. Average weekly changes were compared for counties with and without school mask requirements using a one-sided t-test. A multiple linear regression was constructed that adjusted for age, race and ethnicity, paediatric COVID-19 vaccination rate, COVID-19 community transmission, population density, social vulnerability index score, COVID-19 community vulnerability index score, percentage uninsured, and percentage living in poverty. Statistical analyses were completed using analysis modules for Python. Statistical significance was defined as $p<0.05$ for all analyses. Counties without school mask requirements experienced larger increases in paediatric COVID-19 case rates after the start of school compared with counties that had school mask requirements ($p<0.001$). The average COVID-19 case rates from week −1 to week 1 for counties with school mask requirements was 18.53 cases per 100,000 per day lower than the average change for counties without school mask requirements ($p<0.001$). Comparisons between paediatric COVID-19 case rates during the weeks before (weeks −3, −2, and −1) and after (weeks 0, 1, and 2) the start of school indicate that counties without school mask requirements experienced larger increases than those with school mask requirements ($p<0.05$). After controlling for covariates, school mask requirements remained associated with lower daily case rates of paediatric COVID-19 ($\beta = -1.31$; 95% confidence interval = −1.51 to −1.11) ($p<0.001$). [Data19]
- Cowger et al observed data from 72 public, non-charter school districts in the greater Boston (US) area reporting week in all districts. Data from DESE on Covid-19 cases, student enrolment, and staffing during the 2021–2022 school year. 2311 Massachusetts schools (approximately 95%) participated in at least one such program. From 1 month before the statewide masking policy was rescinded through the end of the school year, statewide testing recommendations did not differ according to masking or vaccination status. The dates during which masking requirements were in place for each school district were obtained from school-district websites or local news sources. Overall, the lifting of masking requirements was associated with an additional 44.9 Covid-19 cases per 1000 students and staff (95% CI, 32.6 to 57.1) during the 15 weeks after the statewide masking policy was rescinded. This estimate corresponded to an additional 11,901 Covid-19 cases (95% CI, 8651 to 15,151), which accounted for 33.4% of the cases (95% CI, 24.3 to 42.5) in school districts that lifted masking requirements and for 29.4% of the cases (95% CI, 21.4 to 37.5) in all school districts during that period. Also, an additional 81.7 Covid-19 cases per 1000 staff (95% CI, 59.3 to 104.1) during the 15-week period, with these cases accounting for 40.4% of the cases (95% CI, 29.4 to 51.5) among staff in school districts that lifted masking requirements. Persons who had a positive test for Covid-19 were instructed to isolate for at least 5 days, the additional cases translated to a minimum of approximately 17,500 missed school days for students and 6500 missed school days for staff during the 15-week period. [Data20]
- Han et al used a scaled model of a 28-row cabin mock-up platform. The cabin model was scaled down from a full-sized cabin. The cabin had 28 rows, with 168 aircraft seats. Heat load was set to 50 W and occupants wrapped with nickel-chromium. The experimental platform was placed in a thermostatic chamber. Temperature control accuracy of the thermostatic chamber was ±1 ◦C. Thermosphere anemometers were used to measure the distribution. The platinum resistances were used to measure the temperature distribution. 13th row (Z = 1.315 m) cross-section was selected as the measurement section, which is located 1.5 cm in front of the occupant. To investigate the influence of the longitudinal scale on the flow field structure, the study analysed the velocity field, temperature field and vortex structure in the narrow and long cabin environments to investigate the influence of the longitudinal scale. It was concluded that the transient flow field produces an asymmetric phenomenon, and the supply air jets on both sides alternately dominated; the coupling effect of the human thermal buoyancy and the air supply jet made the flow field structure more complicated in the cabin; the longitudinal scale leads to full development of the unstable flow field. It is easy to cause longitudinal instability of the flow field. Consequently, the velocity distribution of different rows is different, and the heat transfer effect of different rows of passengers is different. The unstable airflow created unstable longitudinal vortex structures, affected by the cabin geometry. Around passengers close to the open aisle, many vortex structures were observed. Fewer and more concentrated vortex structures were seen in the more bounded flow around passengers in middle and sidewall seats. [Data26]

- Pi et al used a publicly available dataset (VOC) to create the Xiamen dataset, which was generated from a video recorded at a street intersection in Xiamen City, China, on April 16, 2020. Only video segments containing pedestrians walking across the intersection were extracted from the raw video footage with the intention of human contact tracing. Detected pedestrians were projected onto an orthogonal map for contact tracing by tracking movement trajectories and simulating the spread of droplets among the healthy population. There was a 69-70% precision in their analysis. Convolutional neural networks (CNNs) used to generate quantifiable metrics of contact tracing. Results show that the proposed technique is capable of tracing and documenting infection sources, times, and locations (This could be useful as a tool within airports for boarding/unloading). [Data1]
- Spengler et al used a TSI 7565 Qtrak on three flights and measured air contaminants including ozone (O_3), carbon dioxide (CO_2), carbon monoxide (CO), ultrafine particles (UFP), particle matter ≤ 2.5 μm ($PM_{2.5}$), volatile and semi-volatile organic compounds (VOCs and SVOCs), aldehydes, and tricresyl phosphate (TCP) isomers. These flights were on three different airlines: airline A (20 flights), airline B (39 flights), and airline C (24 flights). Environmental parameters measured included relative humidity (RH), cabin pressure (P), temperature (T), and cabin sound levels (dB(A)). Monitors were located either in an aisle seat or a middle seat and it was assumed that operative temperature equalled the air temperature. Data collected from 83 flights. Measurements were recorded continuously, at one-minute intervals, from 10,000 feet ascent through 10,000 feet descent. TCP isomers, VOCs, SVOCs, and aldehydes were collected via integrated samplers. For each analysis batch, except VOC canisters in airline A, at least five duplicates and five blanks were included to estimate the signal-to-noise ratios. Sensors and samplers were situated in the middle of the economy class. Instruments with pumps and batteries were positioned under the seat, and VOCs and aldehydes samplers were placed at the back of the seat with inlets at seat pocket height of 50 cm. Carbon dioxide values ranged from 863 to 2,056 ppm during cruise and were highly correlated ($r^2=0.7$) with load factors. While still very much below the 5,000 ppm limit set by FARs (FAA 2011), recent studies show impaired cognitive function at CO_2 exposures in the range of 1,000 ppm to 2,500 ppm, raising concerns about possible diminutions of flight crew performance that needs further evaluation. [Data7]
- Yabe et al used anonymized large scale mobility data collection from more than 200k mobile phones in Tokyo, Japan to examine the movement of the general population in the week before the declaration of state of emergency. They analysed the temporal changes in i) human mobility behaviour changes, ii) rates of social contacts, and iii) correlations of such mobility changes with the transmissibility of COVID-19 to understand the impacts of non-pharmaceutical interventions during the COVID-19 outbreak with an unprecedented spatiotemporal granularity and scale. The analysis concluded that by April 15th (1 week from declaring state of emergency), human mobility behaviour had decreased by around 50%, resulting in a 70% reduction of social contacts in Tokyo, showing the effectiveness of non- compulsory measures. [Data9]
- Sukul et al monitored exhaled breath profiles within mask space in older (age 60–80 years) and young to middle-aged (age 20–59 years) adults by high-resolution real-time mass-spectrometry. Peripheral oxygen saturation (SpO_2) and respiratory and haemodynamic parameters were measured (noninvasively) simultaneously. Volunteers rested by sitting on a chair for ⩾10 min before actual sampling. They spontaneously inhaled and exhaled only via the mouth. The transfer-line of PTR-ToF-MS was connected to a PEEK extension line order to directly sample breath-resolved VOCs from the mask dead space. The PTR transfer line was fixed at the back of subject's head. The PEEK line was placed along the subject's right/left cheek and was inserted within the mask dead space up to the front of the subject's lips. The recruitment of subjects in FFP2 and surgical mask experiments were at random. Young to middle-aged adults were measured for 30 min and older adults were measured for 15 min. The measurements in older adults were stopped once they attained SpO_2 <94% FFP2 masks had a more pronounced effect than surgical masks. Older adults were more vulnerable to FFP2 mask-induced hypercarbia, arterial oxygen decline, blood pressure fluctuations and concomitant physiological and metabolic effects. Profound, consistent and significant ($p \leqslant 0.001$) changes in SpO_2 (⩾60_FFP2-15 min: 5.8±1.3%↓, ⩾60_surgical-15 min: 3.6±0.9%↓, <60_FFP2-30 min: 1.9±1.0%↓, <60_surgical-30 min: 0.9±0.6%↓) and end-tidal carbon dioxide tension ($P_{ET}CO_2$) (⩾60_FFP2-15 min: 19.1±8.0%↑, ⩾60_surgical-15 min: 11.6±7.6%↑, <60_FFP2- 30 min: 12.1±4.5%↑, <60_surgical- 30 min: 9.3±4.1%↑) indicate ascending deoxygenation and hypercarbia. Secondary changes ($p \leqslant 0.005$) to haemodynamic parameters (e.g. mean arterial pressure (MAP) ⩾60_FFP2-15 min: 9.8±10.4%↑) were found. Exhalation of bloodborne volatile metabolites, e.g. aldehydes, hemiterpene, organosulfur, short-chain fatty acids, alcohols, ketone, aromatics, nitrile and monoterpene mirrored behaviour of cardiac output, MAP, SpO_2, respiratory rate and $P_{ET}CO_2$. Exhaled

humidity (e.g. ⩾60_FFP2-15 min: 7.1±5.8%↑) and exhaled oxygen (e.g. ⩾60_FFP2-15 min: 6.1±10.0%↓) changed significantly ($p \leqslant 0.005$) over time. [Data11]

- Rahimi et al conducted a cross-sectional study in August 2020 in Ahvaz, southwest Iran. Using a multistage sampling method, a total of 10,440 pedestrians selected from 8 urban districts and 92 neighbourhoods of the city. The data gathered by observation method. Percentage, mean and standard deviation were used to describe the variables. Chi-square test, fisher exact test and Chi-square for trend used to assess relationship between two categorical variables. They used an unconditional logistic regression model to control confounding factors. Observation stations were determined from detailed maps of urban divisions and were selected from the crowded passages of each neighbourhood. At each station, data of 60 pedestrians were collected including gender, approximate age, use of facemask, gloves and shield, type of facemask, and correct use of facemask. Insufficient coverage of the mouth and nose, wearing facemask upside down or inside-out were defined as “incorrect or unacceptable” use of the mask. Observation was performed during the busy hours of each area from 9.00 to 13.00 and 17.00 to 23.00 Observation in public The most common age group was 10 to 39 years and 67.9% of the participants were male. The overall prevalence of face mask usage was 45.6% (95% CI, 44.6–46.5). In general, as the age increased, the prevalence of face mask use significantly increased (p for trend < 0.001). Women used face masks significantly higher than men (60.2% vs. 38.7%, $p < 0.001$). Among the pedestrians who used the mask, 75.6% wore facemask correctly. The most common type of facemask used by the pedestrians were surgical (medical) masks (63.8%). In total, the prevalence of facemask usage was significantly higher during a.m. (49.4%) compared to p.m. (43.9%), ($p < 0.001$). 1.7 and 0.3% of Pedestrians had worn gloves and shielded respectively. Women used shields and gloves significantly higher than men (3.6% vs. 0.7%, $p < 0.001$). Also, women used shields more than men (0.5% vs. 0.3%, $p = 0.036$). [Data18]
- Bustamente et al developed a microsimulation model of the Naranjal Station. Surveys were conducted at the station gates and during the disembarkation of people from the feeder buses. This information is used to know the destination of the users and thus determine the possible distributions and walking paths of pedestrians in the microsimulation model. To obtain the speeds of the pedestrians within the station for the calibration process, two points were located in the upper passageway and two in the lower passageway of the station, each one 15 metres. The walking time of a representative sample of 40 pedestrians was measured. With this information, it will be evaluated whether the simulation model developed in the Vissim software represents the real behaviour of pedestrians at the station. Taking into account a volume of 13,482 pedestrians entering the Naranjal station at peak hour, it was obtained the maximum capacity number of people at the station of 4166 pedestrians respecting the meter and a half of social distancing. *The maximum pedestrian density obtained is 0.54 people/m2 and a space module of 1.85 m2/p having a level of service D. The maximum pedestrian density before covid-19 is 1.27 people/m2 and a space module of 0.70 m2/p having a level of service F.* [Data21]
- Feng et al firstly looked at field observations. Here, the goal is to study pedestrian behaviour as unobtrusively as possible. This data collection method usually requires researchers to record pedestrian behaviour in specific situations. Studies, which use field observations are predominantly centred around four themes: evacuation behaviour, pedestrian walking dynamics, group behaviour and pedestrian behaviour during large-scale events. The review paper discerns five main gaps, namely: 1. the difficulty in studying pedestrian behaviours in large, complex scenarios; 2. the lack of comprehensive methods to capture all essential behavioural data simultaneously; 3. the current difficulties to study new types of high-risk scenarios; 4. the lack of comparisons of pedestrian behaviour data among different data collection methods to represent real-life pedestrian behaviour; and 5. the relatively high costs of most experimental methods. The review showed that new technologies such as applying VR experiments to (1) study pedestrian behaviour in the environments that are difficult or cannot be mimicked in real-life; (2) conduct the same experiments repeatedly to explore effects of various factors on pedestrian behaviour; (3) gain more accurate behavioural data and deep understanding of the decision-making process of pedestrian behaviour. The second opportunity is applying large-scale crowd monitoring to study pedestrian movements in large complex environments and incident situations in more detail. The third opportunity is utilizing the Internet of Things to track pedestrian dynamics and unravel new insights regarding pedestrian movement types and locations that are difficult to investigate at the moment. [Data22]
- Fraser et al used a model to observe why some prefectures encountered more cases per week of COVID-19 per 100,000 residents than others, using an ordinary least squares model (OLS). First, they examined why some prefectures encountered any cases per week of COVID-19, using a logit model. Second, they modeled why some prefecture-weeks encountered higher case fatality rates than others, using OLS models. Third, to validate their findings on the link to social capital, they used these individual reports and

OLS models to examine why some individual with confirmed cases of COVID hailed from prefectures with higher levels of linking social capital than others. They hypothesized that areas characterized primarily by strong bonding social ties might see higher levels of COVID spread, as they would lack diverse sources of information from experts and outsiders. However, if a community experiences an outbreak, then the existence of stronger bonding ties can aid with sick residents, helping them reach medical personnel along with food, water, and psychological support. They discovered communities with stronger vertical ties, but fewer local, horizontal ties found themselves with higher rates of mortality. The study looked at weekly infection and case fatality rates for Japan's 47 prefectures based on anonymized records of 62,722 individual cases of COVID-19 from February 10 to August 31 from Japan's Ministry of Health, Labor, and Welfare. They analysed this data at the aggregate, prefecture-week level and at the individual level. They employed a data time-lag given the approximate 5 day average delay for an infected person to show symptoms. Mobility was assessed using aggregate level data from Facebook's Data for Good project and Google Android user mobility data to confirm that their results were consistent across different samples of resident mobility. Health care systems, government finances, gender balance, age, income, and education levels of communities, alongside further demographic controls were controlled for in the models. They modelled these infection rates using weekly fixed effects, compared with weekly random effects and first-order autocorrelation. [Data24]

Data References:

Data1. Nipun,YP, Nath, D, Sampathkumar, S, and Behzadan. AH, Deep Learning for Visual Analytics of the Spread of COVID-19 Infection in Crowded Urban Environments. American Society of Civil Engineers. 2021.

Data2. Azuma,K, Kagi,N, Yanagi,U, Osawa,H, Effects of low-level inhalation exposure to carbon dioxide in indoor environments: A short review on human health and psychomotor performance, Environment International, Volume 121, Part 1, 2018, Pages 51-56,

Data3. Toffolutti,V, Plach,S, Maksimovic,T, Piccitto,G Mascherini,M, Mencarini,L, Aassve,A, The association between COVID-19 policy responses and mental well-being: Evidence from 28 European countries, Social Science & Medicine, Volume 301, 2022, 114906, ISSN 0277-9536

Data4. Arvelo,I, Pagone,F, Persky,J, Carpio, CE, Arnold,P, Clements,N, Decay rates of two tracer gases compared to DNA-tagged liquid aerosol tracer particles: Impact of varying dilution rate and filtration, Building and Environment, Volume 212, 2022, 108819, ISSN 0360-1323,

Data5. Haghani,M, Bliemer,MCJ, Goerlandt,F, Li,J, The scientific literature on Coronaviruses, COVID-19 and its associated safety-related research dimensions: A scientometric analysis and scoping review, Safety Science, Volume 129, 2020, 104806, ISSN 0925-7535,-1323,

Data6. Parker,MEG, Li,M, Bouzaghrane, MA, Obeid,H, Hayes,D, Frick,KT, Rodríguez,DA, Sengupta,R, Walker,J, Chatman,DG, Public transit use in the United States in the era of COVID-19: Transit riders' travel behavior in the COVID-19 impact and recovery period, Transport Policy, Volume 111, 2021, Pages 53-62

Data7. Spengler,JD, Vallarino,J, McNeely,E, and Estephan,H, National Air Transportation Center of Excellence for Research in the Intermodal Transport Environment (RITE), Airliner Cabin Environmental Research (ACER) Program, 2012

Data8. 2020-COVID-Manuscript-FINAL

Data9. Yabe T, Tsubouchi K, Fujiwara N, Wada T, Sekimoto Y, Ukkusuri SV. Non-compulsory measures sufficiently reduced human mobility in Tokyo during the COVID-19 epidemic. Sci Rep. 2020 Oct 22;10(1):18053

Data10. Lordo,RA, Buehler,SS, & James,RR, Relating Air Quality and Other Factors to Comfort and Health Related Symptoms Reported by Passengers and Crew on Commercial Transport Aircraft (Part 2), Battelle, 2018

Data11. Sukul,P, Bartels,J, Fuchs,P, Trefz,P, Remy,R, Rührmund,L, Kamysek,S, Schubert,JK, Miekish, W, European Respiratory Journal 2022 60: 2200009

Data12. National Research Council 2022. Emerging Hazards in Commercial Aviation Report 1: Initial Assessment of Safety Data and Analysis Processes. Washington, DC: The National Academies Press

Data13. Echeverría-Huarte, I., Garcimartín, A., Hidalgo, R.C. et al. Estimating density limits for walking pedestrians keeping a safe interpersonal distancing. Sci Rep 11, 1534 (2021).

Data14. Jahedinia, Fatemeh et al. "Simulation of luggage-laden passengers' behavior in the evacuation process based on a floor field CA model case study: Tehran metro-rail transfer corridor." SIMULATION (2022)

Data15. Cao,Z, Shao,M, Xu,L, Mu,S, Qu,H, MaskHunter: real-time object detection of face masks during the COVID-19 pandemic, The Institution of Engineering and Technology, IET Image Processing, Volume 14, Issue 16, 2020, Pages 4359-4367
Data16. Yu Wu, PhD; Liangyu Kang, MD; Zirui Guo, MD; Jue Liu, PhD; Min Liu, PhD; Wannian Liang, PhD, Incubation Period of COVID-19 Caused by Unique SARS-CoV-2 Strains A Systematic Review and Meta-analysis, JAMA Netw Open. 2022;5(8):e2228008
Data17. Lifelike_Characteristics___ALIFE2021 (2)
Data18. Rahimi, Z., Shirali, G.A., Araban, M. et al. Mask use among pedestrians during the Covid-19 pandemic in Southwest Iran: an observational study on 10,440 people. BMC Public Health 21, 133 (2021). https://doi.org/10.1186/s12889-020-10152-2
Data19. Budzyn SE, Panaggio MJ, Parks SE, et al. Pediatric COVID-19 Cases in Counties With and Without School Mask Requirements — United States, July 1–September 4, 2021. MMWR Morb Mortal Wkly Rep 2021;70:1377–1378
Data20. Cowger TL, Murray EJ, Clarke J, Bassett MT, Ojikutu BO, Sánchez SM, Linos N, Hall KT. Lifting Universal Masking in Schools - Covid-19 Incidence among Students and Staff. N Engl J Med. 2022 Nov 24;387(21):1935-1946.
Data21. Bustamante,V, Luis,J, et al. "Optimization of passengers boarding in the BRT system based on the security protocols established by the Covid-19 pandemic." 2020 Congreso Internacional de Innovación y Tendencias en Ingeniería (CONIITI) (2020): 1-6.
Data22. Feng,Y, Duives,D, Daamen,W, Hoogendoorn,S, Data collection methods for studying pedestrian behaviour: A systematic review, Building and Environment, Volume 187, 2021, 107329, ISSN 0360-1323,
Data23. Drury,J, Reicher,S, Hopkins,N, The psychology of physical distancing, BPS, 2020
Data24. Fraser T, Aldrich DP. The dual effect of social ties on COVID-19 spread in Japan. Sci Rep. 2021 Jan 15;11(1):1596.
Data25. Qian,H, Zhang,N, Dong,Z, Wei,D, Mereness,R, Armstrong,J, Pepper,C, Koolhof,I, Airport human behavior study, Boeing Research & Technology
Data26. Han,Y, Zhang,Y, Gao,Y, Hu,X, Guo,Z, Vortex structure of longitudinal scale flow in a 28-row aircraft cabin, Building and Environment Volume 222, 15 August 2022, 109362

Passenger Performance: 13 studies in total, 12 studies summarized. Summaries focus on the passenger behaviours/actions/scenarios that have been examined and the factors that influence them.

- Bidder et al examined the non-economic impact of COVID-19 on tourist behaviour, from the perspective of travel intention and regain of travellers' confidence in travelling again during and post-pandemic. Data were collected with an online questionnaire using the snowball sampling method. A total of 150 respondents completed the questionnaire. A descriptive statistical test was used to analyse the data collected. It collected numerical data to describe the non-economic impact of COVID-19 on travel behaviour based on tourist travel in Borneo. 55% indicated that they would only be motivated to travel again if the COVID-19 vaccine would become available, 23% were concerned about crowds, 46% were concerned about their overall health and safety wellbeing. The top five health, safety, and hygiene measures that might help restore travellers' confidence were mask-wearing (91%), social distancing (88%), hand sanitizing (88%), non-crowded places (7%) and disinfection and sterilization (6%). [Pax2]
- Pan et al study focused on the mask use of airline passengers when they flew during COVID-19, using the theory of planned behaviour (TPB) model to examine the relationship between nine context-specific predicting factors and the mask-wearing intention in the aircraft cabin. The TPB suggests that behaviour is immediately determined by behavioural intention, which in turn is affected by three factors –attitude, subjective norms, and perceived behavioural control (PBC). A survey instrument was developed to collect data from 1124 air travellers, and the data was statistically analysed using structural equation modelling and logistic regression, focused on US air travellers from between May 12 and May 15, 2021. The survey questionnaire for this study consisted of four major sections: (1) demographics, (2) travel and mask experience, (3) factor impact on mask-wearing intentions during flight, and (4) willingness to pay more to switch to airlines that offer different mask policies. *Results showed that attitude, descriptive norms, risk avoidance, and information seeking significantly influenced the travellers' intention to wear a mask during flight in COVID-19.* Group analysis further indicated that the four factors influenced mask-wearing intentions differently on young, middle-aged, and senior traveller. [Pax3]

- Anderson et al presented a description of the response by the federal government and the United States (U.S.) airline industry from the perspective of a flight attendant union between the early days of the COVID-19 pandemic and the date the article was issued in 2022. Specifically, the issues of ventilation, face masks, aggressive passengers, quarantine and isolation, and vaccinations are reviewed, including actions taken by the executive branch of the U.S. government, regulators, airlines, manufacturers, and the crew member union. The union stated the COVID-19 pandemic has significantly affected flight attendants' health, safety, and security. *The estimated "average infection probability" for a 12-h flight without masks ranged from 0.8 percent to 11 percent. When modelled with all passengers wearing masks, those numbers dropped by between 32-73%, depending on the mask quality. And if all passengers were assumed to remove their masks for 1 h to eat, then the model predicted an increase in the average infection probability, ranging from 8-59%.* Eating/drinking, intoxication and politicizing mask-wearing were all factors contributing to the inconsistent mask-wearing. [Pax11]
- Gao et al explored the process of boarding within the air traveling process due to its high susceptibility to health safety risks, using the methodology of building an agent-based mathematical model and running computer simulations to find the optimal boarding strategy to be applied by Low-Cost Carriers in HKIA under the New Normal in order to achieve practical efficiency and safety. Factors such as luggage and carry-ons, walking, seat interference, and disobedience are considered in the modelling process. This paper established a mathematical model to emulate the process of boarding in order to investigate the optimal boarding strategy to be applied by LCC post-COVID. An agent-based model would then be simulated via computer program codes to derive the efficiency by considering the simulated time and safety by observing whether passengers could effectively distance themselves during the simulation processes. Factors of luggage and carry-ons, walking, seat interference, and disobedience are considered in the modelling process. MCU 10.3mins, random 8.1mins, F2B 21.9mins. Not clear if movement impairments modelled or if quick boarding equates to reduced transmission. [Pax12]
- Herbig et al investigated whether higher recirculation air rates in aircraft cabins negatively affected passenger health and well-being and if occupancy plays a role in this. Participants rated comfort, health symptoms, and sleepiness multiple times. Heart rate (variability), as a stress marker, was measured continuously. In total, 283 males and 276 females (N = 559) participated, resulting in 50.6% men and 49.4% women with an overall mean age of 42.68 years (SD = 15.85; range: 18–79 years). 56.2% of participants achieved general qualification for university entrance/A level, 0.5% left school without graduation. The subjects flew 5.3 times per year on average (SD = 18.3; range: 0–260). BMI (M = 24.91; SD = 4.83) and general health (SF-8: M = 15.13; SD = 4.36) were in the normal range. In a 2 (occupancy: full and half-occupied) X 4 (ventilation regime) factorial design with stratified randomization, participants were exposed in an aircraft segment in a low-pressure tube during a 4-h simulated flight. Ventilation regimes consisted of increasing proportions of recirculated air up to a maximum CO_2 concentration of 4200 ppm. ANCOVA results showed hardly any effect of both factors on self-reported health symptoms, strong main effects of occupancy on comfort measures, and interaction effects for sleepiness and physiological stress parameters: Participants in the half-occupied cabin hardly reacted to increased recirculation air rates and show overall more favourable responses. Participants in the fully occupied cabin reported higher sleepiness and had stress reactions when the recirculation air rate was high. [Pax4]
- Zahraee et al aimed to determine customers' satisfaction with the aviation industry during the COVID-19 pandemic. A questionnaire survey was conducted in China to investigate the Chinese passengers' satisfaction with 22 elements in four stages: *Pre-Flight, In-Flight, After-Arrival, and Others* (Face mask requirement, HEPA filters, etc.). Second, the work explored the measures that will benefit the airlines by investigating the measures taken by 49 major airlines worldwide, especially considering the operational cost and passengers' safety. The work would determine the measures airlines have taken to deal with COVID-19 and analyze passengers' satisfaction with 22 measures in four stages: Pre-Flight, In-Flight, After-Arrival, and Others (Face mask requirement, HEPA filters, etc.). Quantitative data refers to passenger satisfaction among different responses, which is the primary data collected by the questionnaire. The research collects 22 responses from passengers. It was found that cabin selection and passengers who travelled after the start of COVID-19 were the groups that affected passengers' satisfaction levels on responses. The top 3 satisfied measures were ''Provide hygiene products for passengers and staff", ''A thermal scanner to monitor body temperature during check-in", and ''Disinfect the cabin after each flight, even for a previous flight of the connecting flight". The bottom 3 measures were ''Protective clothing is required to board the plane", ''Adopt a special boarding method such as boarding in the order from back to front", and ''No in-flight meals and drinks (only snacks and water)". Airlines'

responses primarily focused on reducing the operation cost, ensuring the safety and interests of the passengers and improving the income and cash of the company. [Pax5]

- Cusack et al examined the commute mode choices of essential workers in Philadelphia, Pennsylvania, USA to explore the extent to which active transportation to work is explained by individual, social, and environmental factors and whether active transportation choices reflect inequalities. Drawing on the theory of planned behaviour and the social-ecological model, the study utilized data from an online survey (N = 213) completed between June and August 2020. Bivariate analyses compare respondents who commuted using active transportation modes to those who did not using chi-square and ANOVA tests. Structural and social investments that make bicycling and walking safer commuting alternatives during COVID-19 could contribute to sustained behaviour change as well as community engagement which is necessary for implementation efforts. Nearly half of respondents changed their commute mode during the pandemic, most often to limit exposure to COVID-19. The full model, accounting for 54% of variation in active transportation commuting, indicated significantly lower odds of active transportation use among non-white (Odds Ratio [OR]: 0.155) respondents and those who reported time constraints (OR: 0.450), concerns about safety from traffic (OR: 0.482), and greater satisfaction with community support for bicycling and pedestrian issues (OR: 0.551) and significantly higher odds among those who reported safety concerns around germs (OR: 1.580). [Pax6]
- Abdulhassan et al aimed is to identify potential concerns and countermeasures transport children in a safer manner amid the Coronavirus crisis by considering the design of school bus cabins and the anthropometric characteristics of children. Compartmentalization (which is to have seat backs high enough to reduce passenger travel distance in the event of an accident) is commonly used to protect passengers from head-on and rear-end collisions. Federal Motor Vehicle Safety Standard (FMVSS) no. 222 requires the vertical height of a school bus seat to be greater than 61 cm for school buses manufactured after October 21, 2009 (NHTSA, 2011). The average sitting height of 6 to 7 year-old children ranges between 62 and 66 cm (Burton, 2018). The Occupational Safety and Health Administration (OSHA) defines the breathing zone of healthcare workers exposed to anaesthetic gases as a hemisphere forward of the worker's shoulders with a radius of approximately 6 to 9 in." (Occupational Safety and Health Administration, 2000). The breathing zone of younger school bus passengers is primarily in the same compartment defined by the seat back of the seat in front of them. COVID-19 mitigation strategies for busing operation and cabin design aim to provide as safe and healthy a passenger environment as possible considering both practicality and cost-effectiveness. Nearly 26 million children are transported daily on approximately 480,000 school buses in the United States (National School Transportation Association, 2013). The risk of virus transmission may be reduced by adhering to Centers for Disease Control and Prevention (CDC) guidelines, and additional bus specific considerations such as structured loading and unloading criteria, face coverings guidelines, incorporation of a bus monitor, and potential modifications/design changes for existing/future school buses. [Pax7]
- Karunakaran et al assessed the impact of covid on human error in air incidents - especially given the need for new tech/practices during operation. Details of three decades of selective aircraft maintenance accidents and are analyzed to arrive to the significant aviation safety factor. Review of accident investigation practices in covid and non-covid environments (across 14 incidents in India). The route of error mitigation and high standard technological training with human factor knowledge, to aircraft maintenance students are analyzed in detail with the opportunity of percentages of error reduction. The technological applications in air transportation and aircraft maintenance have tripled during the pandemic. The pandemic has brought a severe threat to the aviation safety. [Pax8]
- Yang et al conducted a survey to assess whether risk compensation would occur among travellers' health-related behaviours after COVID-19 vaccination, potentially aggravating the transmission of the virus. A self-administered online survey was designed and distributed over WeChat to identify the difference in health behaviours before and after COVID-19 vaccination among travellers at a train station in Taizhou, China, from 13 February to 26 April 2022. A total of 602 individuals completed the questionnaire. the results revealed no statistical difference between the health behaviours reported by the vaccinated and unvaccinated groups. For participants who received the first dose of the vaccine hand washing frequency decreased by 4.1% ($P = 0.145$) and the duration of public transport travel increased by 3.4% ($P = 0.437$) but mask-wearing duration increased by 24.7% ($P = 0.014$). Participants vaccinated against COVID-19 three times showed no statistical differences in harmful health behaviours mask-wearing duration decreased by 7.0% ($P = 0.927$), their hand washing frequency decreased by 4.8% ($P= 0.905$), and the duration of public transport travel increased by 2.5% ($P = 0.287$). After vaccination, when compared to themselves before vaccination, participants exhibited better health behaviours (increased hand washing

frequency and mask-wearing duration, and decreased duration of public transport travel) to some extent. In conclusion, the study found no evidence of risk compensation among travellers. After being vaccinated, health behaviours partly improved among travellers. [Pax9]

- UK Rail Innovation COVID-19 Contributions from UK Industry brochure is a collaboration between KTN and Innovate UK to promote some examples of how UK innovators can contribute to the rebuilding and growth of rail in UK and around the world based on post-pandemic UK rail use. Methods identified: cabin airflow modelling (plastic shields), air sterilization (rensair hospital-grade air purification), sterilization and hygiene (entex - decontamination booth, portable disinfectant room fogger, electrox sterilizing water), intercede spectrum virus sensor, NoBACZ antimicrobial barriers, sym-wall aqueous ozone decontamination system, Orion Eco cleaning products; staff solutions and tracing. TfL have initiated the use of Social Distancing and Contactless ticketing. [Pax10]
- Colak et al investigated how airport management has been impacted by the sudden and prolonged fall in the demand for air travel within the air transport industry (UK) during pandemic. The case was studied through the Business Model Canvas, with documentary evidence supplemented with 31 in-depth interviews from the Government, airports, airlines, and other aviation organizations and from a variety of stakeholder roles within airports across the country. Interviewees were asked about how airport business models responded to COVID-19 and how they were likely to change in the future, as a consequence. A qualitative approach is adopted for this study, by which the 9 subsections of the BMC are mapped to a semi-structured interview and used to engage industry stakeholders. COVID-19 encouraged airports to restructure key components in their business models according to the findings. Airports have significant fixed costs, and it has been especially challenging to run terminals and operations with little or no revenue from conventional channels. Revenue passenger kilometres in the air transport sector globally experienced a 65.9% fall from 2019-2020. The most significant impact factor had been the sudden demand shock which was followed by a lack of global passenger traffic for 2 years. The study finds 4 future airport business drivers and approaches have emerged: 1) Cost-effectiveness and minimization, 2) Diversification of revenue streams and intensified commercial activities, 3) Enhanced digitalization and operational efficiency, and 4) Sustainability focused approach had shaped their strategic approach to problems and solutions during the pandemic. [Pax13]

Passenger Performance References:

Pax1. Scott Parr, Ph.D.; Brian Wolshon; John Renne, Ph.D.; Pamela Murray-Tuite, Ph.D., A.M.ASCE; and Karl Kim, Ph.D., Traffic Impacts of the COVID-19 Pandemic: Statewide Analysis of Social Separation and Activity Restriction, Nat. Hazards Rev., 2020, 21(3): 04020025

Pax2. Bidder,C, Aidi,MZ, Hong,LM, Fatt,BS, Kibat,SA, Mogindol,SH, Daniel,SD, and Jailani,SE, COVID-19: Travel Intention and Restoring Travellers' Confidence, Chapter 12, pp126-140, ESTEEM Journal of Social Sciences and Humanities, Volume 5, No. 1, April 2021

Pax3. Pan,JY, Liu,D, Mask-wearing intentions on airplanes during COVID-19 – Application of theory of planned behavior model, Transport Policy 119 (2022) 32–44 Available

Pax4. Herbig,B, Norrefeldt,V, Mayer,F, Reichherzer,A, Lei,F, Wargocki,P, Effects of increased recirculation air rate and aircraft cabin occupancy on passengers' health and well-being – Results from a randomized controlled trial, Environmental Research 216 (2023) 114770

Pax5. Zahraee, SM, Shiwakoti,N, Jiang, H. et al., A study on airlines' responses and customer satisfaction during the COVID-19 pandemic, International Journal of Transportation Science and Technology, https://doi.org/10.1016/j.ijtst.2022.11.004

Pax6. Cusack,M, Individual, social, and environmental factors associated with active transportation commuting during the COVID-19 pandemic, Journal of Transport & Health 22 (2021) 101089.

Pax7. Abulhassan,Y, Davis,GA, Considerations for the transportation of school aged children amid the Coronavirus pandemic, Transportation Research Interdisciplinary Perspectives 9 (2021) 100290

Pax8. Karunakaran C.S. and Ashok Babu J., Impact of human factors in aircraft accident mitigation and aircraft maintenance training needs in post COVID-19 aviation, Aircraft Engineering and Aerospace Technology, Volume 94, Number 8, 2022, 1296–1302

Pax9. Yang,M, Wang,L, Xu,L, Ke,M, and Sun,L, Health Behaviours among Travellers Regarding Risk Compensation Following COVID-19 Vaccination in Taizhou, China, Canadian Journal of Infectious Diseases and Medical Microbiology, Volume 2023, Article ID 1329291, https://doi.org/10.1155/2023/1329291

Pax10. UK Rail Innovation COVID-19 Contributions from UK Industry

Pax11. Anderson,J, COVID-19 in the Airline Industry: The Good, the Bad, and the Necessary, NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy 2022, Vol. 32(2) 92–99
Pax12. Gao,H and Zheng,JQ, Changes of COVID-19 Pandemic to the Future Boarding Process of Airlines (1), 2022 6th International Conference on Informatics and Computational Sciences (ICICoS)
Pax13. Colak, O., Enoch, M., Morton, C., Airport business models and the COVID-19 pandemic: An exploration of the UK case study, Journal of Air Transport Management (2022), doi: https://doi.org/10.1016/j.jairtraman.2022.102337.

Modelling Efforts: 43 articles were examined, with 19 summaries included below. These were examined to establish the factors that were included in the models currently employed – to establish whether they might inform the trials planned as part of this work.

- Kim et al looked at peer-reviewed publications, reports and studies conducted in the public, private, and non-governmental sectors on the response and recovery from the COVID-19 pandemic. They identified the lessons and gaps in knowledge for further research for knowledge to action in transportation policy. The paper called for further research on: integration between public health and transportation, technology for contact tracing and tracking travellers, focus on vulnerable and at-risk groups, re-engineering of travel demand models, challenges with Big Data and information technologies, trust relationships, conflict management, transdisciplinary knowledge and engagement, demands for training and education, and transformative change to support community resilience, it does not talk about modelling. [Mod1]
- Chen et al observed the number of passengers boarding/deboarding a bus at each stop observed to inform the use of their optimization model (using dynamic programming). The goal was to reduce the number of contact points. [Mod2].
- Wang et al used coupled Wells-Riley (WR) and Computational Fluid Dynamics (CFD) modelling (WR-CFD) (in Smartfire) to simulate COVID-19 infection probability (IP) due to susceptible being exposed to quanta generated from index patients on a long-distance trains cabin. To validate their model, they collected data on reported COVID-19 infection probability for passengers travelling on long distance trains. [Mod3].
- Schultz et al used mixed-integer programming, genetic algorithm, an agent-based model and infection risk model to simulate an optimized boarding procedure of an aircraft and estimate boarding time and infection rate compared to a baseline scenario with random seat allocation and boarding order. [Mod4].
- Namilae et al used a pedestrian and infection risk model (simulation) to estimate infection risk during the processes of boarding and deplaning. and inflight movement, taking into account people movement and type of mask wearing. They modelled passengers as homogeneous particles, and then inputted the passenger trajectories and seating arrangements into a fine-scaled infection spread model to identify infection risk. For model validity, they collected data from three flights that had detailed information on in-flight COVID-19 seating arrangements and infection profiles of the passengers. [Mod5].
- Haghpanah et al observed assisted evacuation of hospital patients with and without COVID in four examined scenarios (a) pre-COVID, (b) I1: separated COVID patients, (c) I2: separated COVID patients with a larger nursing team, (d) I3: separated COVID patients with a dedicated exit path, using a simulation in Netlogo. They used data for classification and attributes of non-ICU patients (speeds, size, need of assistance, preparation time). [Mod6].
- Kalachev et al observed an influenza outbreak in a boarding school in England and COVID-19 data from the fall of 2020 in Missoula County, Montana, USA to develop a statistical/Susceptible-Infected-Recovered (SIR) disease propagation model in order to predict disease transmission in general public. They interpreted the reported data and assigned the data to the compartment in SIR model. Correctly interpretating data and assigning data to the right compartment will lead to reasonable model predictions, otherwise, if the data types are misaligned with the model compartment, there could be erroneous results. [Mod7]
- Borjigin et al examined the probability of infection given the bus design, use of different masks, bus operation parameters and mitigation measures (capacity, ventilation, duration between stops and overall duration) using an agent-based modelling approach [Mod8]. Passengers were initially identified as being infected or uninfected and the levels were monitored. They generated the number of infected people during bus operation with mitigation measures considering probability of infection (different masks), passenger capability, and ventilation (windows open/closed). Infection was estimated using a simple single probability infection model within ABM. [Mod8]
- Islam et al examined infection exposure (measured as person-minutes of contact) of four different boarding procedures: 1. 1-Zone, 2. 6-Zones business-first, 3. Back-to-front, 4. Back-to-front business-first using a

simulation/ABM. They used data on boarding procedures, luggage stowing time and movement speed for the model. [Mod9].

- Ghaffarzadegan et al collected time series data for official reports of death, recovered, and cumulative number of infected over time in Iran as well as unofficial data points including four observations about the number of Iranian passengers diagnosed with COVID-19 upon arrival in international airports, and three estimates about the total number of deaths from COVID-19, and data on population size and travel scope. They used this data to develop a statistical/Susceptible, Exposed, Infectious, and Recovered (SEIR) mode to predict disease transmission in general public. There are two endogenous mechanisms in SEIR model. (1) contact rate to be endogenously changing in response to perceived risk of infection, (2) endogenous changes in screening and reporting of cases over time. They used the simulation to estimate cumulative infected (c), death (d), current infected population (e), and reproduction number in order to observe the spread of the disease in its early phases. [Mod10]
- Johansson et al used FAA and EASA aircraft evacuation regulation and data on evacuation and dimension of exit types, time to unfasten seatbelt, leave seat, collect bag from storage, row speed with and without luggage to simulate two types of airplane evacuations. The two types of evacuations considered in the model were a rapid deplaning and 90s deplaning. Body size, walking speed and comfort distance were attributes given to the passengers. Six scenarios were simulated in Pathfinder and FDS+Evac: 90s, 90s increased aisle width, 90s increased/decreased body size, rapid deplaning with no luggage, rapid deplaning with luggage, rapid deplaning with no luggage and no comfort distance. Distributions for evacuation time were shown for both software tools. [Mod14]
- Uyar et al simulated the movement of passengers in an LAWA airport terminal using Flow software to determine how comfortable it would be to circulate within the proposed layout and identify any potential issues before finalizing the design. They used data on a Southwest Airlines flight schedule for LAX terminal 1, maximum passenger capacity, survey from LAX on purpose to travel, information on itinerary types and dwell times. Passengers were profiled based on whether they travel for business or leisure, itinerary assumptions, dwell time, walking speeds. Areas of congestion in the airport terminal were identified. [Mod15]
- Davis et al examined the particles expelled by a cough on a 5-row, 30-seat section of the 737 Boeing Sky Interior by simulating the airflow of the cough expelled using computational fluid dynamics (CFD). Each passenger was profiled as either an index or susceptible passenger and they were assumed seated with no mask. Non-volatile mass inhaled for each passenger shown for different flow rates, with different positioning of index passenger. Data on the plane design, particle size distribution and rate of airflow from cough data was used, and experimental measurements by the TRANSCOM/AMC team was taken for comparison. [Mod18].
- Delcea et al examined boarding time, aisle seat risk, window seat risk and number of type-3 seat interferences for a reverse pyramid method of boarding a plane (with social distancing of 1m and middle seat of each aisle unoccupied) using simulation in Netlogo. Data was collected on the reverse pyramid method and walking speeds from field trials. The population was divided into three groups: window seat, front aisle seat, back aisle seat, also accounting for varied walking speed and the time to store bags. They looked at results weighted for each of the examined factors to evaluate how the reverse pyramid should be adapted for COVID-19. [Mod20].
- Cotfas et al examined seat interferences, touching luggage, risk to aisle seats, risk to window seats using simulation in Netlogo for five boarding methods (of which the method had been discussed in other peer-reviewed articles): Airplane configuration (random), WilMa, Back-to-Front by group, Back-to-Front by row, Modified reverse pyramid half zone. They accounted for scenarios with social distancing at 1m, 1.5m, 2m and the middle seat of each aisle not occupied. Passengers were profiled based on whether they were a front or back seat passenger or an aisle or window seat passenger, passengers also were attributed values for their time to store luggage, speed. Used this examined data from the model to evaluate the best current model and what needs to be improved in future models. [Mod22].
- Milne et al evaluated the use of multiple boarding processes when using Apron buses between the terminal and plane using simulation in Netlogo. The boarding methods considered have all been discussed in other peer-reviewed materials, they were Random, Back-to-Front, Back-to-Front mix, WilMA, Reverse Pyramid, Steffen. There were also methods for boarding the buses, each consisted of 10 bus journeys with 12 passengers on each bus. Social distancing of 1m and 2m was considered, the middle seat of each aisle was not occupied, there were also 7 luggage scenarios accounted for. Passengers were profiled on their choice of seat (aisle, window, front, back), and each boarding method was evaluated based on boarding time, seat interferences, aisle seat risk and window seat risk. [Mod25].

- Harweg et al used self-propelled agents (ABM), social-force-based simulation and infectious disease modelling to track the spread of infectious diseases by modelling aerosol traces and concentration of virus load in the air in an airport terminal setting. The simulation showed rising numbers due to infections by newly infected agents do not occur until about four days. [Mod27].
- Hanna et al used basic science models, including the slab model, the Gaussian plume model, and the diffusivity (K) model to look at the dispersion of air from a passenger in Boeing 767 and 777 Aircrafts. Assumptions made on diameter of bead (1 μm here), which plane is chosen to be used for each run (both are used but mainly the 767), section of plane studied (mostly aft data here), scenario (inflight used here), Gaspers on/off (assumed off here), mannequin breathing or coughing (assumed breathing here), mask on mannequin or no mask (off scenario used here). Time series curves for different seating positions of passengers are compared. [Mod28].
- Trent et al observed inhaled mass due to breathing and coughing from a person in an aircraft and a commercial building. Methods from Davis and Zee et al was used to model. Each occupant had a breathing zone defined in front of their face. Air distribution nozzles were located above each row on either side of the aisle and return air grilles were located at every window seat position below the window near the floor. Computational fluid dynamics (CFD) studies were performed tracking particles released from a single cough and from sinusoidal tidal breathing to compare the lifespan and movement of particles within an aeroplane to an ICS. Both the cough and breathing were modelled for the airplane environment, but only the cough was modelled for the ICS. The total mass inhaled by other occupants was compared based on environment and position of occupant. [Mod29].

Modelling Effort References:

Mod1. Kim, K. E. (2022). Ten Takeaways from the COVID-19 Pandemic for Transportation Planners. Transportation Research Record, 0(0). https://doi.org/10.1177/03611981221090515

Mod2. Chen, F, Peng,H, Ding,W, Ma,X, Tang,D, Ye,Y, Customized bus passenger boarding and deboarding planning optimization model with the least number of contacts between passengers during COVID-19,Physica A: Statistical Mechanics and its Applications,Volume 582,2021,126244,ISSN 0378-4371,https://doi.org/10.1016/j.physa.2021.126244.

Mod3. Wang,Z, Galea,ER, Grandison,A, Ewer,J, Jia,F, A coupled Computational Fluid Dynamics and Wells-Riley model to predict COVID-19 infection probability for passengers on long-distance trains,Safety Science,Volume 147,2022,105572,ISSN 0925-7535,https://doi.org/10.1016/j.ssci.2021.105572.

Mod4. Schultz,M, Soolaki,M, Salari,M, Bakhshian,E, A combined optimization–simulation approach for modified outside-in boarding under COVID-19 regulations including limited baggage compartment capacities,Journal of Air Transport Management,Volume 106,2023,102258,ISSN 0969-6997,https://doi.org/10.1016/j.jairtraman.2022.102258.

Mod5. Namilae,S, Wu,Y, Mubayi,A, Srinivasan,A, Scotch,M, Identifying mitigation strategies for COVID-19 superspreading on flights using models that account for passenger movement, Travel Medicine and Infectious Disease, Volume 47, 2022, 102313, ISSN 1477-8939, https://doi.org/10.1016/j.tmaid.2022.102313.

Mod6. Haghpanah,F, Ghobadi,K, Schafer,BW, Multi-hazard hospital evacuation planning during disease outbreaks using agent-based modeling,International Journal of Disaster Risk Reduction,Volume 66,2021,102632,ISSN 2212-4209,https://doi.org/10.1016/j.ijdrr.2021.102632.

Mod7. Kalachev L, Landguth EL, Graham J. Revisiting classical SIR modelling in light of the COVID-19 pandemic. Infect Dis Model. 2023 Mar;8(1):72-83. doi: 10.1016/j.idm.2022.12.002. Epub 2022 Dec 16. PMID: 36540893; PMCID: PMC9755423.

Mod8. Borjigin, S.G., He, Q., Niemeier, D.A., COVID-19 transmission in U.S. transit: A scenario-based approach with agent-based simulation modeling (ABSM), Communications in Transportation Research,Volume 3, December 2023, 100090

Mod9. Islam T., Lahijani M. Sadeghi, Srinivasan A., Namilae S., Mubayi A. and Scotch M. 2021, From bad to worse: airline boarding changes in response to COVID-19R. Soc. open sci.8201019201019

Mod10. Ghaffarzadegan N, Rahmandad H. Simulation-based estimation of the early spread of COVID-19 in Iran: actual versus confirmed cases. Syst Dyn Rev. 2020 Jan-Mar;36(1):101-129. doi: 10.1002/sdr.1655. Epub 2020 Jul 6. PMID: 32834468; PMCID: PMC7361282.

Mod11. Shah Y, Kurelek JW, Peterson SD, Yarusevych S. Experimental investigation of indoor aerosol dispersion and accumulation in the context of COVID-19: Effects of masks and ventilation. Phys Fluids (1994). 2021 Jul;33(7):073315. doi: 10.1063/5.0057100. Epub 2021 Jul 21. PMID: 34335009; PMCID: PMC8320385.

Mod12. Khoshnaw SHA, Shahzad M, Ali M, Sultan F. A quantitative and qualitative analysis of the COVID-19 pandemic model. Chaos Solitons Fractals. 2020 Sep;138:109932. doi: 10.1016/j.chaos.2020.109932. Epub 2020 May 25. PMID: 32523257; PMCID: PMC7247488.
Mod13. Ronchi, E., Scozzari, R., & Fronterrè, M. (2020). A risk analysis methodology for the use
Mod14. Johansson,A, (2019), A Modelling Study on the Impact of Luggage and Airworthiness Certification on Aircraft Evacuation, Report 5584, ISRN: LUTVDG/TVBB--5584--SE, Lund University
Mod15. Uyar, G, Izaki, Å, Anklesaria, F & Spencer, R. (2022). Applying Flow simulation framework to model passenger behaviour in an airport terminal in North America. Proceedings of the 13th Space Syntax Symposium, Western Norway University of Applied Sciences, Bergen, Norway, June 2022
Mod16. D'Orazio, M., Bernardini, G. and Quagliarini, E., 2020. How to restart? An agent-based simulation model towards the definition of strategies for COVID-19" second phase" in public buildings. arXiv preprint arXiv:2004.12927.
Mod17. Squazzoni, F, Polhill, JG, Edmonds, B, Ahrweiler, P, Antosz, P, Scholz, G, Chappin, E, Borit, M, Verhagen, H, Giardini, F and Gilbert, N (2020) Computational models that matter during a global pandemic outbreak: A call to action. Journal of Artificial Societies and Social Simulation, 23 (2). ISSN 1460-7425
Mod18. Zee, M., Davis, A.C., Clark, A.D. et al. Computational fluid dynamics modeling of cough transport in an aircraft cabin. Sci Rep 11, 23329 (2021). https://doi.org/10.1038/s41598-021-02663-8
Mod19. Li J, Yuan P, Heffernan J, Zheng T, Ogden N, Sander B, Li J, Li Q, Bélair J, Kong JD, Aruffo E, Tan Y, Jin Z, Yu Y, Fan M, Cui J, Teng Z, Zhu H. Fangcang shelter hospitals during the COVID-19 epidemic, Wuhan, China. Bull World Health Organ. 2020 Dec 1;98(12):830-841D. doi: 10.2471/BLT.20.258152. Epub 2020 Sep 29. PMID: 33293743; PMCID: PMC7716094.
Mod20. Delcea, C., Milne, R. J., & Cotfas, L.-A. (2020). Determining the Number of Passengers for Each of Three Reverse Pyramid Boarding Groups with COVID-19 Flying Restrictions. Symmetry, 12(12), 2038. https://doi.org/10.3390/sym12122038
Mod21. Milne RJ, Cotfas L-A, Delcea C, Crăciun L, Molănescu A-G (2020) Adapting the reverse pyramid airplane boarding method for social distancing in times of COVID-19. PLoS ONE 15(11): e0242131. https://doi.org/10.1371/journal.pone.0242131
Mod22. Cotfas, L.-A., Delcea, C., Milne, R. J., & Salari, M. (2020). Evaluating Classical Airplane Boarding Methods Considering COVID-19 Flying Restrictions. Symmetry, 12(7), 1087. https://doi.org/10.3390/sym12071087
Mod23. Qian, X. and Ukkusuri, S.V., 2020. Modeling the spread of infectious disease in urban areas with travel contagion. arXiv preprint arXiv:2005.04583.
Mod24. Smedberg, E. (2022). Egressibility: Applying the concept of accessibility to the self-evacuation of people with functional limitations. [Licentiate Thesis, Division of Fire Safety Engineering]. Lund University. ISBN 978-91-8039-256-3
Mod25. Milne RJ, Delcea C, Cotfas LA, Ioanas C. Evaluation of Boarding Methods Adapted for Social Distancing When Using Apron Buses. IEEE Access. 2020 Aug 11;8:151650-151667. doi: 10.1109/ACCESS.2020.3015736. PMID: 34786284; PMCID: PMC8545341.
Mod26. Ronchi,E, Lovreglio,R, EXPOSED: An occupant exposure model for confined spaces to retrofit crowd models during a pandemic, Safety Science, Volume 130, 2020, 104834,
Mod27. Harweg, T.; Wagner, M.; Weichert, F. Agent-Based Simulation for Infectious Disease Modelling over a Period of Multiple Days, with Application to an Airport Scenario. Int. J. Environ. Res. Public Health 2023, 20, 545
Mod28. Hanna, S, Transport and dispersion of tracers simulating COVID-19 aerosols in passenger aircraft, Indoor Air, 2021, 32, 1, 0905-6947
Mod29. TRENT,S, DAVIS,A, WU,T, MENARD,D, CUMMINS,JJ, SANTARPIA,JL, OLSON,N, Inhaled Mass and Particle Removal Dynamics in Commercial Buildings And Aircraft Cabins, ASHRAE Journal 2022
Mod30. Patil,P, Kazemzadeh,K, Bansal,P, Integration of charging behavior into infrastructure planning and management of electric vehicles: A systematic review and framework, Sustainable Cities and Society, Volume 88, 2023, 104265
Mod31. Kerr CC, Stuart RM, Mistry D, Abeysuriya RG, Rosenfeld K, Hart GR, et al. (2021) Covasim: An agent-based model of COVID-19 dynamics and interventions. PLoS Comput Biol 17(7), 2021
Mod32. Rahn S, Gödel M, Köster G, Hofinger G (2022) Modelling airborne transmission of SARS-CoV-2 at a local scale. PLoS ONE 17(8), 2022
Mod33. Lau,Z, Griffiths,IM, English,A, Kaouri,K, Predicting the spatio-temporal infection risk in indoor spaces using an efficient airborne transmission model, Proceedings of the Royal Society A, Mathematical, physical and engineering sciences, Vol 478, 2259, 2022

Mod34. Balasundaram, S. and Venkatagiri,S, A structured approach to implementing Robotic Process Automation in HR. Journal of Physics: Conference Series 1427 (2020).
Mod35. Teslya A, Pham TM, Godijk NG, Kretzschmar ME, Bootsma MCJ, Rozhnova G (2020) Impact of self-imposed prevention measures and short-term government-imposed social distancing on mitigating and delaying a COVID-19 epidemic: A modelling study. PLoS Med 17(7)
Mod36. Mukherjee,D, Wadhwa,G, A mesoscale agent based modeling framework for flow-mediated infection transmission in indoor occupied spaces, Computer Methods in Applied Mechanics and Engineering, Volume 401, Part A, 2022, 115485.
Mod37. Islam T, Lahijani MS, Srinivasan A, Namilae S, Mubayi A, Scotch M. 2021 From bad to worse: airline boarding changes in response to COVID-19. R. Soc. Open Sci. 8: 201019.
Mod38. Fischetti, M, Fischetti, & Stoustrup, J, (2020). Mathematical optimization for social distancing.
Mod39. Schultz,M, and Soolaki,M, (2022) Optimized aircraft disembarkation considering COVID-19 regulations, Transportmetrica B: Transport Dynamics, 10:1, 880-900
Mod40. Janzwood, S, 2020,. Evacuating Communities Affected by Disasters During Future COVID-19 Waves, InterSystemic Cascades Brief #4, Cascade Institute: pp. 1-15
Mod41. Bruyninckx,B, 'Density' and 'Capacity' as COVID-19 Exit Strategy Parameter for Events in Belgium, 2020.
Mod42. Calcagno,P, Consilvio,A, Febbraro,AD, and Sacco,N, Reshaping metro station spaces to improve social distancing during COVID-19 pandemic, 2021 7th International Conference on Models and Technologies for Intelligent Transportation Systems (MT-ITS), Heraklion, Greece, 2021, pp. 1-6
Mod43. Stettler MEJ et al. 2022 Source terms for benchmarking models of SARS-CoV-2 transmission via aerosols and droplets. R. Soc. Open Sci. 9: 212022.

Reopening Post-Covid: 10 documents were reviewed with nine referenced below (albeit briefly).

- Davidson et al (2020) produced findings from ongoing semi-structured interviews (n=21) involving responders. Conducted April/May 2020. Means to ensure communication channels between local and central government remain open. Provide briefing of the purpose of resilience fora and the structure of meetings. Importance of facilitating communication [ReOp1].
- Boardroom@Crisis focused on reopening business events [ReOp2]. Attempted to ensure personnel and personal Safety; manage use of prevention materials; enable physical distancing, and distance attractions; produce safety measures in support health screening; deny entry to those who fail tests; sanitzer locations; manage ventilation; attendee flow management and encourage/enforce measures; clear display of requirements; provide medical services; pre-event registration; manage (monitor) information; and monitor crowd movements.
- Kim reviewed 100+ peer-reviewed publications and government/non-government studies and conducted online/inperson surveys(n=416) [ReOp4]. Lessons related to (1) integration of public health/transportation; (2) technology for contact tracing and tracking of travellers; (3) focus on vulnerable; (4) updating of demand models to account for social distancing, quarantine, and public health interventions; (5) establishing trust between the general public, government, private sector, and others; (6) managing conflict during emergencies; (7) complexities of multi-disciplinary knowledge; (8) training and education.
- Sadik-Khan [ReOp5] examined emerging practices in transportation / street design during the pandemic. Examined street design (by walking, shared streets, cycling, market areas, Transit, School Streets, Dining, Loading, Pick-up / Queuing, Health /Sanitation, Open / Play Streets, Communication); response and recovery (supporting most vulnerable/local economies/public health, bring communities in, adapt response); develop strategies that allow people to access essential services without traveling long distances; aids to helping people maintain physical distance while moving around the city; policy considerations: stay-at-home, pre-vaccine re-opening, vaccine/post-covid considerations; encouraging physical distance: remove individual parking, reduce width of vehicle lanes, shift parking away from curb, designate areas as local access, close vehicle lanes; engagement: engage with stakeholders/advocates/community groups, encourage feedback, identify and convey clear goals; design: place barriers/signs at driver decision points, use visible/reflective surfaces.
- NMDC [ReOp6] stated that all employers carry out a COVID-19 risk assessment, monitor spread (e.g. track and trace), reduce risk through preventative measures (increasing handwashing, work from home, social distancing, self-isolation, reducing activity times, remove face-to-face environments where possible, reducing contacts), share results, and identify who needs to be in work. Protect those identified.

- Perkins and Will [ReOp7] produced a report that provided guidance on: Understand pandemic phases, establishing a framework for return and associated risks (capacities, return protocols, etc.), assessing employee readiness, facility capacity, order of employee return, evaluation of remote work (% of workforce), scheduling, operational updates (adoption of different protocols), messaging (need for new etiquettes, etc.).
- SGSA produced guidance for sports grounds on social distancing [ReOp8] that outlined establishing social distanced capacities, identifying spectator responsibilities, social distancing across different environments (standing, seating, exits, etc.), conducting a local risk assessment, managing movement (developing a management plan, provide sufficient staff support (especially given potential for staff sickness), reaching out to future attendees, communicating with attendees onsite, medical provisions, testing effectiveness of procedures in place), general resources (PPE, cleaning, sanitizer stations, toilet facilities / use, ventilation), and managing movement (circulation into, around and out of facility).
- CLC [ReOp9] develop procedural guidance on protecting the workforce including guidance intended to provide consistent measures in line with Government recommendations on social distancing (2m), with a focus on: self-isolation (especially in relation to the vulnerable), procedure if someone falls sick, travel to site location (ideally using own transport), access points (reducing points while increasing spacing), handwashing (increasing facilities), toilet provisions (reduce number of people using at same time), eating arrangements (stagger eating times), changing rooms (stagger access times), cleaning services, and the avoidance of close contact (introduction of PPE, reduce lift capacities, remove pinch-points, reduce number/size of meetings, etc.).
- SGSA [ReOp10] provided considerations for allowing football games without spectators primarily addressing concerns with: the players, back staff teams, support staff, employees, etc. - not the general public / spectators; and operational considerations required regarding: event safety policies, health&safety policies, a risk register, an event management/stewarding/counter terrorism plan, a zone ex plan, fire safety plan, communication strategy, medical plan and broadcasting facilities.

Reopening References:

ReOp1. Davidson,L, Carter,H, Drury,J, Amlôt,R, Haslam,A, Stott,C, Coming together to respond to COVID-19: Recommendations to promote an effective multi-agency response. Report 1, Protocols for Hair and the Optimisation of Novel and Existing Decontamination Interventions through eXperimentation (PHOENIX), 2020

ReOp2. Addressing COVID-19 Requirements for Re-Opening Business Events, May 2020, Prepared by Boardroom@Crisis BV

ReOp3. COVID-19 Recovery Framework, Developed by the Institute of Place Management (High Street Task Force), 2020

ReOp4. Kim, K., Ten Takeaways from the COVID-19 Pandemic for Transportation Planners, Transportation Research Record, 1–14, 2022.

ReOp5. Sadik-Khan,J, Streets for Pandemic Response & Recovery, NACTO, 2020.

ReOp6. Good Practice Guidance for Reopening Museums, National Museum Directors' Council, 2020.

ReOp7. Road Map for Return: Guidance for a return to the office during COVID-19, Perkins and Will, 2020.

ReOp8. Guide to Safety at Sports Grounds - Supplementary Guidance 02: Planning for social distancing at sports grounds, Sports Grounds Safety Authority July 2020

ReOp9. Site Operating Procedures – Protecting Your Workforce, Construction Leadership Council, April 2020.

ReOp10. Sport without Spectators: Key safety considerations for football grounds, Sports Grounds Safety Authority, 2020.

Healthcare Modelling: 20 documents were reviewed with all of them referenced below (albeit briefly).

- Martos et al used an individual-based network model to simulate the spread of COVID-19 among hospital patients in 4- and 6-beds bay, which are typical in UK hospital settings [HM1, HM2]. They varied the location of the infected person, recovery/incubation periods, symptomatic/asymptomatic patients, removal of infected patients, and the benefits of testing. Findings indicate that 4-bed bay reduce spread in general, while the location of the infected person in a 6-bed bay affects infection.

- Jiminez et al developed an ABM to simulate to compare the effectiveness of medical treatments against healthcare-acquired infections [HM3]. The model represented 164k interactions between patients and healthcare workers, with treatments evaluated 100 times.
- van Kleef et al reviewed the modelling approaches employed to investigate healthcare associated infections [HM4]. Several databases (MEDLINE, EMBASE, Scopus, CINAHL plus and Global Health) were searched for dynamic mathematical models of such transmissions. The main research themes identified from 96 articles were the evaluation of infection control effectiveness, transmission routes, movement patterns between healthcare institutes, development of antimicrobial resistance, and strain competitiveness.
- Friesen and McLeod reviewed ABM examining patient flow and the dynamics of infection spread [HM5]. The models were categorized according to Environment (topography, visualization), Agent (demographic profiles, behavioural rules), Interventions (flow management, infection management), Validation and Verification.
- Truszkowka et al, proposed an agent-based modelling platform to simulate the spread of COVID-19 in small towns and cities, at the individual level [HM6]. The platform is tested against data from New Rochelle, NY as it was one of the first outbreaks in the US. The model includes functionality representing testing, treatment, and vaccination, the impact of other illnesses with symptoms similar to COVID-19, and the potential to explore testing approaches, in hospitals or drive-through facilities, and vaccination strategies (potentially able to prioritize vulnerable groups).
- Codella et al developed an agent-based simulation model to study C. difficile transmission in a midsized hospital [HM7]. Agents represented patients, health care workers, and visitors. CDI progression was modelled using a Markov chain, with transmission mechanism the interaction between agent/environment interactions.
- Illingworth et al applied a network reconstruction algorithm to infer viral transmission between patients and health care workers during the first wave of the epidemic at Cambridge University Hospitals in the UK [HM8]. Based dates of reporting symptoms, recorded locations, and viral genome sequence data, they showed an uneven pattern of transmission between individuals, with patients more likely to be infected by other patients than by healthcare workers. Further, the data were consistent with superspreading events with 21% of individuals causing 80% of transmission events.
- Christopher et al employed statistical models to investigate MRSA infections and associated morbidity in a hospital in India across 50 months [HM9]. Seventy-two patients were found to have developed MRSA infections of which 49 (68%) died. We estimated that 4.2% of patients were MRSA-positive when admitted, that there were 0.39 MRSA infections per patient month, and that the ward-level reproduction number for MRSA was 0.42.
- Rubin et al designed an ABM of CD infection based on representing patients/healthcare workers, interactions between them, room contamination, hand hygiene, and patient antimicrobial use [HM10]. Six interventions were tested to assess their impact (either individually or combined): testing; isolation and treatment of symptomatic patients; improved hand hygiene and contact precautions; improved hand hygiene; and improved environmental cleaning. Implementing multiple interventions levels had a large impact on infection rates, with most of the impact coming from improved hand hygiene and isolation/treatment cases.
- Baek et al evaluated the effects of different intervention strategies on an outbreak in a 2500-bed tertiary hospital in South Korea [HM11]. The effectiveness of intervention strategies such as front door screening, quarantine early testing, and PPE for medical staff/visitors were evaluated. The model suggested that the early testing (within eight hours) of infected cases (81% reduction) and monitoring the quarantine ward for newly hospitalized patients (70% reduction) are effective measures.
- HSIB examined how six trusts in the NHS attempted to minimize infection (across 7-8/2020), but identified that people were being admitted to hospital without signs of COVID-19 and discharged after having contracted COVID-19 [HM12]. The work highlighted (1) a lack of clarity regarding responsibilities/ownership/process for guidance development regarding infection prevention/ control; guidance does not reflect full-set of set of mitigation measures; focus on PPE; guidance overload for NHS regarding local use of additional resources; lack of consistency across guidance; insufficient patient/staff testing; irregular staff testing/surveillance; risk of asymptomatic staff transmission; changing guidance re PPE increased anxiety; staff found it hard to follow PPE guidance; hospital design affected trusts' ability to comply with guidance and staff intervention activities; managed patient access/egress flows built confidence; staff reported significant levels of fatigue.
- Kerr et al describe the methodology of Covasim, an open-source ABM model that includes country-specific demographic information on age structure and population size; transmission networks in different social

layers (e.g. households, schools, workplaces, long-term care facilities, and communities), age-specific disease outcomes; and viral dynamics [HM13]. Covasim supports the representation of different types of intervention, including physical distancing and protective equipment, pharmaceutical interventions (e.g. vaccination) and testing (e.g. symptomatic and asymptomatic testing), isolation, contact tracing, and quarantine. Covasim was applied to epidemic dynamics in more than a dozen countries.

- Blanco et al simulated influenza transmission at a hypothetical US hospital to quantify the individual and joint effectiveness of several known influenza infection measures [HM14]. This employed a susceptible-exposed-infected-recovered (SEIR) compartmental model, with the population comprised of patients and health-care workers, who were then interacting with its larger community population. This reflected assumed vaccination levels. From this analysis, the most effective individual strategies were (in order of effectiveness) hand-washing, health-care worker vaccination, pre-vaccination of patients, patient isolation, antiviral treatment, and use of face masks. It was found that the use of all strategies combined could potentially halve the number of observed hospital cases of influenza, falling to 40% when more representative uptake levels were assumed.
- Piana et al measured surfaces from hospital and living spaces to identify the presence of viral RNA / fomites [HM15]. Human-borne contamination by droplets and biological fluids was monitored. A total of 92 swab samples were collected during the pandemic, including indoor and outdoor surfaces exposed to human-borne contamination. Traces of biological fluids were frequently detected in spaces open to the public and on objects that are touched with the hands. However, viral RNA was not detected in hospital wards or other indoor and outdoor surfaces. Handled objects accumulated the highest level of multiple contaminations by saliva, nose secretions, and faecal traces. This supported the priority role of handwashing in prevention.
- Nguyen et al conducted a review [HM16] to establish (1) how simulation models have been used to investigate the mitigation of healthcare associated infections, (2) how these models evolved over time, (3) identify gaps in their adoption and (4) recommendations for future development. This involved a systematic search of studies using system dynamics, discrete event simulation, and agent-based models. The complexity of simulation models significantly increased but were heavily concentrated on transmission dynamics of staph infections in the hospitals of high-income countries. Healthcare associated infections in other health care settings, the influence of contact networks within a health care facility, nor patient sharing and referring networks across health care settings were sufficiently understood.
- Ciccolini et al demonstrated that it is possible to design an effective surveillance system for healthcare-associated infections that spread between hospitals as a result of patient movements based on a relatively small number of sentinel hospitals [HM17]. They applied mathematical models to patient admission data to NHS and Dutch admission data. Relatively short detection times are achieved when 10–20% of hospitals are used as sentinels with a drop-off in benefits after this point. Hospital selection can be further enhanced using a heuristic optimization approach to allowing approximately half as many hospitals to produce a comparable impact.
- Ali et al conducted a longitudinal study was conducted (between May - September, 2016) examining the incidence, prevalence and risk factors of healthcare associated infection (HAI) in an Ethiopian hospital [HM18]. 1015 admitted patients were tracked and biological specimens collected from those patients suspected to have an HAI. This recorded an incidence rate of 28.15 per 1000 patient days. The highest incidence was in the intensive care unit with 207.55 per 1000 patient days in contrast to the lowest incidence was reported from ophthalmology with 0.98 per 1000 patient days. For those who had a surgical procedure, the risk of HAI was found to be high in those with history of previous hospitalization while young adults had a lower risk of developing HAI.
- Heiman et al studied the impact of injunctive and descriptive norms on mask wearing during the COVID-19 pandemic [HM19]. They examined two years of data from the United States (n = 915) and tracked mask wearing given perceived injunctive (prescribed actions) and descriptive (reported actions) mask wearing norms as the pandemic unfolded. Longitudinal trends suggested that norms and behaviour were tightly coupled, changing quickly in response to public health recommendations. Modelling suggested that descriptive norms caused future increases in mask wearing across multiple waves of data collection. Injunctive norms had less frequent and generally weaker impact on future mask wearing. They noted, 'during uncertain times, cooperative behaviour is more strongly driven by what others are actually doing, rather than what others think ought to be done'.
- Zemouri et al estimated the transmission probability of airborne infectious diseases via mathematical modelling [HM20] - for Mycobacterium tuberculosis, Legionella pneumophila, measles virus, influenza virus, and coronaviruses using a modified version of the Wells-Riley equation, which incorporated the indoor air quality by using carbon dioxide as a proxy and included the protection rate from medical face masks and

N95 respirators. Scenario-specific/ uncertainty/ sensitivity analyses were run to produce probability rates. A high transmission probability was generated when high patient infectiousness, an absence of respiratory protection, and poor indoor air quality were assumed. The highest transmission probabilities were estimated for measles virus, coronaviruses, influenza virus, and M. tuberculosis (84.0%). The low-risk scenario leads to transmission probabilities of 4.5% for measles virus and 0% for the other pathogens.

Healthcare Modelling References:

HM1. Martos,DM, Parcell,BJ, and Eftimie,R, Modelling the transmission of infectious diseases inside hospital bays: implications for COVID-19, MBE, 17(6): 8084–8104.

HM2. Moreno-Martos,D, Foley,S, Parcell,B, Trucu,D, and Eftimie,R, A computational investigation of COVID-19 transmission inside hospital wards and associated costs, MBE, 19(7): 6504–6522.

HM3. Jiménez,JM, Lewis,B, and Eubank,S, Hospitals as Complex Social Systems: Agent-Based Simulations of Hospital-Acquired Infections, COMPLEX 2012, LNICST 126, pp. 165–178, 2013.

HM4. Friesen,MR, and Mcleod,RD, A Survey of Agent-Based Modeling of Hospital Environments, IEEE Access, 10.1109/ACCESS.2014.2313957

HM5. van Kleef,E, Robotham,JV, Jit,M, Deeny,SR, and Edmunds,WJ, Modelling the transmission of healthcare associated infections: a systematic review, BMC Infectious Diseases 2013, 13:294.

HM6. Truszkowska,A, Behring,B, Hasanyan,J, Zino,L, Butail,S, Caroppo,E, Jiang,Z, Rizzo,A, and Porfiri,M, High-Resolution Agent-Based Modeling of COVID-19 Spreading in a Small Town, Adv. Theory Simul. 2021, 4, 2000277.

HM7. Codella,J, Safdar,N, Heffernan,R, Alagoz,O, An Agent-based Simulation Model for Clostridium difficile Infection Control, Med Decis Making 2015;35:211–229.

HM8. Illingworth,CJR, Hamilton,WL, Warne,B, Routledge,M, Popay,A, Jackson,C, Fieldman,T, Meredith,LW, Houldcroft,CJ, Hosmillo,M, Jahun,AS, Caller,LG, Caddy,SL, Yakovleva,A, Hall,G, Khokhar,FA, Feltwell,T, Pinckert,ML, Georgana,I, Chaudhry,Y, Curran,MD, Parmar,S, Sparkes,D, Rivett,L, Jones,NK, Sridhar,S, Forrest,S, Dymond,T, Grainger,K, Workman,C, Ferris,C, Gkrania-Klotsas,C, Brown,NB, Weekes,MP, Baker,S, Peacock,SJ, Goodfellow,IG, Gouliouris,T, de Angelis,D, Torok,ME, Superspreaders drive the largest outbreaks of hospital onset COVID-19 infections, eLife 2021;10:e67308. DOI: https://doi.org/10.7554/eLife.67308.

HM9. Christopher,S, Mariam Verghis,R, Antonisamy,B, Sowmyanarayanan,TV, Brahmadathan,KN, Kang,G, Cooper,BS, Transmission Dynamics of Methicillin-Resistant Staphylococcus aureus in a Medical Intensive Care Unit in India,July 2011, Volume 6, Issue 7 ,e20604.

HM10. Rubin MA, Jones M, Leecaster M, Khader K, Ray W, et al. (2013) A Simulation-Based Assessment of Strategies to Control Clostridium Difficile Transmission and Infection. PLoS ONE 8(11): e80671. doi:10.1371/journal.pone.0080671.

HM11. Baek YJ, Lee T, Cho Y, Hyun JH, Kim MH, Sohn Y, et al. (2020) A mathematical model of COVID-19 transmission in a tertiary hospital and assessment of the effects of different intervention strategies. PLoS ONE 15(10): e0241169. https://doi.org/10.1371/journal.pone.0241169.

HM12. COVID-19 transmission in hospitals: management of the risk – a prospective safety investigation, Healthcare Safety Investigation Branch I2020/018, 2020.

HM13. Kerr CC, Stuart RM, Mistry D, Abeysuriya RG, Rosenfeld K, Hart GR, et al. (2021) Covasim: An agent-based model of COVID-19 dynamics and interventions. PLoS Comput Biol 17(7): e1009149. https://doi.org/10.1371/journal.pcbi.1009149

HM14. Blanco,N, Eisenberg,MC, Stillwell,T, and Foxman,B, What Transmission Precautions Best Control Influenza Spread in a Hospital?, American Journal of Epidemiology, Vol. 183, No. 11, 2016.

HM15. Piana A, Colucci ME, Valeriani F, Marcolongo A, Sotgiu G, Pasquarella C, Margarucci LM, Petrucca A, Gianfranceschi G, Babudieri S, Vitali P, D'Ermo G, Bizzarro A, De Maio F, Vitali M, Azara A, Romano F, Simmaco M, Romano Spica V. 2021. Monitoring COVID-19 transmission risks by quantitative real-time PCR tracing of droplets in hospital and living environments. mSphere 6:e01070-20. https://doi.org/10.1128/mSphere.01070-20.

HM16. Nguyen,LKN, Megiddo,I, Howick,S, Simulation models for transmission of health care−associated infection: A systematic review, American Journal of Infection Control 48 (2020) 810−821.

HM17. Ciccolinia,M, Donker,T, Grundmann,H, Bonten,MJM, and Woolhouse,MEJ, Efficient surveillance for healthcare-associated infections spreading between hospitals,PNAS, 2014, vol. 111, no. 6, 2271–2276. www.pnas.org/cgi/doi/10.1073/pnas.1308062111.

HM18. Ali,S, Birhane,M, Bekele,S, Kibru,G, Teshager,L, Yilma,Y, Ahmed,Y, Fentahun,N, Assefa,H, Gashaw,M, and Gudina,EK, Healthcare associated infection and its risk factors among patients admitted to a tertiary hospital in Ethiopia: longitudinal study, Antimicrobial Resistance and Infection Control (2018) 7:2.
HM19. Heiman,SL, Claessens,S, Ayers,JD, Beltrán,DG, Horn,AV, Hirt,ER, Aktipis,A, & Todd,PM, Descriptive norms caused increases in mask wearing during the COVID-19 pandemic, Scientific Reports, (2023) 13:11856.
HM20. Zemouri,C, Awad,SF, Volgenant,CMC, Crielaard,W, Laheij,AMGA, and de Soet,JJ, Modeling of the Transmission of Coronaviruses, Measles Virus, Influenza Virus, Mycobacterium tuberculosis, and Legionella pneumophila in Dental Clinics, Journal of Dental Research 2020, Vol. 99(10) 1192–1198.

General Covid Material: This involved the review of 30 articles, 16 of which are summarized below.

- Mawani et al [G1] examined COVID-19-related sick leave provisions. In the absence of adequate provisions, workers work through illness, harming themselves and contributing to the spread of COVID-19. Recommendations for preventing this in construction workers include health protection for workers (physical distancing, accommodation and transportation health and safety, personal protective equipment), social protection (sick leave, compensation during sick leave and quarantine, health insurance), occupational health and safety training, communication, and water and sanitation.
- Delcea et al observed that the best-performing back-to-front variations regarding health metrics are the configurations which feature the existence of approximately equal-sized boarding groups [G2]. However, if the airline focuses on the comfort of the passengers or speed of boarding, then unequal group sizes is more beneficial.
- Khojasteh et al highlight the value of cross-sectoral decision-making and how mitigation measures can be developed that are beneficial for both crises (Covid-19 and climate change) [G3]. There is scientific consensus that interactions between climate change and the COVID-19 pandemic can provoke detrimental effects on the public's physical and mental health.
- Wang et al examined the risk of airborne Covid-19 transmission [G4]. Exposure of the virus-laded fine droplets with a diameter below 10 μm occupied over 90% of the total exposure dose among the four transmission routes. As the patient inject flow increased, the exposure dose from the long-range route decreased while the exposure dose from the short-range route increased. The number of secondary infections generated by an initial infector was independent of the initial proportion of infectors in fever clinics. It is influenced only by the patient inject flow, medical process, and layout. With the patient inject flow exceeding the critical service capability, the growth rate of the cross-infection risk increased by nearly 30-fold. Placing waiting areas in locations where patients pass frequently poses a greater risk of infection.
- Zhao et al examined the piston effect introduced by human movement at an airport terminal [G5]. Previous studies focused on ventilation effects and droplet dispersion in otherwise static environments, whereas individual movement has rarely been considered. Zhao et al demonstrated that the droplet diffusion pattern produced by several individuals walking was different from that produced in stable cases. The droplets mainly affected individuals *behind* the patient during walking. At 0.5 m, the droplet concentration is approximately 21.1% higher than that at 0.2 m.
- Milne et al engaged in modeling and experiments to examined a single-door Airbus A320 configuration with one aisle, thirty rows, and three seats on each side of the aisle in economy class configuration [G7]. To represent social distancing when seated, they assumed that the middle seats will be left empty. For airlines focused on reducing risk during boarding, the ‘back-to-front by row – WilMA’ method was most effective; however, if greater emphasis is placed on more efficient boarding times then ‘back-to-front by row – WilMA – offset 2 and back-to-front by row – WilMA – offset 3’ should be used, assuming aisle social distancing is 1 m and 2 m respectively.
- Page-Tan et al [G8] identified six kinds of evacuation approaches to large-scale emergencies: overall evacuation, local evacuation, long-distance evacuation, sheltering in place, reductions in local movement, reductions in long-distance movement. Increased evacuation-related mobility did not lead to increased cases of COVID-19. Sheltering-in-place during a disaster led to decreased COVID-19 transmission rates.
- Aghabayk et al examined rail passenger perception of crowding conditions [G9]. They noted that passengers are willing to experience less crowding in exchange for more travel time or more cost;

failure to consider crowding on public transportation can lead to overestimation of demand at high crowding levels.

- COVID-19 may be transmitted during a passenger flight. Guo et al [G11] found that most confirmed cases of covid-19 transmission were located in the middle rows of economy class. Within this area, covid-19 prevalence did not differ among passengers in different seats. Passengers seated in the 2 rows in front of a confirmed case were at a higher risk of being infected.
- Fang et al simulated the effect of taking recommended or mandatory measures on virus transmission [G12]. The final infected number was limited if the recommended or mandatory measures were taken immediately during the alert phase of COVID-19 outbreaks.
- Blocken et al suggest that avoiding substantial droplet exposure in the scenario conditions examined in this study can be achieved by either avoiding walking / running in the slipstream of someone else who is running or by keeping larger social distances (where such distances need to increase inline with the walking or running speed) [G15]. The equivalent social distance for walking and running in the slipstream is defined as the distance that should be kept between the leading and trailing walker/runner to avoid substantial exposure to slipstream droplets, similar to the case where two people are standing still at 1.5 m distance. In the absence of head wind, tail wind and cross-wind, for walking at 4 km/h this distance is about 5 m and for running at 14.4 km/h this distance is about 10 m.
- Bazant et al suggest the inadequacy of the Six-Foot Rule in mitigating indoor airborne disease transmission, and explore a physically informed alternative for managing exposure [G16]. If implemented, our safety guideline would impose a limit on the exposure time in indoor settings, violation of which constitutes an exposure for all of the room's occupants.
- Barnett et al examined numerous data sets to estimate the probability that a passenger boarding a US domestic flight over the observation period (nine months) carried contagious Covid-19 [G18]. That probability varied considerably over the period considered. The point estimate for the probability of contracting Covid-19 on board an average domestic flight was about 1 in 2000 for the nine-month study period, although subject to uncertainty.
- Wang et al used experimental data for the B777-200 aircraft and a modified Wells-Riley model to estimate the inflight infection probability (assuming aerosol transmission) within economy class and business class sections of the aircraft [G19]. It demonstrated that there is a significant reduction in aerosol concentration due to cabin ventilation and filtration system, but that this did not necessarily mean that there is a low probability or risk of in-flight infection. However, mask wearing, particularly high-efficiency ones, significantly reduced this risk.
- Peng and Jimenez collected data using low-cost CO2 sensors and suggested that keeping the CO2 level and the physical intensity and vocalization level of the activities as low as practically feasible in indoor environments should reduce the risk [G21].
- Blomquist et al concluded that risk of symptomatic COVID-19 due to transmission on short to medium haul flights is likely low, at approximately 3% but less than 10% if sat within two rows of an infectious individual [G29].

General Covid References:

G1. Mawani,NF, Gunn,V, O'Campo,P, Anagnostou,M, Muntaner,C, Wanigaratne,S, Perri,M, Ziegler,C, and An,A, COVID-19 Economic Response and Recovery: A Rapid Scoping Review, International Journal of Health Services, 2021, Vol. 51(2) 247–260

G2. Delcea, C., Cotfas, L.-A., Milne, R.J., Xie, N. and Mierzwiak, R. (2022), Grey clustering of the variations in the back-to-front airplane boarding method considering COVID-19 flying restrictions, Grey Systems: Theory and Application, Vol. 12 No. 1, pp. 25-59.

G3. Khojasteh,D, Davani,E, Shamsipour,A, Haghani,M, Glamore,W, Climate change and COVID-19: Interdisciplinary perspectives from two global crises, Science of The Total Environment, Volume 844, 2022, 157142.

G4. Wang,J, Tang,H, Wang,J, Zhong,Z, An agent-based study on the airborne transmission risk of infectious disease in a fever clinic during COVID-19 pandemic. Building and Environment, Volume 218, 2022. 109118.

G5. Zhao,Y, Feng,Y, Ma,L, Impacts of human movement and ventilation mode on the indoor environment, droplet evaporation, and aerosol transmission risk at airport terminals, Building and Environment, Volume 224, 2022. 109527.

G6. Haghani,M, Bliemer,MCJ, Goerlandt,,F, Li,J, The scientific literature on Coronaviruses, COVID-19 and its associated safety-related research dimensions: A scientometric analysis and scoping review, Safety Science, Volume 129, 2020. 104806.
G7. Milne,RJ, Delcea,C, Cotfas,L, Airplane boarding methods that reduce risk from COVID-19, Safety Science, Volume 134, 2021, 105061.
G8. Page-Tan,C, Fraser,T, COVID-19 to go? The role of disasters and evacuation in the COVID-19 pandemic, Global Environmental Change, Volume 73, 2022, 102471.
G9. Aghabayk,K, Esmailpour,J, Shiwakoti,N, Effects of COVID-19 on rail passengers' crowding perceptions, Transportation Research Part A: Policy and Practice, Volume 154, 2021, Pages 186-202.
G10. Colak,O, Enoch,M, Morton,C, Airport business models and the COVID-19 pandemic: An exploration of the UK case study, Journal of Air Transport Management, 2022, 102337, ISSN 0969-6997.
G11. Guo,Q, Wang,J, Estill,J, Lan,H, Zhang,J, Wu,S, Yao,J, Yan,X, Chen,Y, Risk of COVID-19 Transmission Aboard Aircraft: An Epidemiological Analysis Based on the National Health Information Platform, International Journal of Infectious Diseases, 118, 2022, 270-276.
G12. Fang,Z, Huang,Z, Li,X, Zhang,J, Lv,W, Zhuang,L, Xu,X, Huang,N, How many infections of COVID-19 there will be in the "Diamond Princess" - Predicted by a virus transmission model based on the simulation of crowd flow, Cornell University, Physics and Society, 2020.
G13. Konda A, Prakash A, Moss GA, Schmoldt M, Grant GD, Guha S, Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks, ACS Nano, 2020;14(5): 6339-6347.
G14. Rule,A, Ramachandran,G, Koehler,K, Comment on Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks: Questioning Their Findings, ACS Nano 2020 14 (9), 10756-10757.
G15. Blocken, B., Malizia, F., Druenen, T.V., & Marchal, T. Towards aerodynamically equivalent COVID-19 1.5 m social distancing for walking and running. 2020.
G16. Bazant MZ, Bush JWM, A guideline to limit indoor airborne transmission of COVID-19. Proc Natl Acad Sci U S A. 2021 Apr 27;118(17).
G17. Walkinshaw, DS, A Brief Introduction To Passenger Aircraft Cabin Air Quality. Ashrae Journal 62 (2020): 12-16.
G18. Barnett, A., Fleming, K. Covid-19 infection risk on US domestic airlines. Health Care Manag Sci 25, 347–362 (2022).
G19. Wang,Z, Galea,ER, Grandison,A, Ewer,J, Jia,F. Inflight transmission of COVID-19 based on experimental aerosol dispersion data, Journal of Travel Medicine, Volume 28, Issue 4, May 2021.
G20. Mello,IF, Squillante,L, Gomes,GO, Seridonio,AC, de Souza,M, Epidemics, the Ising-model and percolation theory: A comprehensive review focused on Covid-19, Physica A: Statistical Mechanics and its Applications, Volume 573, 2021, 125963.
G21. Peng,Z, and Jimenez,JL, Exhaled CO2 as a COVID-19 Infection Risk Proxy for Different Indoor Environments and Activities, Environmental Science & Technology Letters 2021 8 (5), 392-397.
G22. Kim,D-Y, Kim,K-Y, Exposure Assessment of Airborne Bacteria and Fungi in the Aircraft, Safety and Health at Work, Volume 13, Issue 4, 2022, Pages 487-492.
G23. Nikitin,N, Petrova,N, Trifonova,E, and Karpova,O, Influenza Virus Aerosols in the Air and Their Infectiousness, Department of Virology, Lomonosov Moscow State University, 1/12 Leninskie Gory, Moscow 119234, Russia, 2014.
G24. Guallar,MP, Meiriño,R, Donat-Vargas,C, Corral,O, Jouvé,N, Soriano,V, Inoculum at the time of SARS-CoV-2 exposure and risk of disease severity, Internation Journal of Infectious Diseases, Volume 97, p290-292, August 2020.
G25. Kirking,HL, Cortes,J, Burrer,S, Hall,AJ, Cohen,NJ, Lipman,H, Kim,C, Daly,ER, Fishbein,DB, Likely Transmission of Norovirus on an Airplane, October 2008, Clinical Infectious Diseases, Volume 50, Issue 9, 1 May 2010, Pages 1216–1221.
G26. Domingo,JL, Marquès,M, Rovira,J, Influence of airborne transmission of SARS-CoV-2 on COVID-19 pandemic. A review, Environmental Research, Volume 188, 2020, 109861, ISSN 0013-9351.
G27. Nicas,M, and Sun,G, An Integrated Model of Infection Risk in a Health-Care Environment, Risk Analysis, Vol. 26, No. 4, 2006.
G28. Rimoin,AW, Mulembakani, PM, Johnston,SC, Smith, JOL, Kisalu,NK, Kinkela,TL, Blumberg,S, Thomassen,HA, Pike,BL, Fair,JN, Wolfe,ND, Shongo,RL, Graham,BS, Formenty,P, Okitolonda,E, Hensley,LE, Meyer,H, Wright,LL, and Muyembe,J, Major increase in human monkeypox incidence 30 years after smallpox vaccination campaigns cease in the Democratic Republic of Congo, PNAS, 107 (37) 16262-16267, 2010.

G29. Blomquist,PB, Bolt,H, Packer,S, Schaefer,U, Platt,S, Dabrera, G, Gobin,M, Oliver,I, Risk of symptomatic COVID-19 due to aircraft transmission: a retrospective cohort study of contact-traced flights during England's containment phase, Influenza and other respiratory viruses, Volume 15, Issue 3, p331-335, 2021.

G30. Liu, Y., Ning, Z., Chen, Y. et al. Aerodynamic analysis of SARS-CoV-2 in two Wuhan hospitals. Nature 582, 557–560 (2020).

Appendix 1B: Review Case Studies

Hertsberg et al.

This represents a brief summary of the following article:

- Hertzberg, V.S., Weiss,H., Elon,L., Si, W., Norris,S.L., and The Fly Healthy Research Team, Behaviors, movements, and transmission of droplet-mediated respiratory diseases during transcontinental airline flights, PNAS, April 3/2018, vol. 115, no. 14,3623–3627.

The article outlines a concern with air travel serving as a conduit for the rapid spread of newly emerging infections and pandemics. Hertzberg *et al*. suggest that movements and behaviours of airplane passengers and crew may facilitate disease transmission. They highlight that very little is known about how the various environments, roles, and activities, interact on airplanes and their function in enabling infection transmission. To investigate this, a data-driven network model was developed to simulate infection transmission by large respiratory droplets to determine the spread of a disease on the network.

A study was undertaken to collect passenger and crew movement data and environmental data to feed into the model. The researchers conducted data collection in the economy cabin of 10 transcontinental US flights, flying between Atlanta and five West-Coast destinations, with flight durations between 211 and 313 minutes. Fights occurred in the morning or afternoon: seven were fully occupied while in the remaining three flights there were 2, 3 and 17 unoccupied seats respectively. A total of 14 researchers were used during each flight. All flights were single aisle aircrafts, most of which were Boeing 757s. Eight of the flights occurred during the traditionally recognized annual influenza season (October 2012 to March 2013), while two other flights occurred in May 2013.

Environmental data collection. Air and surface samples were collected for qPCR testing for 18 common respiratory viruses:

- Air sampling pumps used to collect air samples from 5 different time points (pre-flight, one-quarter of the flight, half of the flight, three-quarters of the flight and post-flight) and one sample collected throughout the whole flight from 10,000ft on ascend to 10,000ft on decent.
- Swabs used to collect surface samples at 8 locations before passengers boarded and after they deplaned. The locations of the surfaces include lavatory outside and inside door handles, as well as tray table top and bottom, and seat-belt buckle from two separate seats.

Passenger and crew movement data collection. Observers recorded all movements of passengers and crew using a specially designed iPad app. The observers were placed every five to seven rows as pairs in seats across the aisle from each other.

Observation Zones. Each observer pair was responsible for recording movement and behaviours of passengers and crew within their “virtual zone” which consisted of the row in which the observers were seated and the rows in front of them up to the next observer pair or the front of the plane, typically another four rows. Zones were demarcated visually by ribbons that were hung from the overhead bins.

Data Collection Tool. A specially designed iPad app was used by observers to collect data. Using the Numbers spreadsheet app, three data collection spreadsheets were used: “Flight Information”, “Passenger Description”, and “Movements”.

The Flight Information spreadsheet was used to record basic descriptive information about a flight (see Table 1).

Table 1: Flight information data.

Flight Information Data
Flight number and date
Departure and arrival airports
Aircraft model
Number of rows in the economy cabin
Seat arrangement
Lavatory arrangement
Flight start and end times
Observer name
Observer seat number
Empty seat numbers
Seatbelt sign on and off times

The Passenger Description spreadsheet was used for each observer to record descriptive information about each passenger in their virtual zone (see Table 2). This was *filled in during the boarding process* and contained columns for row and seat number.

Table 2: Passenger description data.

Passenger Description Data
Gender
Approximate age (senior, adult, youth, child)
Approximate ethnicity (white, African American, Asian, Latino, other)
Approximate hair colour (brown, black, blonde, red, grey, white, bald, other)
Hair style (free text entry)
Approximate height (tall, medium, short)
Approximate body type (thin, medium, heavy)
Clothing (entered as free text)
Free-form comment field

The Movements spreadsheet was used to record movements and behaviours (see Table 3). When an individual rose from their seat and stepped into the aisle in an observation zone, or when someone from another zone travelled through an observation zone, this behaviour was recorded on a row of this sheet.

Table 3: Movement data.

Movement Data
Start and stop time of behaviour
Passenger’s row and seat number (if known)
Demographic (i.e., which crew member, or man, woman, or child for passengers)
Passengers’ shirt colour
Passengers’ hair colour
Were they entering or exiting the zone and in which direction
Row number if stopping to converse with another passenger
Going to front or back lavatory
Talking with a passenger
Checking the overhead bin
Passing through and in what direction
Standing in the galley
For crew, serving and trash collection
Free-form comment field

A number of passenger actions were observed along with a set of objects with which the passenger might interact (see Table 4).

Table 4: Assumed Actions and Objects from Hertzberg et al.

Action	Action Modifier	Object
Move		Passenger
Enter		Crew
Exit		Seat
Use / Check		Overhead bin
Stand		Aisle
Sit		Galley
Cough	Severity	Lavatory (front)
Speak		Lavatory (back)
Serve		
Collect		

Environmental data analysis. Environmental samples were tested for influenza A, influenza B, influenza A subtype H5N1, respiratory syncytial virus A, respiratory syncytial virus B, parainfluenza virus 1, parainfluenza virus 2, parainfluenza virus 3, parainfluenza virus 4, rhinovirus F1, rhinovirus F2, coronavirus 229E, coronavirus OC43, coronavirus NL63, human metapneumovirus, adenovirus F1, and adenovirus F2.

Passenger and crew movement data analysis. After each flight, observations were compiled from the observation zones. Researchers aggregated and prepared the data for subsequent analysis of behaviours, movements, and contact networks.

Network-based transmission model and simulations. The analysed data was then used to construct a dynamic-network model which was used to simulate direct influenza transmission during flight. Two scenarios were considered:

1. A passenger seated midcabin in 14C (14th row, aisle seat) with the transmission rate of 0.018 per minute of contact.
2. An infectious crew member with the transmission rate of 0.0045 per minute of contact.

The model calculated the probability of each passenger being within a 1m radius of an infected person at least once during a flight, based on seating position, and the probability that the infectious person will infect each of the passengers.

The researchers presented descriptive statistics (e.g., proportion, median, interquartile range). These were expressed per person and per flight. Medians are reported and deemed representative of the average.

Environmental data

- All environmental sample test results were negative, therefore did not indicate any significate findings in relation to pathogen burden.

Passenger and crew movement data

- The number of contacts (within 1m) decreases with increased distance of seating position from the aisle.
- For passengers who moved during the flight, the number of non-tribe contacts increased as the length of flight increased, regardless of their seat position.
- For passengers seated in aisle or middle seats who did not move during the flight, the number of non-tribe contacts increased as the length of flight increased. No association was found for passengers in window seats who did not move.

- The most common passenger behaviours were waiting for, using, or exiting a lavatory and checking the overhead bins.

Model outputs

- In scenario 1, the passengers seated in the 11 nearest seats to the infectious passenger have a high probability of becoming infected. The probability of transmission to each of the other passengers is quite low, less than 0.03. On average, this manifests as 0.7 additional infected passengers per flight (IQR: 0.4–1.5). The results of simulations for other seats indicate, on average, at most two additional infected passengers per flight.
- In scenario 2, the infectious crew member will infect 4.6 passengers (IQR: 3.2–5.7).

The key results report in the article are shown in Table 5.

Table 5: Main results.

Data description	Data	Category	Dyad
Movement from seat	38% do not move from seat	Movement	Cruise
Movement from seat	38% leave seat once	Movement	Cruise
Movement from seat	13% leave seat twice	Movement	Cruise
Movement from seat	11% more than twice	Movement	Cruise
Time spent out of seat	5.4 min, (IQR = 3.3–8.9)	Movement	Cruise
Movement by window seat	43% (range: 29 – 62%)	Movement	Cruise
Movement by middle seat	62% (range: 47 – 72%)	Movement	Cruise
Movement by aisle seat	80% (range: 75 – 85%)	Movement	Cruise
LAV use - 0 times	50% did not use (range: 42 – 58%)	Movement	Cruise
LAV use = 1 time	38% used it once (range: 34 – 53%)	Movement	Cruise
LAV use = 2 times	9% (range: 4 – 13%)	Movement	Cruise
LAV use = >2 times	3% (range: 1 – 6%)	Movement	Cruise
LAV use (waiting for, using, or exiting a lavatory	825 passengers, average time 4.3 min (IQR: 2.7–7.0)	Movement	Cruise
Overhead bin use	135 passengers, average time 1 min (IQR: 0.4–2.0)	Movement	Cruise
Queue time at front LAV	3.1 min, IQR: 1.7–4.9	Movement	Cruise
Queue time at back LAV	1.7 min, IQR: 1.0–3.2	Movement	Cruise
Time crew member was in contact with passengers for	67 min (IQR: 43–80); 238 min of observation (range: 196–290)	Movement	Cruise
Time crew member was in galley	155 min (IQR: 128–178), 238 min of observation) (range: 196–290)	Movement	Cruise
# of passengers who had close contact with an individual seated beyond a 1-m radius from them	1296 (84%)	Movement	Cruise
of the 1296, # of those that they had contact with	44 (IQR: 30–60) for a duration of 47 person-minutes (IQR: 18–98) at 0.4min (IQR: 0.2–1.7) per contact	Movement	Cruise
Duration of crew - crew contact	206 person-minutes (IQR: 164–239)	Movement	Cruise
Duration of crew - pax contact	1,149 person-minutes (IQR: 851–1,391)	Movement	Cruise
number of contacts in aisle seats	64, IQR: 50–77	Movement	Cruise

number of contacts in middle seats	58, IQR: 45–73	Movement	Cruise
number of contacts in window seats	12, IQR: 11–34	Movement	Cruise

Conclusion:

The study indicates:

- Transmission is likely to be limited to one row in front of, or behind an infectious passenger.
- An infectious flight attendant can generate several separate infections.

Limitations:

- The study solely looked at inflight transmissions; however, transmissions could occur in the airport, on the jetway or on the plane when it is stationary of taxiing.
- The model assumed that droplets are the main transmission route, however significant transmission may also occur via smaller virus-laden particles which have larger dispersion distances. The study does not include the potential for seat backs to block transmission.

Appendix 2: Review of automated data extraction tools

A review of 22 current technologies has been conducted. These technologies are designed to capture or extract data on people movement. These were identified from commercially available packages (from online sources) or from research literature.
These technologies are categorized according to the following criteria:

- Background Information:
    - Company
    - System name
    - Location
    - Weblink
    - Cost
- System:
    - Technology Used
    - Approach (e.g. sensor, data extraction, etc.).
    - Solution type (e.g. technology, service, etc.).
    - Footage requirements (e.g. of third party video provided to system).
    - Methodology description (i.e. system functionality).
    - Application Area (i.e. where the functionality might be applied).
    - Output (i.e. what it produces).
- Commentary:
    - Pros Cons/Limitations (i.e. informal assessment given needs of project).
    - Additional notes.

Company	System name	Location	Weblink	Technology	Approach	Solution type	Cost	Footage requirements	Methodology description	Application Area	Output	Pros	Cons/Limitations	Additional notes
CrowdScan	CrowdScan	Belgium	https://www.crowdscan.be/	electromagnetic	Sensor - object detection	Technology provider (hardware and software)	Contact to ask	No requirement on CCTV Dedicated hardware (wireless sensor)	Measuring crowd density in real-time using a wireless sensor network.	Open space, passage	Real time crowd density/flow rate in open data format	1.Real time 2. Not rely on CCTV, nor lighting condition 3. Could cover distance up to 200m 4. Privacy-friendly data	1. Probably can't get precise location and trajectory 2. Need to plan and install sensors.	Good for estimating density and flow rates
Civil Safety Research (IAS-7)	PeTrack	Germany	https://www.fz-juelich.de/en/ias/ias-7/services/software/petrack	2D Video Analytics	Video - object detection	Technology provider (software)	Open Source	Camera placed over head/ceiling mounted pedestrian wearing head markers	Automatically extract accurate pedestrian trajectories from video recordings	Controlled environment (lighting etc.)	The joint trajectories of all pedestrians provide data like velocity, flow and density at any time and position	1. full pedestrian location and trajectory data	1. Sensitive to camera position, lighting 2. Rely on head markers to automate the process 3. low density, small region	Low-cost tool for controlled environment to conduct pedestrian experiment.
Axiomatic	SafeCount, Stereoscopic Counter	UK	https://peoplecounting.co.uk/	infrared beam/3D Stereo Video Analytics	Sensor/video - object detection	Service (hardware and software)	On website	Camera placed over head/ceiling mounted	Use overhead infrared sensor/3D camera to detect and count ppl at certain location, mostly entrance	Indoor environments such as retail, tourism, transport, entertainment, leisure etc. Entrance door, exit	Real time people count at gates	1. Real time 2. Not rely on CCTV, nor lighting condition	1. Unable to track people in space but only count at certain point 2. Low density	Infrared beam for single lane, video for multiple lanes. Only useful to know the number of people within a confined space counted from the entrance/exits.
vemcogroup	Xovis, Irisys, Brickstream, Hikvision	International UK office	https://vemcogroup.com/solutions/people-counting	infrared beam/3D Stereo Video Analytics	Sensor/video - object detection	Service (hardware and software)	Contact to ask	Camera placed over head/ceiling mounted	Use 2D infrared sensor and 3D Stereo Video sensor produced by other manufacturers to provide people counting solution	Indoor environments such as retail, malls, supermarkets, leisure, education, airports, transportation etc. Could be used in outdoor environments.				
COUNTEREST		Spain	https://counterest.net/?lang=en	2D Video Analytics - Deep Learning algorithms	Video - object detection	Technology provider (software)	Contact to ask	Unknown	Apply Deep Learning algorithms on images in clients' servers, people counters based on the image	Indoor environments such as museum, retail, leisure	Online dashboard			No detailed information available.
Acorel		UK/France	https://acorel.com/en/sensors-equipment/	infrared beam/3D Stereo Video Analytics/Laser	Sensor/video - object detection	Technology provider (hardware and software)	Contact to ask	Camera placed over head/ceiling mounted	Use overhead infrared sensor/3D camera/laser sensors to detect and count ppl	Air/rail transport, public & commercial areas				Focuses on people flowrates using overhead devices
Viscando	OTUS3D	Sweden	https://viscando.com/applications/traffic/	2D Video Analytics - AI/ML	Video - object detection	Technology provider (software)	Contact to ask	Camera placed at certain height	3D + Machine Learning: Automated traffic counting and classification to identify and track individuals/traffic in the scene.	intersections, shared space	Real time people tracking and counting	1. Real time	1. Sensitive to lighting and position of camera 2. No detailed information 3. Low density counting/tracking	Real-time automatic tracking and counting (pedestrians, bicycles, vehicles)
V-Count	Ultima AI, Ultima Go	UK	https://v-count.com/	3D Stereo Video Analytics	Video - object detection	Technology provider (hardware and software)	Contact to ask	Camera placed over head/ceiling mounted	Installed on the ceiling to monitor the entrances of the preferred location. The sensor camera anonymously detects and counts the heads of the people entering and exiting. Designed for retail environment.	Indoor environments		1. Real time 2. Not sensitive to low light 3. Zone analytics (Zone counting, dwell time, heatmap) 4. Group counting 5. Mask detection 6. Gender (age?) recognition	Require ceiling mounting to cover the monitored area/small region	

												7. Wide coverage 8. Anonymous counting		
Xovis	Xovis AERO Passenger Flow Management System (PFMS)	Swiss	https://www.xovis.com/solutions/airport	3D Stereo Video Analytics	Video - object detection	Technology provider (hardware and software)	On website	Camera placed over head/ceiling mounted	Installed on the ceiling to monitor the preferred location. The sensor camera anonymously detects and counts the heads of the people entering and exiting.	Airport		Designed for airport application		Passengers are recognized as distinct from one another even if they are only 20 cm away from each other. https://api.xovis.com/fileadmin/user_upload/data/technology/use-cases/Xovis-brochure-Airports.pdf
RetailNext	TRAFFIC 2.0 and Aurora sensor	USA UK office	https://retailnext.net/	3D Stereo Video Analytics	Video - object detection	Technology provider (hardware and software)	Contact to ask	Camera placed over head/ceiling mounted	Use artificial intelligence algorithm based on deep learning to anonymously detect people with incredible accuracy.	Indoor environments			Require ceiling mounting to cover the monitored area/designed for retail	Business oriented
AXIS	AXIS People Counter	Sweden	https://www.axis.com/products/axis-people-counter	2D Video Analytics	Video - object detection	Technology provider (hardware and software)	Contact to ask	Unknown	Bi-directional people counting	Indoor environments such as retail, education, public transport etc. Entrance door, exit				
CrowdVision	CrowdVision	UK	https://www.crowdvision.com/solutions-airports/#tab2	2D Fisheye Video Analytics	Video - object detection	Technology provider (software)	Contact to ask	fisheye lens	CrowdVision is an AI-based software solution that uses video analytics to provide real-time insights into high-density crowd movements. It can accurately track individual people and provide data on crowd density, flow, and dwell time.	Airport		Developed as a solution for airport		
Quuppa	Quuppa Intelligent Locating System	Finland	https://www.quuppa.com/	RTLS - BLE	Device-Based - Object Tracking	Technology provider (hardware and software)	Contact to ask	No requirement on CCTV Dedicated Bluetooth tags and locators	Quuppa is an indoor positioning system that uses Bluetooth Low Energy (BLE) beacons and advanced algorithms to track people and objects in real-time. It can accurately track individuals in high-density crowds and provide data on crowd density, movement, and dwell time.	Indoor environments				
iOmniscient	iOmniscient	USA	https://iomni.ai/our-solutions/	2D Video Analytics - AI/ML	Video - object detection	Technology provider (software)	Contact to ask	Unknow	iOmniscient is a video analytics software solution that uses AI-based algorithms to provide real-time insights into high-density crowd movements. It can accurately track people and provide data on crowd density, flow, and dwell time.	Indoor/outdoor environments				

									Heuristic + Neural Network/ Deep Learning + Active/ Guided Learning algorithms resulting in fast & accurate results with minimal computing infrastructure.					
Inpixon	Inpixon	International UK office	https://www.inpixon.com/technology/rtls	RTLS - UWB, BLE, WiFi, Tags, smartphone	Device-Based - Object Tracking	Technology provider (hardware and software)	Contact to ask	No requirement on CCTV	Inpixon is an indoor mapping and positioning system that uses Wi-Fi and Bluetooth signals to accurately track people and provide data on crowd density, movement, and dwell time. It can be used to monitor and manage crowds in large indoor spaces, such as convention centers, airports, and shopping malls	Indoor environments				RTLS primarily leverage radio-frequency (RF) technologies like UWB, BLE and Chirp, as well as wireless devices, such as tracking tags and smartphones, alongside other integrated components, to continuously determine the position of people and objects in areas GPS is not able to reach. This delivers actionable location data that can be used to visualize the location of key personnel, assets, vital equipment
Teledyne FLIR	Brickstream 3D Gen 2	International UK office	https://www.flir.co.uk/browse/industrial/people-counting-and-tracking/	RTLS - BLE/3D Stereo Video Analytics	Video - object detection	Technology provider (hardware and software)	Contact to ask	Camera placed over head/ceiling mounted	3D imaging processing	Indoor environments/Could be used outdoor		Application in passenger flow and queuing times monitoring	Require ceiling mounting to cover the monitored area/gate/entrance	
Eurecam	COMPTIPIX 3D	France	https://eurecam.net/en/	2D/3D Video Analytics	Video - object detection	Technology provider (hardware and software)	Contact to ask	Camera placed over head/ceiling mounted	3D stereoscopic image produces a depth map that allow sensor to perform people tracking, heatmap and enumeration.	Indoor environments			Require ceiling mounting to cover the monitored area/small region	
PFM	3D stereoscopic counters	UK	https://www.pfm-footfall.com/how-it-works/	Thermal/3D Stereo Video Analytics	Video - object detection	Technology provider (hardware and software)	Contact to ask	Camera placed over head/ceiling mounted	3D stereoscopic counters use 2 lenses to facilitate depth perception. Depth information allows a camera to distinguish a group of people as separate objects. Therefore, it counts accurately even when more than 10 people are entering and exiting the store simultaneously. Note: no video images are processed. Thermal counters can be placed on the ceiling at the entrance of store. They accurately detect people by their body heat profile. Therefore, they count bi-directionally even when	Indoor environments/mostly entrance			Require ceiling mounting to cover the monitored area	

									a number of people are passing simultaneously.					
TRAF-SYS	Overhead People Counting Sensors	USA	https://www.trafsys.com/hardware/	3D Stereo Video Analytics	Video - object detection	Technology provider (hardware and software)	Contact to ask	Camera placed over head/ceiling mounted	The Eclipse People Counter provides an accurate video-based people counting solution with built-in Ethernet connectivity. The counter uses advanced Image Recognition Technology to provide accurate data under a broad set of environmental conditions, such as high traffic, dynamic lighting, and wide entrance areas.	Indoor environments		Extended coverage with different lenses	Require ceiling mounting to cover the monitored area	
Prodco	PC-3DR Stereoscopic Traffic Camera with A.I.	Canada	https://www.prodcotech.com/people-counting/	3D Stereo Video Analytics	Video - object detection	Technology provider (hardware and software)	Contact to ask	Camera placed over head/ceiling mounted	Prodco's 3D camera leverages embedded A.I., high speed 3D video processing, Bluetooth/Wi-Fi technology to accurately count the number of shoppers entering/exiting an entrance, floor or a specified zone. Advanced features include tracking shopper behavior such as passer-by and capture rates, first/repeat visit, shopper dwell time, visit frequency, gender, staff and security guard exclusion and much more.	Indoor environments				
Irisys	Vector 4D	UK	https://www.irisys.net/	infrared beam	Sensor - object detection	Technology provider (hardware and software)	Contact to ask	Sensor placed over head	uses a technology called infrared time-of-flight to anonymously detect and measure the movement of people	Indoor environments		Anonymity (no personal information is collected)	Require ceiling mounting to cover the monitored area	
OpenCV	OpenCV		https://opencv.org/	2D Video Analytics - AI/ML	Video - object detection	Technology provider (software)	Open Source	Camera placed at certain height/sturdy view & lighting	Open-source computer vision lab which can be used to developed people counting & tracking application.	Indoor/outdoor environments				How Artificial Intelligence counts people and vehicles from CCTV cameras - YouTube https://www.youtube.com/watch?v=oXlwWbU8l2o

Note:

- The vast majority claimed to have an accuracy level of between 95%-99% in their effective range if they mention about accuracy level.
- Most venders who use 3D Stereo Video Analytics require ceiling mounting camera/sensor to cover the monitored area, usually at the entrance or pathway, in a retail environment.
- Although some claim to work well in counting crowds, no solid proof is given to show their system performance in high density situations.

Appendix 3A: Field Observations

Trial Field Observations - Overview

This appendix outlines the planning and execution of field observations conducted by NRC and GHD staff in early 2023. The intention of these observations was to test the effectiveness of the provisional plans developed, the technology employed, and the assumptions made to ensure that the data collected met the needs of this work (i.e., could be applied within FAA models).

The work conducted during these field observations was to explicitly try out approaches and learn methodological, logistical and procedural lessons to enhance the scope and content of the data collected in Phase II (see Figure 1) – ensuring that it better meets the needs of end users (e.g. FAA modelers).

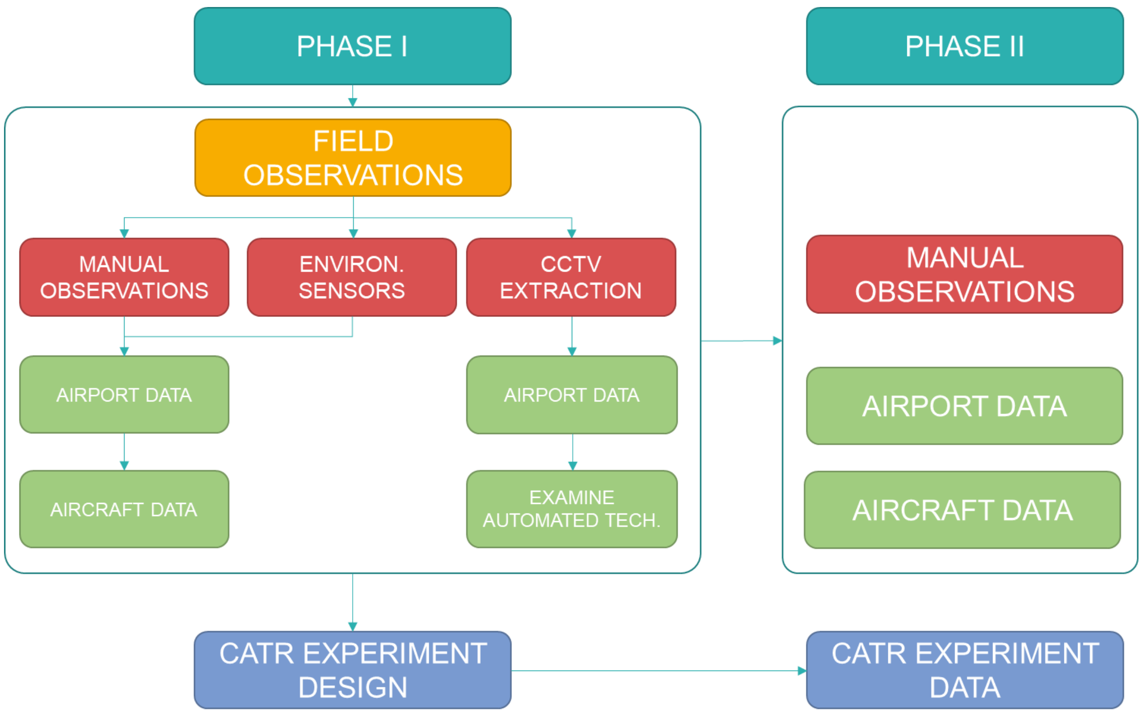


Figure 1: Relationship between activities in Phase I and Phase II.

GHD and NRC staff took part in field observations in April 2023. These observations involved the development, management and execution of data collection activities at Airport#1, Airport#2, Airline#1 and Airline#2. These activities unfolded as follows:

- Detailed planning and preparatory meetings between NRC / GHD – 25-26/4/23. This included developing the data collection templates, creating an approach to gridding space for observation needed, finalising observer roles, and catering for logistical issues presented by changes to aircraft and airport access.
- Overnight visit to Airport#1 25/4. This included establishing camera positions, grid locations of interest, identifying observer positions, and developing gridded areas and recording them (see Figure 2).

Figure 2: Overlay of pre-determined grids to simplify passenger counts.

- Overnight trip to Airport#2 via Airline#1 to test data collection approach and prototype iPad design (30/4-1/5/23). This involved six team members deploying to gate locations and onboard to conduct observations.
- Debrief on data collection efforts with NRC staff (2/5/23) informing an update to the method employed and development of the iPad app design to simplify the data collection activity.
- Return trip to Airport#2 via Airline#2 (3/5/23). This involved four team members deploying to gate locations and onboard to conduct observations, while another team member remained at the gate at Airport#1 to focus data collection activities there.
- Debrief on data collection efforts involving GHD/NRC staff (4/5/23). Further iteration of iPad app design and data collection method.
- Review of CATR experimental capabilities and gaps in other data collection methods, given experience of field observations. Meeting involved GHD and wider NRC team (e.g. those involved in CATR infrastructure development, Environmental Data Collection, Respiration Measurements and Acoustic Assessment). Primarily to prioritise next steps and identify first lessons learned from field observations.

The purpose of these observations was to test the provisional data collection methodology developed and enhance it to address a number of open questions including general concerns such as the:

- Potential value of **overlap between manually observed data and CCTV footage**.
- Impact of different **notation** approaches adopted to capture qualitative and quantitative data.
- An assessment of **viable data that can be collected at the gate, jetway and onboard** using different data collection methods (i.e. impact of video vs manual observations). Examination of how data might be represented – across locations and formats.
- Potential for comparing **human behaviour with environmental data**. This is based on reliability of syncing time between human behaviour and environmental data collection.
- **Insights for CATR trials** – behavioural scope, method, data format, data compilation.

In addition, insights were collected that addressed more technical questions including the:

- Impact of adopting different **time increments** on data collected (i.e. increased sample size vs. reduced time granularity), and on resolution of activity/dwell times.
- Impact of **grid size** on distancing measures (in absence of automated passenger locating). It might be possible to test cell sizes of 1m x 1m and 2m x 2m. If not, default to 2m x 2m. A grid of 1m x 1m was used in this case.
- Impact of using **tablet vs. documentation on the efficiency and reliability of the observers**. Tablets might simply be a reproduction of the template or an app allowing more flexible data entry. This was to be determined with observers adopting different technologies to collect data. Therefore, observers with comparable roles used different data collections technology.
- **Minimising the time spent recording data by individual observers reducing the likelihood of fatigue and error.**

Locations and Activities of Interest

Dyads were identified by the FAA outlining the episodes of passenger movement of particular interest. This provided the scope of the work to be conducted, but also suggested the locations and activities of interest – as well as implicitly indicating the modular approach necessary. In effect, data was to be gathered on passenger activities in certain times/locations. These data-sets reflected passengers' actions within those spaces, without necessarily producing a consistent narrative across all of the spaces at the individual level – in essence, to capture as much information as possible within each dyad, but not tracing the actions of any individual across the dyads. Apart from avoiding some of the methodological challenges in doing this, this modular approach allows the data to be recombined in different ways providing modelers with the capacity to make different assumptions regarding the dyads or perturbing the data to change specific elements of movement seen, and therefore have access to model a larger number of scenarios.

The dyads (combinations of human and environmental factors producing episodes) provided by the FAA are shown in Figure 3.

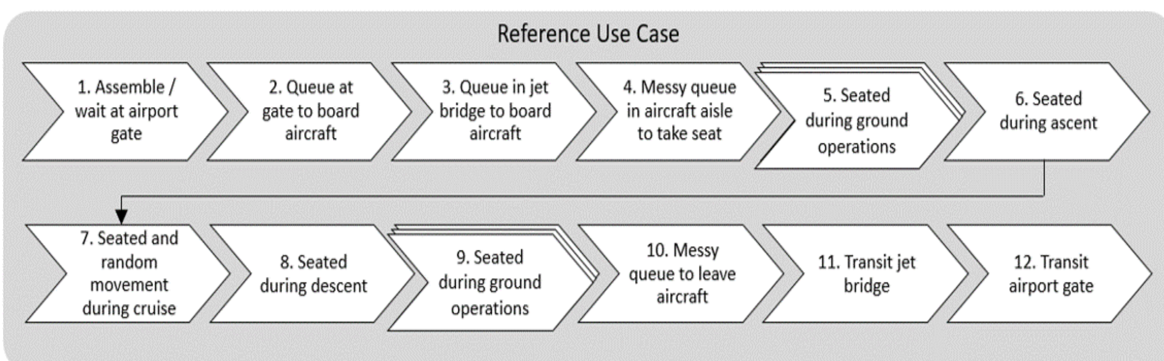
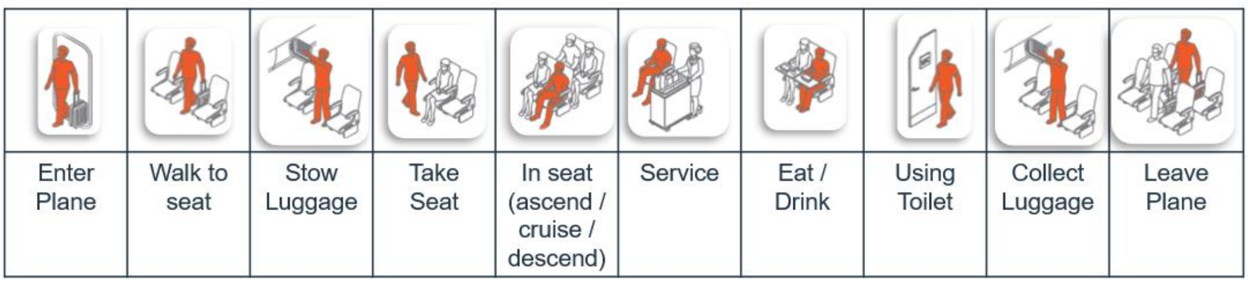


Figure 3: FAA dyads used in both Behavioural and Environmental data collection efforts.

The earlier literature reviews conducted and the conceptual model developed provide a basis for identifying the locations to be found in those dyads, the passenger actions at these locations, and the factors that might influence them or be affected by them. Figure 4 outlines the focus of the data collection activities. At the airport(s), the focus will be determined by fixed location types, each of which will likely involve multiple passenger actions. Onboard, the focus will be driven by the visual catchment area of the observer that is afforded by the vantage point (either looking ahead or along the row). Each observer will have access to two groups of passengers deemed to be in their catchment area: those in the same row and those in the two rows directly ahead of them. The relative location of the passengers to the observer, will afford the observer access to different data: the observer will capture actions / status changes for those passengers in the rows ahead of them; they will capture the same information plus actions that occur below the top of the seat of those passengers in the same row.

These locations are identified as they inform the activities likely to be performed. It is not suggested that all of the actions identified will be observed or analysed; however, it is useful to identify a broad set of actions (deemed to potentially influence exposure) and then prioritise a sub-set of them for detailed assessment accordingly.

(a)



(b)

Figure 4: Actions of interest.

By combing the insights provided in Figure 4 and the original dyads shown in Figure 3, a provisional estimate of the actions to be examined was established (see Figure 5). This identified a set of sub-locations / phases within the original dyads. This is useful as it promotes a more considered review of the actions in context with the passenger timeline.

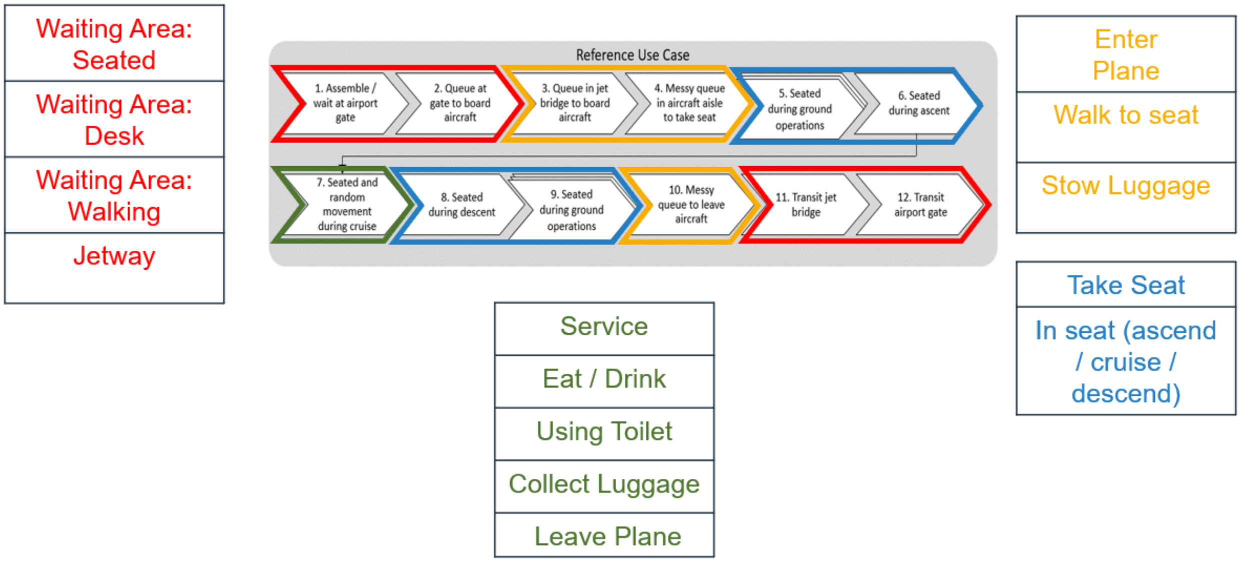


Figure 5: Actions applied to FAA dyads.

Several assumptions were required to enable data to be collected across these different locations during meaningful time periods:

- Sections of seating observed at the gate(s) are representative of the wider seating area at each gate; i.e. the selection of the seats was not biased or reflecting particular locations that might accidentally influence the results. Once a location was selected, the proposer justified its location based on practicality, capacity to collect useful results and quality of the catchment area afforded by the location.
- Time increments were selected to allow a representative snapshot of performance to be established. Difference in observations and conditions allow dynamics to be recorded over time.
    - Much of the data collected was at 180s time increments – to allow observers to work their way through their assigned sample in the given time, recording changes to the actions being performed status changes (e.g. speaking then eating, sitting then standing, etc.). There was some variation in this time-step to allow the impact of changes to be better understood.
- It is possible for observers to synchronise timings between observers and between human and environmental observations.
    - In both manual and digital approaches, times were recorded – either establishing the time step to which observations were to be associated, or recording the precise time associated with a condition as generated by the app.
- The timeline used at the gate did not exclude significant sets of data of interest.
- Queues at desk are broadly linear, at least at the front section – allowing gridding to be directly applied.
- Queues will form at or near desk both for pre-boarding information gathering and boarding. These activities will place demands on the staff operating the desk.
- It is unlikely that the view afforded an observer at the jetway will allow detailed observation of the entire queue. Therefore, a simplified approach is adopted focusing on the front of the queue.
- Boarding observations in the aisle will likely involve spatial overlap across the observers. However, it is highly unlikely such observations will be conducted at precisely the same time and therefore will just represent different data points in the sample space.
- It is likely that observers onboard will only be able to view above shoulder activity ahead of them, while observing more detailed passenger actions along their own row.
- Observed crew activities in economy can be observed and are broadly representative of crew activities in rest of aircraft.

- Unless observers choose to wear masks, observers will follow the mask wearing practice of the passengers – to ensure that they fit in.

Definitions and Metrics

Table 1 and Table 2 outline the metrics developed for the initial field observations. In essence, these reflect the operationalisation of measures for which we want to generate data through observation. These will be translated into the template design – be it paper or iPad. They are deliberately simple given the time constraints on the observer – however, should still allow a degree of consistency between observers responsible for manual observations. These will be associated with the time step and so can be associated with delays / action times to the resolution of the time step – and allow direct comparison with the environmental conditions observed to the same level of refinement.

Table 1: Actions and attributes.

Factor	Observation (All Y/N)	Definition of observation and format of the metric	Note-taking
Demographics	• **A**dult • **C**hild • **E**lderly	– From teenager up to people in their 50s. Basically default. – Aged 10 and below. – People in their 60s and above.	Tick the space mark ed with A,C and E (or ✗ for empty space)
Mask Wearing	• **C**orrect • **I**ncorrect • **N**ot warn	– Wearing mask which covers both noise and mouth. – Wearing mask which does not cover noise and mouth at the same time. – No mask.	Tick the space mark ed with C and I (or ✗ for not warn)
Status	• **Si**tting • **St**anding • **Be**nding • **Re**clined • **E**mpty space	– A person is sitting straight with/without an associated action. – A person is standing with/without an associated action. – A person is bending with/without an associated action. – A person is sitting reclined with/without an associated action. – Empty space/seat within designated region for observation.	Note down the code of the corresponding status in the space.
Action associated with ***status*** including modifier and/or object, people	• **Sp**eak • **E**at/**Dr**ink • **T**ouch/Use/ **M**ove /Collect / Deposit / Carry object • Face • **Move To /Away** • **Co**ugh/Sneeze • **Wa**it • **Sl**eep • Entertain (Read / Watch / Play)	+ Action object [**people**] & Modifier [**Lo**udly] (A person is speaking to someone) + Modifier [**Al**one/**Sh**aring] (A person is consuming) + Action object [**objects**] (A person is touching or using an object) + Action object [**objects**] & Modifier [To **OH**] (A person is moving an object) + Modifier [**To** seat/**Aw**ay from / to OH / to Toilet / to Galley / Along Aisle] (A person is transiting) / + Modifier [**Quickly**] (A person is walking quickly) – No object (A person is coughing or sneezing) – No object (A person is sitting or standing still and awake without any other action) – No object (A person is sleeping without any other action)	Note down the code of the corresponding action in the space, and code for any object/modifier.

Table 2: Objects.

Location	Object	
	External (Objects)	**External (People)**
Airport	Device (phone, headset etc), Seat, Luggage, Face/Mask, Document, Desk, Counter, Ticket swipe, Wall, Movement device	In-Group, Out-Group, Staff, Crew, Baby (being carried)
Aircraft	Device (phone, headset etc), Seat (ahead/behind), Luggage, Face/Mask, Document/newspaper/book, Screen, PSU, Tray, Bag, Overhead, Toilet, Movement device, Call Switch, Payment Device, Toilet Door	Passengers (in row), Passengers (out of row), Crew, Baby (being carried)

Data Extraction Plan

For the manual field observations, a general timeline employed for field observers on the ground:

- Arriving Aircraft – Population deplaning flight before at same gate. Might be too much as timing is not in our control.
    - **No arriving aircraft data.**
- Pre-call (PC) – A period that might be recorded, although precise starting point will be arbitrary.

- **90 mins before the call – start test runs.**
- **30 mins before the call – start observation.**

- Call (C) – After gate call is made. Assumed latest point that we would start count.
  - **Observing full time period.**
- Pre-Board (PB) & **Standby** – Prior to boarding commences.
- Group Call (GC) – From first group announced.
- Remaining Pax (RP) – After final group announced – late arrivals.
  - **Assumed no remaining pax – or conditions are captured elsewhere.**
- Boarding (B) – Passengers moving along aisle to stow and find seats.
- Taxiing – **Observer focusing on staff/aisle start when planes leave the gate.**
- Seated – Ascent period (SA). Passengers seated.
  - **General notes only.**
- Seated – Cruising (SC). General flight conditions. Passengers predominantly seated, with movement to toilets, other passengers, etc.
- Seated – food service (SF). Passengers predominantly seated with crew serving meals/drinks.
  - **Observer focusing on staff/aisle.**
- Seated - Descent period (SD). Passengers seated.
- Deplaning - Door closed (DC). Passengers collect baggage and queue in aisle.
  - **General notes only.**
- Deplaning - Door open (DO). Passengers deplane and move into jetway.
- Post-Flight (PF). Passengers move through gate area.

This timeline was translated into instructions for the observers in the field (e.g. when they should arrive, when they boarded, when they switched roles, etc.) and also where changes in passenger actions might be expected in the data.

Roles and Responsibilities

Six NRC/GHD observers were deployed. Care was shown to assign roles to these observers to enhance the coverage and veracity of data collection effort. Table 3 outlines each of the six staff (labelled 1-6), where they are located for the dyads examined, the technology employed, rest periods, and when they needed to move to the next location.

Table 3: Roles and basic responsibilities.

	At Airport		**In Aircraft**		
Observer	Gate	Jetway	Boarding	In flight	Deplaning
1 – AHS	T1A (Seat) Board at end of first boarding group. [PAPER]		T3 (Aisle) All Boarding	T2 (Seat) 30 min ON / 10 min OFF	T3 (Aisle) At front of aircraft – monitor deplaning. Leave last.
2 – RT		T1C (Jetway) Until all boarded [IPAD]		T2 (Seat) 30 min ON / 10 min OFF	Leave as soon as possible. Monitor Jetway Deplaning?
3 – PL	T1A (Seat) Board at end of first boarding group. [IPAD]		T3 (Aisle) All Boarding	T2 (Seat) 30 min ON / 10 min OFF	T3 (Aisle) Leave last.
4 – SR	T5 (General) Board at end of first boarding group. [PAPER]		T3 (Aisle) All Boarding	T4/T6 Event-Driven	T3 (Aisle) Leave last.
5 - SH	T1B (Desk) Until all boarded [PAPER]			T2 (Seat) 30 min ON / 10 min OFF	T3 (Aisle) Leave last.
6 – SG	T1B (Desk) Until all boarded [IPAD]	-		T2 (Seat) 30 min ON / 10 min OFF	T3 (Aisle) Leave last.

These roles were assigned templates. A template was created for each of the roles mentioned in Table 3. These are outlined at the end of this appendix (see Figure 6-Figure 13).

Development of iPad Application

Lessons Learned

The field observations proved invaluable in identifying omissions, errors and limitations in the approach adopted – as borne out by the data collected. These can be broadly categorised in logistical, technical and methodological. Some of the key lessons learned are now outlined along with the impact that they had on the design for Phase II data collection activities:

Logistical Lessons Learned

- Limitations on observer seating and timing of access to aircraft. No matter how far in advance tickets / seats were purchased, it seemed possible for our locations to be moved. Therefore, reliance on specific locations is not advisable and observer roles/timings and data expectations should be moderated to reflect more conservative assumptions regarding observer access and movement.
- Booking back-to-back flights (i.e., outbound flight and inbound flight on the same plane) can be problematic as the booking system of the airline company does not allow check-in on the return flight with enough time to receive a ticket. Therefore, tickets should be booked as two individual trips as opposed to a return trip.
- Important to get into gate area more than an hour before boarding to ensure that observer locations were available. It is important we have back-up locations and/or make observer positions zonal along with arriving sufficiently early - to provide redundancy.
- Variability noted in the quality of the video footage available – depending on camera position and system employed. To accommodate, additional flexibility has been embedded in the video extraction template and technical solutions sought, with additional emphasis on introducing our own camera systems into the field.
- Passenger population size and aircraft scheduling may change at short notice. Similarly, aircraft can be diverted to other gates at short notice. It is therefore prudent to have back-up flights and not overfit guidance to specific gates, but take a more generic approach.
- Transporting and deploying binders into the field can be challenging and attracts attention from the public. Somewhat ironically, recording data on iPad apps allows easier observer movement and is less suspicious given the prevalence of people interacting with their own devices. This is particularly the case onboard where people are in close quarters.

Technical Lessons Learned

- Inhouse
    - **Tablets functioned as expected and record data locally.** Several GUI updates suggested as result of use in field. Data to be reviewed to identify how it might feed into metrics usable for modelling. Additional functionality (such as availability of a stylus to write freehand notes) will be introduced to account for the wider needs of the different observer roles.
    - **Environmental sensors functioned in airport and at seats**, as expected. Provided immediate access to data collected. They also did not cause undue attention from the public. These will be used in future trials and inform sensor design and implementation into the CATR facility for the experimental design.

- The scale of data produced required us to use multiple USBs to transfer files. It is likely that we might need more robust approach for actual observations – either storing locally on laptops to be uploaded directly to the cloud or with solid state storage.

As part of the field observations each team member collected data using the iPad application. This generated a series of data files that formed the basis of the analysis. This application was very much a work in progress, being used both to test the concept of using such a system (e.g. the reaction of the public), and its effectiveness at capturing the observations made. A set of issues and modifications are outlined in Table 4

Table 4:User Feedback on iPad Functionality.

Feature or instance	Apparent from?	Possible change/edit	Process of review
"No object"	Extracting data	When no object is in use, remove the "FALSE" results submitted for every object in inventory. Perhaps this has to come from a change to the layout of actions and objects (only adding an object if it is required)	It became clear when extracting the data that there was a lot of unnecessary data (in terms of numerous "FALSE" columns to signify no object being used"). This was noted separately by two people at the extraction phase.
Order of actions on app	Pilot observations	Using our experience from observations, reorder actions by typical prevalence to make the app more convenient to use.	Returning to test the app as a dummy run, and from previous notes by users, reodering prevalent actions in a intuitive, hierarchical fashion may make more sense from ergonomics and efficiency standpoint. More time observing and less time navigating an interface should mean more accurate results are recorded.
Separation of logging queue population (#) from individual observations of behaviours	Pilot observations	Hard to keep track of changing queue length while focussing on individuals' behaviours and actions. Suggest a different app that focuses solely on queue length over time, to be carried out separately solely by one observer.	Notes at the trial stages indicated that observing "too much" at any one time may affect the overall accuracy and timely recording of data.
"Counters A-F"	Pilot observations	Change in structure and/or number of 'counters' on app. Can this be simplified to make it faster to log actions/behaviours?	Both field use and reviewing the app interface led me to view the front page as in need of simplifying as I found it difficult to navigate.
Gate (Seating)			
Feature or instance	Apparent from?	Possible change/edit	Process of review
Fixed seating arrangement	Pilot observations	Perhaps a user-defined 'drawable' table (such as one you might use in MS Word, e.g. rows and columns) to mark out the correct seating arrangement on the fly. This could	User observations at the gate where pre-defined seating block grids did not match the reality of the number and layout of seats

		be performed very quickly upon arrival to a gate. A further improvement would be to be able to 'kill' seats, through the middle, for example, to mark out an aisle or aisles	being observed. Updating this should allow for more nuanced analysis.
Page through from seat selection	Pilot observations	After clicking on a seat, the next page has no mention of the seat ID so it can be easy to be distracted by observed actions of others and to lose one's place. A solution would be: a) to apply seat IDs to the rows and columns; b) to have the seat ID present clearly on any subsequent pages of the app so one is remind of observation selection.	User observations from using the app repeatedly during flight testing. With a lot going on and for the user to remember on the fly, it might be useful to have the app do some of the heavy lifting.
Cancel button	Pilot observations and extracting data	A cancellation button which scrubs the data from any future download This simplifies extraction methods. Is this possible?	In both on the ground observations, and in extracting the data, it was clear that a cancel/void button would be useful to quickly return to the home screen and start again. The need to save time and restart if incorrect is of some importance.
Jetway			
Feature or instance	Apparent from?	Possible change/edit	Process of review
Grouping	New requirements	A function to log total number of observed groups? How many travelled in groups vs. those apparently travelling alone?	Have requested notes from Russ to see if has anything to add from his observations
Luggage	New requirements	A simple tracking of luggage carried by passengers. A True/False function?	
Actions of ground staff	New requirements	A method of logging general activity of ground staff at the plane end of the jetway?	

- Airport
    - Airport#1 – relatively last-minute access to the control room was valuable in planning for future efforts, but limited our access to data during the visit timescales available. Also demonstrated variability in footage quality (although updates to video system expected before Phase II activities). However, ongoing discussions with technology developers might resolve the issue entirely and enable remote access for suitably anonymised video or pre-extracted data.
    - Airport#2 – airport staff gave tour to NRC staff while GHD prepared and monitored gate areas. This enabled us to review their general approach and see anonymised passenger counting software. Seems likely that they will follow the lead of Airport#1.
- Aircraft

    - In all instances, Cabin Crew onboard were extremely accommodating and supportive. Gate staff had to deal with ticketing issues delaying our access, although were obviously doing their best to deal with an unfamiliar situation and system difficulties. It did delay observers getting into position, and so will be factored into the design of the procedure.

Methodological Lessons Learned

- A number of bugs were identified in the iPad app that either delayed observer entries, prevented them from checking/correcting previous entries or prevented recording certain types of data. The iPad app has since been updated based on this experience and will also reflect the changes made to actions and situations to be collected.
- **Critical importance of ensuring consistency between environmental and behavioural data resolution** to ensure that identifying observations do not needlessly absorb effort and also that action dictionary is simplified allowing more detailed and consistent recording of data. The observation of higher-level events and plane states (e.g. aircraft phases, service times, etc.) will be documented providing a benchmark against which both environmental and behavioural data can be compared. In addition, the dictionary of actions / objects will be reviewed based on observations to established where there is equivalence between terms and where items were not used.
- **It was often difficult to determine the specific nature of the objects and the interaction with passengers.** It might be prudent to categorise devices as ingroup and outgroup – simplifying the process, reducing the difficulties of observation and make data collection more efficient without losing important details regarding exposure.
- There were many bugs in the templates assigned to observers leading to confusion in recording data or difficulties in interpreting the extracted results. Numerous updates have been made to the templates based on pragmatic insights gained from observations and the move from documentary to tablet-based data collection. Although document-based templates will be kept as a back-up, it is likely that the primary means of manual data collection will be completed through the iPad app.
- There were very few approaches from passengers when using the iPad. Although passengers were not surveyed, we speculate that this is likely due to the prevalence of iPads and mobile devices – observers basically looked like self-absorbed passengers. Therefore, in addition to timestamping and the consistent generation of observations, the use of iPads made observer activities less apparent. To make iPad use even more inconspicuous to passengers, privacy screens will be installed.
- The actors, actions and observers initially observed were reviewed for omissions and redundances, and also prioritised. Therefore, instead of deployed multiple versions of the template, a reduced number of app variants will need to be produced:
    - for basic observations onboard or at the gate,
    - logging movement at the jetway,
    - logging activities in the aisle,
    - logging narrative movement between seat and galley/toilet/passenger (possibly include in basic observation),
    - and a final variant for qualitative observations at the gate.

- Established clear limits on what might be observed by observers in seats. Observers could collect data on passenger actions in their seat row. It was possible to get a clear view of these passengers as needed. The passengers occupying the two rows (six seats) ahead of the observer could only be partially seen. In effect, activities that occurred above the seat back could be clearly seen. Other activities involved some speculation on the part of the observer. This difference should be reflected in the method – with great weight / time afforded to the row observations. Given suitable camera positions (located above rows), it would be possible to observe passengers' actions throughout the CATR facility both reliably and in detail.

- It was only possible to manually record actions conducted at the front of the queue at the gate desk. The movement of those in the queue at the desk was too complicated to capture in a reliable manner. Changes were made to the template to allow observers to capture the interaction between the first person / people in the queue and the staff, and then the number of people in the queue at that time. It should also be noted that the interaction time between the first person and the member of staff was the driver of the queue length.

- Aisle movement was extremely difficult to capture during boarding and deplaning. Movement was complex and many simultaneous actions were performed – meaning that observer inconsistences were identified and observations frequently missed. A modified approach is suggested:

    - An observer responsible for counting the number of people passing them at any point in time, or noting the arrival of each person by logging on modified version of Jetway Logger.

    - Other observers note the number of people standing in a section of the aisle (e.g. five rows ahead of them) at time-step (e.g. every 30s). Movement in the aisle was categorised into three phases: movement into the aisle then stasis; staged movement based on collection of overhead or under seat luggage; free movement assuming all luggage has been collected. It was only possible to make manual observations during the first two stages – in this simplified form, focusing on the location of passengers in the aisle, whether they were wearing a mask, and whether they were touching OH, the seat or something under the seat. More detailed data was not possible given time constraints and speed of movement. Observations will be richer in CATR assuming equivalent task performance and scenario conditions.

- Although able to capture data, the time-increments employed need to be updated. The increment approach was originally designed assuming that the document template was to be used. This was particularly important onboard – where the impact was felt most and where video footage will not be available outside of CATR. The approach required the observer to scan across the sample of passengers for which they had responsibility – in adjacent seats. This would commence every 180s and then the status of each passenger recorded – with estimated changes in action or status captured at a 180s resolution. This produced lots of identical records and produced results at a resolution of 180s. The iPad app allowed a more 'event-based' approach to be adopted, as it automatically recorded the time of the observation. allowing changes in situation / activity to recorded more quickly and recording activity times more accurately.

    - A more effective use of the 180s is then to look along the row for 60s and note changes; look forward to the block or rows to note changes for 60s; look back along the row for 60s to note changes. Then take 60s rest and repeat. This places more emphasis on the row – where more actions can be observed and builds in rest periods for the observers.

- Adopt a **Hierarchical Task Analysis** format to document relationship between observed actions and modelling impact.

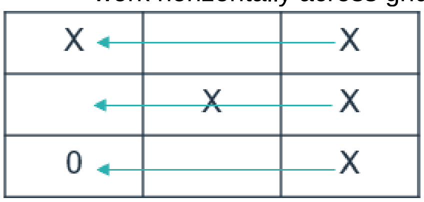
- As with the observations at the gate desk, jetway manual observations were hampered by the limited view of the observer and the occlusion of passengers further into the queue. The observer located at the aircraft exit included the first person in the queue and the activities of the ground staff managing the luggage. Given this, the observer should focus on recording the time for individual passengers to pass, establishing the flow rates achieved, and baggage interaction – passengers depositing baggage and crew collecting it. Observations might be richer if cameras are available in the jetway area and would certainly be richer in CATR trials, assuming the conditions are comparable.

Below is the set of templates developed for manual observations during the trials. These evolved during the trials and informed the development of the data extraction template.

Appendix 3A: Supplementary Material

Data Collection Protocol – Gate - Seating

1. Pre-DC: Review Script. Confirm period over which data collection effort will be performed.
2. Pre-DC: Iteration interval to be determined by estimated time to complete tasks [5]-[9]. **180s.**
3. Pre-DC: Identify sample of seating to be examined. Document where these are and why these are selected.
4. Pre-DC: Print off **Template T1A**. Grid shown applies to section of seated area. If no plan, can be a schematic of seats monitored.
5. Sweep for groups. Mark group locations on diagram.
6. Record demographic information / mask wearing / status for occupied cells.
7. Record observer starting point within the seating grid. From furthest point from observer location, work horizontally across grid, moving to next closest row on grid, then repeating.



8. For each occupied space, record A→M → O, and applicable direction.
9. Cycle through occupied locations in order specified in [6], completing [7].
10. When complete, move to new sheet and return to [5].
11. **Continuous from 30 mins before until Group 1 boarding.**

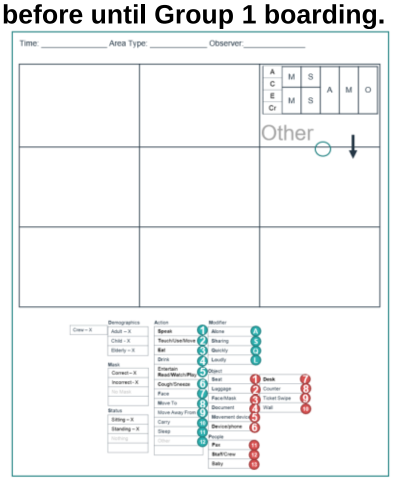
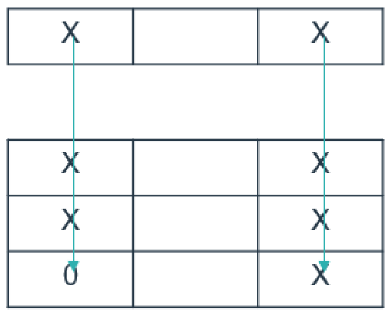


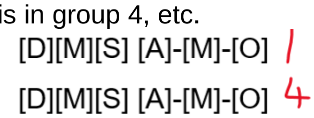
Figure 6: Template T1A

Data Collection Protocol – Gate - Desk

1. Pre-DC: Review Script. Confirm period over which data collection effort will be performed.
2. Pre-DC: Iteration interval to be determined by estimated time to complete tasks [4]-[9]. **180s**
3. Pre-DC: Print off **Template T1B**. Grid shown requires gridding activity described in Data Extraction Plan. Will appear on template. Focus on gridded areas only.
4. Identify staff behind desk (number and location). Identify those in queues.
5. Record demographic information / mask wearing / status for occupied cells.
6. Record observer starting point within the grid. From furthest point from observer, pick staff members, then work backwards along the queue. When complete return to nearest queue and follow same approach.



7. For each occupied space, record A→M → O, and applicable direction.
8. Cycle through occupied locations in order specified in [6], completing [7].
9. When complete, sweep for groups amongst pax. Mark group locations on schematic by assigning group membership to each person – 1, 2, 3…a different number for each group. For instance, first person is in group 1, the second is in group 4, etc.



10. When complete, move to new sheet and return to [4].
11. **Timing (to be confirmed after testing): Continuous from 30 mins before until all boarded.**

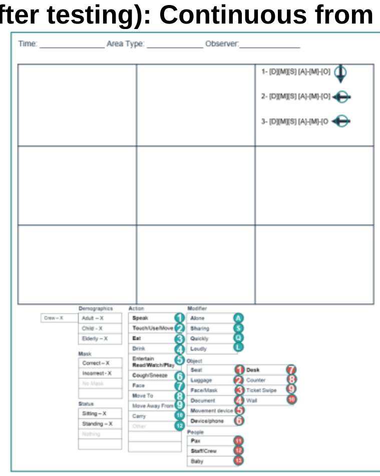
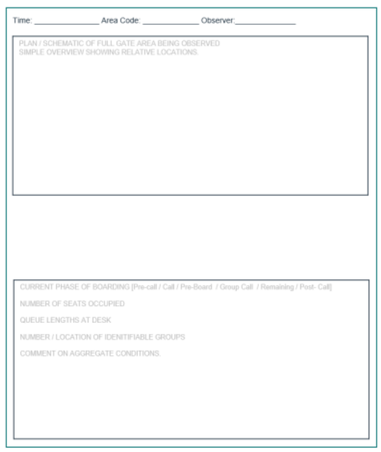


Figure 7: Template T1B.

Data Collection Protocol – Gate - General

1. Pre-DC: Review Script. Confirm period over which data collection effort will be performed.
2. Pre-DC: Set to minimum time step of other observers.
3. Pre-DC: Identify sample seating area if not full area (and fraction of total). Document this.
4. Pre-DC: Print off **Template T5**. Image of whole gate area shown. No grid required, given aggregate estimates. (Unless deemed useful for group location.) 180s time increments – although conditions note as observed within period.
5. Identify current phase of boarding. Unloading of Arriving Aircraft/ Pre-call / Call / Pre-Board / Group Call / Remaining / Post- Call.
6. Count number in seating area sample / Number of empty seats. Adopt same starting point – cycling through area types.
7. Count length of queues at desk. Adopt same starting point – e.g. front to back.
8. Identify aggregate conditions of note – movement between areas, key locations of interaction / congestion.
9. When complete, move to new sheet and return to [5].
10. **Timing : From 30 mins before call to all boarded.**


Time: ____________ Area Code: ___________ Observer:____________

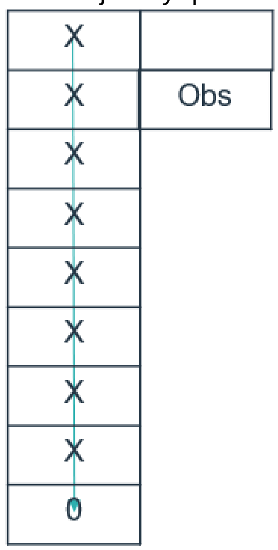
PLAN / SCHEMATIC OF FULL GATE AREA BEING OBSERVED
SIMPLE OVERVIEW SHOWING RELATIVE LOCATIONS.

CURRENT PHASE OF BOARDING [Pre-call / Call / Pre-Board / Group Call / Remaining / Post- Call]
NUMBER OF SEATS OCCUPIED
QUEUE LENGTHS AT DESK
NUMBER / LOCATION OF IDENITIFIABLE GROUPS
COMMENT ON AGGREGATE CONDITIONS.

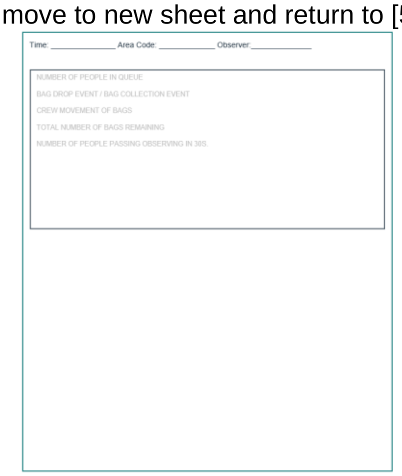
Figure 8: Template T5.

Data Collection Protocol – Jetway

1. Pre-DC: Review Script. Confirm period over which data collection effort will be performed.
2. Pre-DC: Iteration interval to be determined by estimated time to complete tasks [5]-[9]. Likely to be **60s** interval.
3. Pre-DC: Print off **Template T1C**. No grid used here given limited vantage point. Section of jetway being examined should be established. Potential for jetway to have markers photographed to signify distances from aircraft.
4. Boarding: Be in position before boarding. Start observations from when first people start to board.
5. Boarding: Observer positioned at front of jetway queue closest to aircraft (as shown).



6. Boarding: First 30s.
    1. Identify bag deposit activities at space next to door (i.e. number of new drops & total number).
    2. Identify ground crew removal of bags (whether they are active or not).
7. Boarding: For last 30s
    1. Count number of people passing observer – flow rate.
8. Boarding: When complete, move to new sheet and return to [5].


Time: ____________ Area Code: __________ Observer:___________

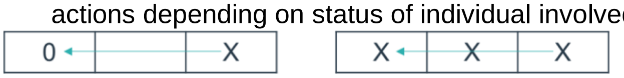
NUMBER OF PEOPLE IN QUEUE
BAG DROP EVENT / BAG COLLECTION EVENT
CREW MOVEMENT OF BAGS
TOTAL NUMBER OF BAGS REMAINING
NUMBER OF PEOPLE PASSING OBSERVING IN 30S.

Figure 9: Template T1C.

Data Collection Protocol – In Flight

1. Pre-DC: Review Script. Confirm period over which data collection effort will be performed.
2. Pre-DC: Use Template T2.
3. Pre-DC: Iteration interval to be determined by estimated time to complete tasks. Likely 180s-300s interval.
4. Pre-DC: Record location, time and flight number of first page. Record assigned seat location within schematic allowing future repetition.
5. Pre-DC: Identify and record seat rows being observed.
6. Record phase of flight being observed. Record demographic information in seats forward of position. Then for seats in same row (starting at furthest point).
7. In same order as [6], Mark group locations on schematic
8. Time Step 1: Conduct forward sweep (see top of template)– involving the two rows immediately ahead of observer. Note starting point within the grid. From furthest point, work horizontally across grid, moving to next closest row on grid, then repeat. Record mask status for occupied cells. Return to starting point. Record visible actions. Likely actions involving head movement – change of direction / hands above head height (if seating), or wider range of actions if standing. Block off own location.

9. Time Step 2: Conduct horizontal sweep (see bottom of template) – involving the row in which the observer is located. Starting from furthest point. Note starting point within the grid. From furthest point, work horizontally across grid to sit next to observer. Record demographics / mask wearing / status for occupied cells. Return to starting point. Record visible actions. Likely fuller range of actions depending on status of individual involved. Block off own location.



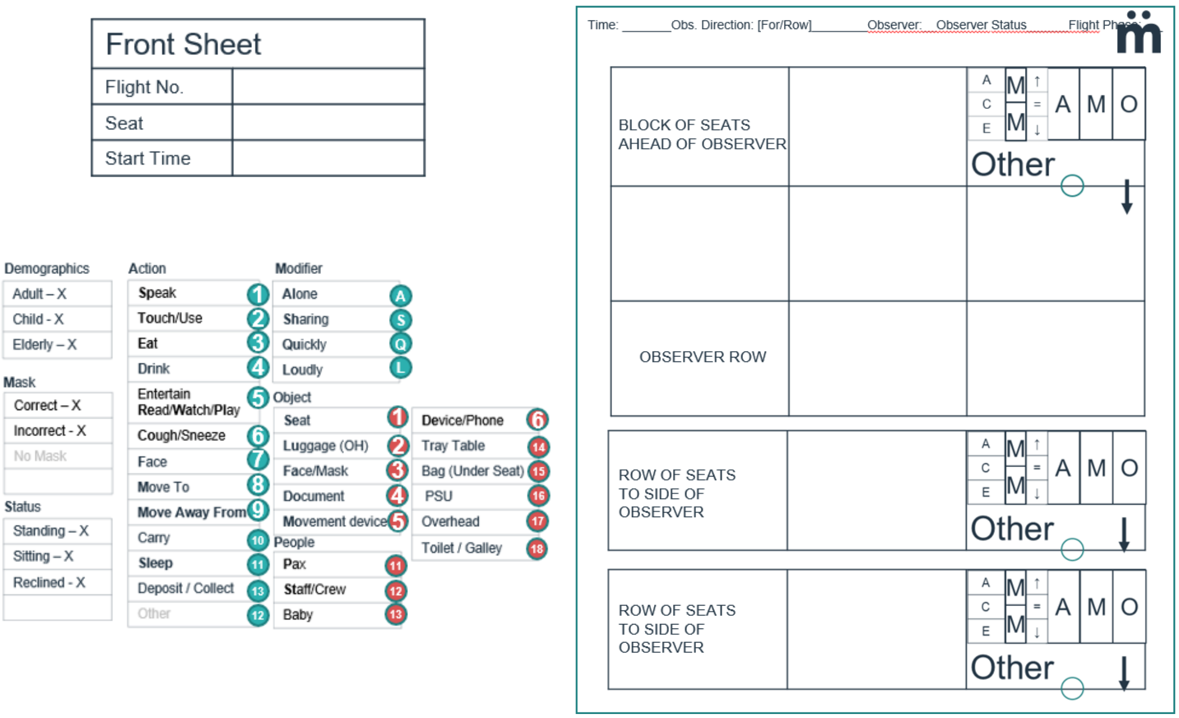
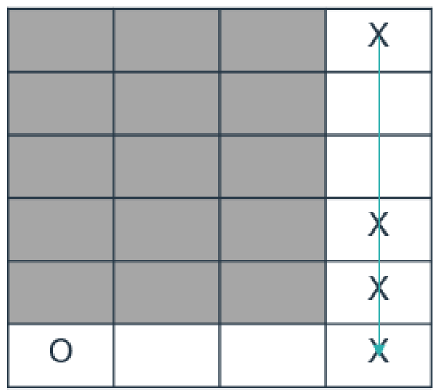


Figure 10: Template T2.

Data Collection Protocol – Aisle Monitoring Boarding / Deplaning

1. Pre-DC: Review Script. Confirm period over which data collection effort will be performed.
2. Pre-DC: Use Template T3.
3. Pre-DC: Record location time and flight number of first page.
4. Pre-DC: Record assigned seat location within schematic allowing future repetition.
5. Pre-DC: Record iteration interval. To be determined from estimated time to complete tasks. Likely 60s-120s interval.
6. Record aisle locations being observed. Count five rows ahead of your location (or as many available) and then visually ‘landmark’ that location (e.g. mark observer row).
7. Record phase of flight being observed.
8. Start at furthest point in aisle.



9. Sweep for groups amongst pax. Mark group locations on schematic by assigning group membership to each person – 1, 2, 3…a different number for each group. For instance, first person is in group 1, the second is in group 4, etc.

[D][M][S] [A]-[M]-[O] 1

[D][M][S] [A]-[M]-[O] 4

10. Start at furthest point that is occupied. Complete entry in Template 3 for that individual: Demographics, Mask, Status, Actions (A→M → O) and Direction.

11. Move to next closest aisle location (nearer row).

12. Cycle through occupied locations.

13. When complete, move to new sheet and return to [8].

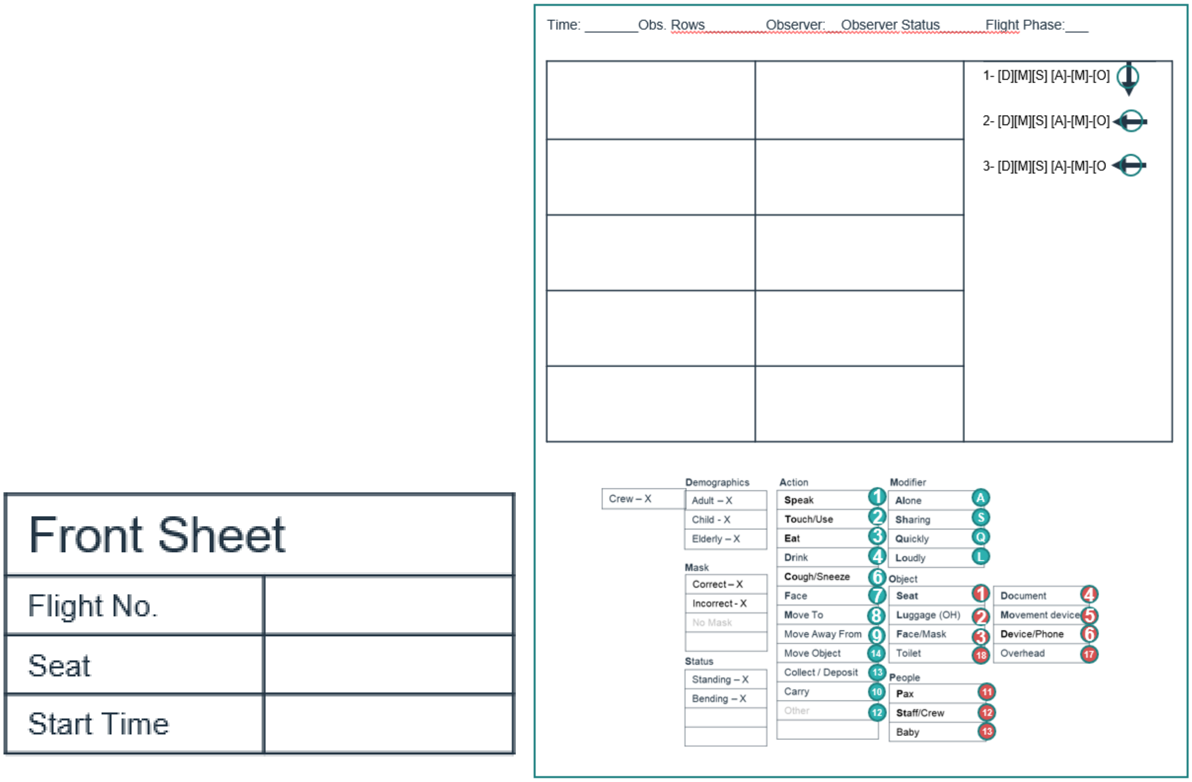


Figure 11: Template T3.

Data Collection Protocol – Aisle Monitoring During Flight / Toilet Monitoring

Observer 6 will alternate between observing aisle movement (Template 4) and toilet activities (Template 6).

The balance of this will be event-driven:

- When crew / pax are in aisle then activities should be recorded.
- Otherwise, toilet queue conditions should be recorded.

Aisle Monitoring During Flight – Observer 6

1. Pre-DC: Review Script. Confirm period over which data collection effort will be performed. Use Template T4.
2. Pre-DC: Record location, start time and flight number of first page.
3. Pre-DC: Record assigned seat location within schematic allowing future repetition.
4. Pre-DC: These recordings will be event-based – relying on the arrival of staff/pax, rather than increments.
5. Record phase of flight being observed (only relevant to aircraft observations).
6. Record start time at location.
7. Record aisle location of crew / pax activity.
8. Sweep for groups amongst pax. Mark group locations on schematic by assigning group membership to each person – 1, 2, 3…a different number for each group. For instance, first person is in group 1, the second is in group 4, etc.

[D][M][S] [A]-[M]-[O] 1

[D][M][S] [A]-[M]-[O] 4

9. Record observer status (standing / sitting).
10. Complete entry in Template 4 for that individual: Demographics, Mask, Status, Actions (A→M → O) and Direction.
11. Record end time at location.
12. When complete, move to new sheet and return to [5].

Front Sheet	
Flight No.	
Observer	
Seat	
Start Time	
Time Step:	Event-based

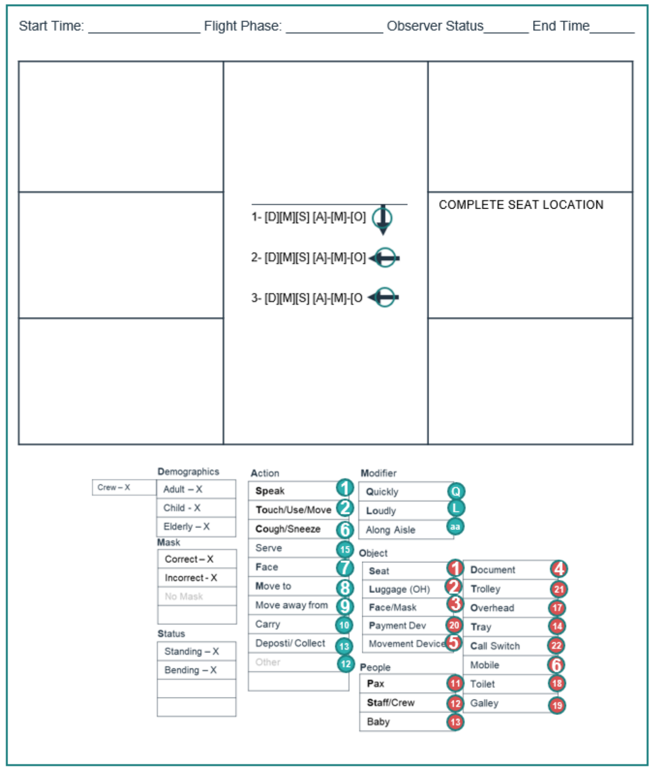


Figure 12: Template T4.

Toilet Monitoring During Flight– Observer 6

1. Pre-DC: Review Script. Confirm period over which data collection effort will be performed. Use Template T6.
2. Pre-DC: Record location time, start time and flight number of first page.
3. Pre-DC: Record assigned seat location within schematic allowing future repetition.
4. Pre-DC: Record iteration interval. To be determined from estimated time to complete tasks. Likely 60s-120s interval.
5. Record location of toilet being observed.
6. Record phase of flight being observed.
7. Record queue length.
8. Complete entry in Template 6 for individuals in the queue: Demographics, Mask, Status, Actions (A→M → O) and Direction.
9. When complete, move to new sheet and return to [5].

Front Sheet	
Flight No.	
Observer	
Seat	
Start Time	
Time Step:	Event-based

Comment	
Flight Phase:	
Toilet #:	
Queue Length	
Toilet #:	
Queue Length	

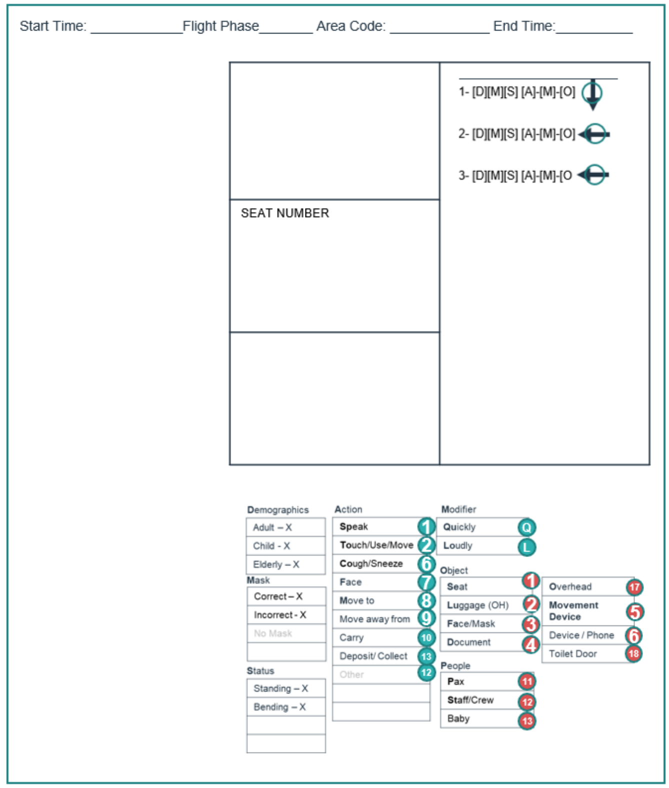
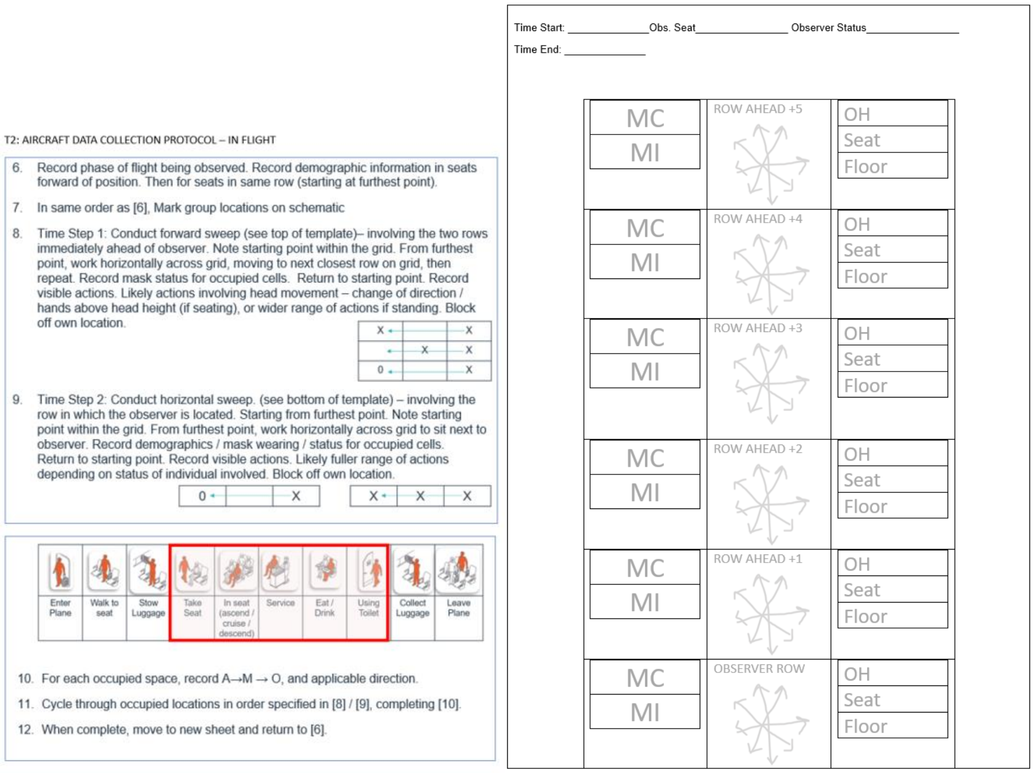


Figure 13: Template T6.

The templates shown above evolved over the trials – being updated based on the information gained. The goal here was to simplify the process without a loss of data collected (compare Figure 14 with Figure 10).


T2: AIRCRAFT DATA COLLECTION PROTOCOL – IN FLIGHT

6. Record phase of flight being observed. Record demographic information in seats forward of position. Then for seats in same row (starting at furthest point).
7. In same order as [6], Mark group locations on schematic
8. Time Step 1: Conduct forward sweep (see top of template)– involving the two rows immediately ahead of observer. Note starting point within the grid. From furthest point, work horizontally across grid, moving to next closest row on grid, then repeat. Record mask status for occupied cells. Return to starting point. Record visible actions. Likely actions involving head movement – change of direction / hands above head height (if seating), or wider range of actions if standing. Block off own location.
9. Time Step 2: Conduct horizontal sweep. (see bottom of template) – involving the row in which the observer is located. Starting from furthest point. Note starting point within the grid. From furthest point, work horizontally across grid to sit next to observer. Record demographics / mask wearing / status for occupied cells. Return to starting point. Record visible actions. Likely fuller range of actions depending on status of individual involved. Block off own location.

10. For each occupied space, record A→M → O, and applicable direction.
11. Cycle through occupied locations in order specified in [8] / [9], completing [10].
12. When complete, move to new sheet and return to [6].

Time Start: ____________ Obs. Seat______________ Observer Status______________

Time End: ____________

MC / MI	ROW AHEAD +5	OH / Seat / Floor
MC / MI	ROW AHEAD +4	OH / Seat / Floor
MC / MI	ROW AHEAD +3	OH / Seat / Floor
MC / MI	ROW AHEAD +2	OH / Seat / Floor
MC / MI	ROW AHEAD +1	OH / Seat / Floor
MC / MI	OBSERVER ROW	OH / Seat / Floor

Figure 14: Later iteration of T2 Template

Appendix 3B: Analysis of Previous Event Video Footage

Trial Video Observations – Overview

Video Template Development

The objective of this work was to apply a provisional template to a comparable people movement scenario in order to determine its applicability and capacity to produce useful data. This work paralleled effort to design a procedure for video data collection to parallel manual observations discussed below.

A simple procedure was created for those involved in video extraction (which paralleled what had been developed for manual observations, discussed below).

- [1] Pre-DC: Visit Airport#1 and Airport#2 control systems to establish footage review facilities.
- [2] Pre-DC: Ensure templates work with representative gridded location of gate area.
- [3] Pre-DC: Scan through video footage to identify period within which gate was being used for flight in question.
- [4] Pre-DC: Identify selection criteria for peak period within this time. For instance, identify start / end times to avoid capturing long period when individuals just waiting.
- [5] Pre-DC: Identify time increments (e.g. 30-60s)
- [6] Examine dictionary to familiarise self with underlying definitions for the observations.
- [7] Refer to spreadsheet template.
- [8] Record location being examined (seating, desk, general)
- [9] Identify snapshot indicated by time increment.
- [10] Sweep for groups and population sizes in each grid. Record in General Population Insights (see Template V1).
- [11] Cycle through individuals in frame associated with location. Record information in Qualitative Data. Complete using Dropdown List (examples shown in Figure 1-Figure 3). Not potential to record identity of individual across multiple increments using Alias. **There is no need for this to be converted to a tablet as data can be inserted directly to spreadsheet or to a template representing the spreadsheet.**
- [12] Continue until all individuals associate with location (or selected sample of location) have been recorded.
- [13] Return to [8] and move on to next location.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Time	Groups Present (including more than 1)	Pop Size – Loc G1	Pop Size – Loc G2	Pop Size – Loc G3	Pop Size – Loc G4	Pop Size – Loc G5	Pop Size – Loc G6	Pop Size – Loc G7	Pop Size – Loc G8	Pop Size – Loc G9	Pop Size – Loc Z1	Pop Size – Loc Z2	Pop Size – Loc Z3	Pop Size – Loc Z4	Pop Size – Loc Z5	Pop Size – Loc Z6

Figure 1: General Population Insights

	A	B	C	D	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Time	Area Code	Observer	Person	Group Identity	People	Demographic	Mask	Direction	Status	Action (1)	Modifier (1)	Object (1)	Action (2)	Modifier (2)	Object (2)	Action (3)	Modifier (3)	Object (3)

Figure 2: Individual Data

People	Demographic	Mask	Status	Action	Modifier	Object
Pax	Adult	Correct	Sitting	Speak	Alone	Seat
Staff/Crew	Child	Incorrect	Standing	Touch/Use	Sharing	Luggage
	Elderly	No Mask	Reclined	Eat	Quickly	Face/Mask
			Bending	Drink	Loudly	Document
			Nothing	Read	To Seat	Movement Device
				Watch	Away From	Device/Phone
				Play		Desk
				Cough/Sneeze		Counter
				Face		Ticket Swipe
				Move		Wall
				Move To		
				Move Away From		
				Sleep		
				Deposit		
				Collect		
				Carry		
				Wait		
				Other		

Figure 3: Example dropdown lists.

This approach was then tested. GHD staff recorded people movement during their attendance of 21 large-scale public events held during the pandemic. These government-sanctioned pilot events (including theatrical, sports, music, business events) were held to explore the impact of specific capacity levels and interventions to reduce covid transmission (e.g., mask wearing, social distancing, etc.) on the crowd behaviour and aggregate conditions produced. They were part of the UK government's effort to assess the potential impact of reopening public events upon the spread of covid.

Footage of the 21 events was examined – focusing on locations that approximated gate areas. Video footage from one of the events was deemed suitable. In this instance, suitability was established by finding conditions that approximated the those in the gate area. For instance, the public has access to seating areas, services, and were exposed to scheduled events that they wanted to attend. This led to them waiting, interacting with other seated members of the public, passing through the space and then tidal flows reflecting motivated movements to events. The goal here was not to generate data representative of passenger behaviour at gate areas, but to test a template design to see if it was possible to capture data reflecting key elements of their behaviour and identify enhancements. The assumption made was that the application of the template to this footage provided useful insights into its application to gate footage. A time was selected when the area was busy to maximize the data collection opportunity.

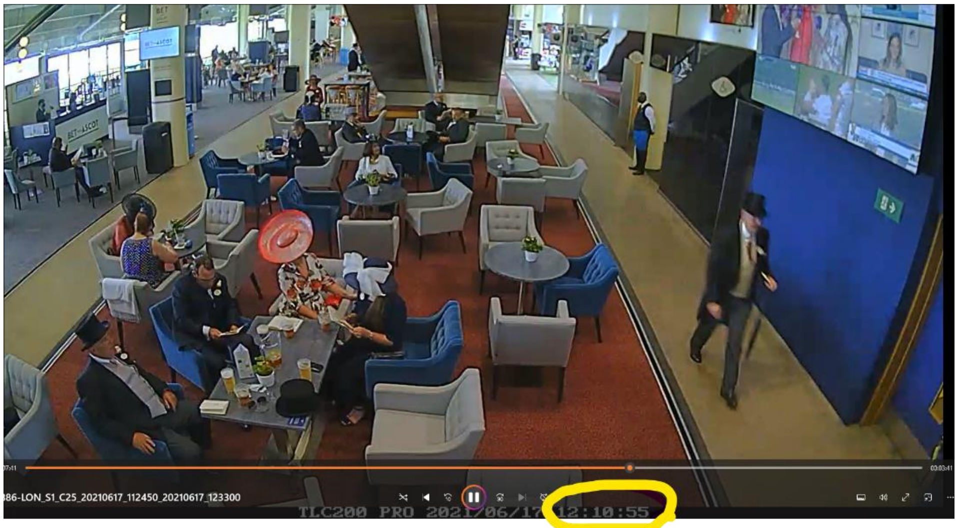


Figure 4: ‘Gate’ location.

The intention was then to capture data from the seated areas and the paths within the yellow lines.

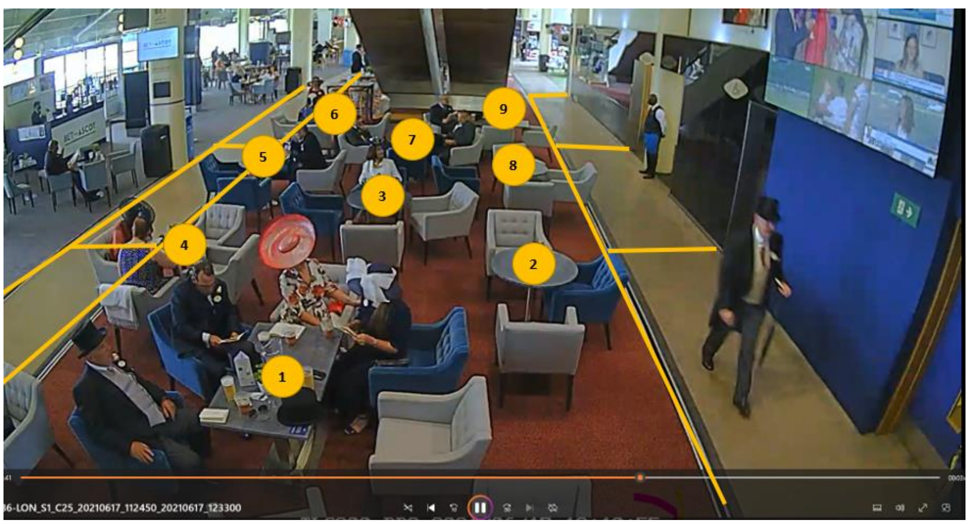


Figure 5: Data collection locations.

Tables were identified and labelled and paths gridded enabling population numbers / densities to be approximated. These are crudely drawn above (see *Figure 5*). The seated areas were also treated as a separate area. In this case you will have nine tables and six standing zones – 15 zones. A 60s time increment was employed given the scale of the video catchment area and the assumed time for an individual to cross the distances shown. As part of the original work, a behavioural dictionary was produced listing a set of actions that were observed in this environment and the associated action definitions – allowing data extraction to reference a consistent baseline reducing inter rater variability.

General observations were made across a selected period of the footage– applicable to each time step examined (time-based):

- Time (12:00, 12:01, etc.)
- Identify # Groups present – for instance, it may be that there are three tables occupied by groups (3 x groups) and a group walking on a path – so your entry would be 4 (Group 1, Group 2, Group 3 and Group 4). You may label the locations and include in the group

name so Group4_03 indicates they are sitting at table 4 at 12:03. This may exclude those alone.
  - Indicate the number of people at each table and in each of the six zones. Basically, the distribution of people across the space. This is critical as it will provide local densities and local distancing.

Footage was then examined at the level of person (person-based). A sub-set of actions and attributes were selected from the original dictionary:

  - For each person in the scene, I want you to record the following:
    - Location (Name of path location / group number indicating table)
    - Mask (correctly, incorrectly, no mask)
    - Status (Standing / Sitting). I am excluding people drunkenly napping on the floor.
    - Action (Walking, Speaking, Eating, Drinking, Touching/Using, Coughing/Sneezing, Other)
      - All – Direction facing:
        - InGroup (facing someone in their own group), OutGroup (facing someone outside of their group), Other (facing away from everyone).
      - If (Action=)Walking
        - (Modifier=) Direction of movement (e.g. G3-G2 or Zone 4 - Zone 5, etc.)
      - If (Action=)speaking:
        - (Modifier=)With InGroup (e.g. someone at their table), OutGroup (e.g. someone not at their table), Device (phone)
      - If (Action=)Eating/Drinking –
        - (Modifier=)Alone (off own plate) or sharing
      - If (Action=)Touching/Using –
        - (Modifier=)Table, Glass, Implement, Other person, Mask, Other

It is apparent that many of these actions and attribute may be relevant to the current work.

We constructed a simple spreadsheet enabling us to capture the data outlined. Two action levels were included allowing motion/action to be represented (e.g., walking and talking). An example record is shown in *Table 1*.

Table 1: Example record of an observed individual.

Person	Loc	Mask	Direction	Status	Action (1)	Modifier (1)	Action (2)	Modifier (2)
G3_26_03	Path3	C	I	Stand	Walk	Path2	Speaking	InGroup

We created an entry for each person in each frame. Operators were asked to develop a method to track individual time-steps. In *Table 1* there is a person at table G3, with ID 26 at time step 03.

Operators also needed to generate a table before they recorded the individual activities documenting grouping (see *Table 2*).

Table 2: Example record of groups present.

Time	Groups Present (including more than 1)	Pop Size – Loc G1 (people at each table)	Pop Size – G2	Pop Size – G2	Etc	Pop Size – Z1 (people in each path zone)	

12:03	4	3	0	1		1	

Data extractors were asked to modify the labelling to enhance the process and the data collected. This was completed for at least 30 time periods. The key objectives here were to:

- Develop a basic spreadsheet design for a data collection method (assuming we are operating from a grid or sectioned visual space) and examining the types of data we might collect.
- Identify lessons learned – in terms of labelling, data recording issues, issues with the observations, developing a data capture spreadsheet. Operators explored ways to better cross-reference via labelling – both in terms of groups/individuals/actions and time.
- Record the time spent on each time interval (the time spent actually reviewing the video and documenting it).
- Generate indicative data output –to show format, etc.

Each operator ended up applying multiple data collection efforts trying out different approaches (spreadsheet designs, labelling types, etc.), documenting what was tried and the outcomes.

This produced a revised set of actions, a visual method of recording groups, basis for development of manual template and iPad app.

Example data output from the analysis is shown in *Table 3*.

Table 3: Example individual data records

Person	Previous Alias?	Previous Alias? (2)	Loc	Mask	Direction	Status	Action (1)	Modifier (1)	Action (2)	Modifier (2)	Action (3)	Modifier (3)
G4_01_00			G4	N	In	Sit	Speak	In	Touch	Device		
G4_02_00			G4	N	In	Sit	Speak	In	Touch	Device		
G5_01_00			G5	N	In	Sit	Speak	In				
G5_02_00			G5	N	In	Sit	Speak	In				
G5_03_00			G5	N	In	Sit	Speak	In				
G6_01_00			G6	N	In	Sit						
G7_01_00			G7	N	In	Sit	Speak	In				
G7_02_00			G7	N	In	Sit	Speak	In				
G9_01_00			G9	N	Out	Stand	Touch	Device				
Z6_01_00			Z6	Y	Other	Stand	Walk	Z6-Z5				
G1_01_01			G1	N	In	Stand	Speak	In	Touch	Bag		
G1_02_01			G1	N	In	Stand	Speak	In	Touch	Bag		
G1_03_01			G1	N	In	Stand	Speak	In				
G1_04_01			G1	N	In	Stand	Speak	In				
G4_01_01			G4	N	In	Sit	Speak	In	Using	Pen		
G4_02_01			G4	N	In	Sit	Speak	In	Using	Booklet		
G5_01_01			G5	N	In	Sit	Speak	In				
G5_02_01			G5	N	In	Sit	Speak	In				
G5_03_01			G5	N	In	Sit	Speak	In				
G6_01_01			G6	N	In	Sit	Touch	Bag				
G7_01_01			G7	N	In	Sit	Speak	In				
G7_02_01			G7	N	In	Sit	Speak	In				
G9_01_01			G9	N	Out	Stand	Touch	Device				
Z3_01_01			Z3	N	Other	Stand	Walk	Z3-G9				
Z4_01_01			Z4	N	In	Stand	Walk	Z4-G1				
Z4_02_01			Z4	N	In	Stand	Walk	Z4-G1				
Z4_03_01			Z4	N	Other	Stand	Walk	Z4-Out				
Z4_04_01			Z4	N	Other	Stand	Walk	Z4-Out				
G1_01_02			G1	N	In	Stand	Speak	In				
G1_02_02			G1	N	In	Sit	Speak	In				

G1_05_02	Z4_02_01		G1	N	In	Sit	Speak	In					
G4_01_02			G4	N	In	Sit	Speak	In	Using	Pen			
G4_02_02			G4	N	In	Sit	Speak	In	Using	Booklet			
G5_01_02			G5	N	In	Sit	Speak	In					
G5_02_02			G5	N	In	Sit	Speak	In					
G5_03_02			G5	N	In	Sit	Speak	In					
G6_01_02			G6	N	In	Sit							
G7_01_02			G7	N	In	Sit	Speak	In					
G7_02_02			G7	N	In	Sit	Speak	In					
G9_01_02			G9	N	Out	Stand	Walk	G9-Z4					
G9_02_02	Z3_01_01		G9	N	Other	Stand	Walk	Z3-G9					
Z6_01_02			Z6	N	Other	Stand	Walk	Z6-Out					
Z6_02_02			Z6	N	Other	Stand	Walk	Z6-Z5					
G1_01_03			G1	N	In	Sit	Speak	In					
G1_02_03			G1	N	In	Sit	Speak	In					
G1_05_03	Z4_02_01		G1	N	In	Sit	Speak	In					
G4_01_03			G4	N	In	Sit	Speak	In	Using	Pen			
G4_02_03			G4	N	In	Sit	Speak	In	Using	Booklet			
G5_01_03			G5	N	In	Sit	Speak	In					
G5_02_03			G5	N	In	Sit	Speak	In					
G5_03_03			G5	N	In	Sit	Speak	In					
G7_01_03			G7	N	In	Sit	Speak	In					
G7_02_03			G7	N	In	Sit	Speak	In					
G9_02_03	Z3_01_01		G9	N	Other	Sit	Using	Device					
Z1_01_03			Z1	N	Other	Stand	Walk	Z1-Z2					
Z1_02_03			Z1	N	Other	Stand	Walk	Z1-Z2					
Z2_01_03			Z2	N	Other	Stand	Walk	Z2-Z1					
Z2_02_03			Z2	N	Other	Stand	Walk	Z2-Z1					
Z2_03_03			Z2	N	Other	Stand	Walk	Z2-Z1					
Z3_01_03	G6_01_03		Z3	N	Other	Stand							
Z3_02_03			Z3	N	Other	Stand	Walk	Z3-Z2					
Z5_01_03			Z5	N	Other	Stand							
Z6_01_03			Z6	N	Other	Stand	Walk	Z6-Z5					
Z6_02_03			Z6	N	Other	Stand	Walk	Z6-Z5					

G1_01_04			G1	N	In	Sit	Speak	In				
G1_02_04			G1	N	In	Sit	Speak	In				
G1_04_04			G1	N	In	Stand	Speak	In				
G1_05_04	Z4_02_01		G1	N	In	Sit	Speak	In				
G4_01_04			G4	N	Other	Sit	Observe	TV				
G4_02_04			G4	N	In	Sit	Using	Book				
G5_03_04			G5	N	In	Sit						
G7_01_04			G7	N	In	Sit	Speak	In				
G7_02_04			G7	N	In	Sit	Speak	In				
G9_02_04	Z3_01_01		G9	N	Other	Sit	Using	Paper				
Z2_01_04	G5_01_03		Z2	N	Other	Stand	Walk	Z2-Z4				
Z2_02_04	G5_02_03		Z2	N	Other	Stand	Walk	Z2-Z4				
Z3_01_04	G6_01_03		Z3	N	Other	Stand						
Z5_01_04			Z5	N	Other	Stand						
Z5_02_04			Z5	N	Other	Stand	Walk	Z5-Z4				
Z6_01_04			Z6	N	Other	Stand	Walk	Z6-Z5				
Z6_02_04			Z6	N	Other	Stand	Walk	Z6-Z5				
Z6_03_04			Z6	N	Other	Stand	Walk	Z6-Z6				
Z6_04_04			Z6	N	Other	Stand	Walk	Z6-Z6				
G1_01_05			G1	N	In	Sit	Speak	In	Touching	Glass	Toasting	
G1_02_05			G1	N	In	Sit	Speak	In	Touching	Glass	Toasting	
G1_03_05			G1	N	In	Sit	Speak	In				
G1_04_05			G1	N	In	Sit	Speak	In				
G1_05_05	Z4_02_01		G1	N	In	Sit	Speak	In				
G1_06_05			G1	N	In	Stand	Speak	In	Touching	Glass	Toasting	
G4_01_05			G4	N	In	Sit	Speak	In				
G4_02_05			G4	N	In	Sit	Speak	In	Using	Booklet		
G5_03_05			G5	N	In	Sit						
G7_01_05			G7	N	In	Sit	Speak	In				
G7_02_05			G7	N	In	Sit	Speak	In				
G9_02_05	Z3_01_01		G9	N	Other	Sit	Using	Paper				
Z3_01_05	G6_01_03		Z3	N	In	Stand	Speak	In				
Z3_02_05			Z3	N	In	Stand	Speak	In				
Z5_01_05			Z5	N	Other	Stand	Walk	Z5-Z4				

Z5_02_05			Z5	N	Other	Stand	Walk	Z5-Z4					
Z5_03_05			Z5	N	Other	Stand	Walk	Z5-Z4					
Z5_03_05			Z5	N	Other	Stand	Walk	Z5-Z4					
G1_01_06			G1	N	Out	Sit	Touching	Bag					
G1_02_06			G1	N	In	Sit	Touching	Booklet					
G1_03_06			G1	N	In	Sit	Speak	In					
G1_04_06			G1	N	In	Sit	Touching	Booklet	Touching	Hat			
G1_05_06	Z4_02_01		G1	N	In	Sit	Touching	Booklet					
G1_06_06			G1	N	In	Sit	Touching	Booklet					
G4_01_06			G4	N	In	Sit	Speak	In	Using	Booklet			
G4_02_06			G4	N	In	Sit	Speak	In	Using	Booklet			
G5_03_06			G5	N	In	Sit	Using	Device					
G7_01_06			G7	N	In	Sit	Speak	In					
G7_02_06			G7	N	In	Sit	Speak	In					
G9_02_06	Z3_01_01		G9	N	Other	Sit	Using	Paper					
Z3_01_06	G6_01_03		Z3	N	In	Stand	Speak	In					
Z3_02_06			Z3	N	In	Stand	Speak	In					
G1_01_07			G1	N	In	Sit	Touching	Booklet					
G1_02_07			G1	N	In	Sit	Touching	Booklet					
G1_03_07			G1	N	In	Sit	Speak	In					
G1_04_07			G1	N	In	Sit	Touching	Booklet	Touching	Hat			
G1_05_07	Z4_02_01		G1	N	In	Sit	Touching	Booklet					
G1_06_07			G1	N	In	Sit	Speak	In					
G4_01_07			G4	N	In	Sit	Speak	In	Using	Booklet			
G4_02_07			G4	N	In	Sit	Speak	In	Using	Booklet			
G7_01_07			G7	N	In	Sit	Speak	In					
G7_02_07			G7	N	In	Sit	Speak	In					
G9_02_07	Z3_01_01		G9	N	Other	Sit	Using	Paper	Using	Device			
Z2_01_07			Z2	N	In	Stand	Walk	Z2-Z3					
Z2_02_07			Z2	N	In	Stand	Walk	Z2-Z3					
Z3_01_07	G6_01_03		Z3	N	In	Stand	Speak	In					
Z3_02_07			Z3	N	In	Stand	Speak	In					
G1_01_08			G1	N	In	Sit	Speak	In	Touching	Booklet	Touching	Eyeglasses	
G1_02_08			G1	N	In	Sit	Speak	In	Touching	Booklet			

G1_03_08			G1	N	In	Sit	Speak	In				
G1_04_08			G1	N	In	Sit	Speak	In	Touching	Booklet		
G1_05_08	Z4_02_01		G1	N	In	Sit	Touching	Device	Touching	Eyeglasses		
G1_06_08			G1	N	In	Sit	Speak	In	Touching	Hat		
G4_01_08			G4	N	In	Sit	Speak	In	Using	Booklet		
G4_02_08			G4	N	In	Sit	Speak	In	Using	Booklet		
G5_03_08	G5_03_06		G5	N	In	Stand						
G7_01_08			G7	N	In	Sit	Speak	In				
G7_02_08			G7	N	In	Sit	Speak	In				
G9_02_08	Z3_01_01		G9	N	Other	Sit	Using	Paper	Using	Device		
Z3_01_08	G6_01_03		Z3	N	In	Stand	Speak	In				
Z3_02_08			Z3	N	In	Stand	Speak	In				
Z3_03_08			Z3	N	In	Stand	Walk	Z3-Z6				
G1_01_09			G1	N	In	Sit	Touching	Booklet				
G1_02_09			G1	N	In	Sit	Using	Device				
G1_03_09			G1	N	In	Sit	Speak	In				
G1_04_09			G1	N	In	Sit	Touching	Booklet				
G1_05_09	Z4_02_01		G1	N	In	Sit	Touching	Device				
G1_06_09			G1	N	In	Sit	Speak	In				
G4_01_09			G4	N	In	Sit	Speak	In	Using	Booklet		
G4_02_09			G4	N	In	Sit	Speak	In	Using	Booklet		
G5_03_09	G5_03_06		G5	N	In	Sit	Using	Device				
G6_01_09	Z3_02_08		G6	N	In	Sit	Speak	In				
G7_01_09			G7	N	In	Sit	Speak	In				
G7_02_09			G7	N	In	Sit	Speak	In				
G9_02_09	Z3_01_01		G9	N	Other	Sit	Using	Paper	Using	Device		
Z3_01_09	G6_01_03		Z3	N	In	Stand	Speak	In				
Z3_03_09			Z3	N	In	Stand	Walk	Z3-Z2				
Z3_04_09			Z3	N	In	Stand	Walk	Z3-Z2				
Z6_01_09			Z6	N	In	Stand	Walk	Z6-Z6				
G1_01_10			G1	N	In	Sit	Touching	Booklet				
G1_02_10			G1	N	In	Sit	Touching	Booklet				
G1_04_10			G1	N	In	Sit	Speak	In	Touching	Booklet		
G1_05_10	Z4_02_01		G1	Y	In	Sit	Speak	In	Touching	Booklet		

G1_06_10			G1	N	In	Sit	Speak	In				
G4_01_10			G4	N	In	Sit	Speak	In	Using	Booklet		
G4_02_10			G4	N	In	Sit	Speak	In	Using	Booklet		
G5_03_10	G5_03_06		G5	N	In	Sit	Using	Device				
G6_01_10	Z3_02_08		G6	N	In	Sit	Speak	In				
G6_02_10	Z3_01_09	G6_01_03	G6	N	In	Stand	Speak	In				
G7_01_10			G7	N	In	Sit	Speak	In				
G7_02_10			G7	N	In	Sit	Speak	In				
G9_02_10	Z3_01_01		G9	N	Other	Sit	Using	Paper				
Z6_01_10			Z6	N	In	Stand	Walk	Z6-Out				
Z6_02_10			Z6	N	In	Stand	Walk	Z6-Out				
G1_01_11			G1	N	Other	Sit	Observe	TV				
G1_02_11			G1	N	In	Sit	Touching	Booklet				
G1_04_11			G1	N	In	Sit	Touching	Booklet				
G1_06_11			G1	N	Other	Sit	Observe	TV				
G3_01_11			G3	N	Other	Sit	Observe	TV				
G4_01_11			G4	N	In	Sit	Speak	In	Using	Booklet		
G4_02_11			G4	N	In	Sit	Speak	In	Using	Booklet		
G5_03_11	G5_03_06		G5	N	In	Sit	Using	Device				
G6_01_11	Z3_02_08		G6	N	In	Sit	Speak	In				
G6_02_11	Z3_01_09	G6_01_03	G6	N	In	Stand	Speak	In				
G7_01_11			G7	N	In	Sit						
G7_02_11			G7	N	In	Sit	Using	Device				
G9_02_11	Z3_01_01		G9	N	Other	Sit	Using	Paper				
Z5_01_11			Z5	N	In	Stand	Walk	Z5-Z4				
G1_01_12			G1	N	In	Sit	Speak	In				
G1_02_12			G1	N	In	Sit	Touching	Booklet				
G1_04_12			G1	N	In	Sit	Speak	In	Touching	Booklet		
G1_06_12			G1	N	In	Sit	Speak	In				
G3_01_12			G3	N	In	Sit	Using	Device				
G4_01_12			G4	N	In	Sit	Speak	In	Using	Booklet		
G4_02_12			G4	N	In	Sit	Speak	In	Using	Booklet		
G5_03_12	G5_03_06		G5	N	In	Sit	Using	Device				
G6_01_12	Z3_02_08		G6	N	In	Sit	Speak	In				

G6_02_12	Z3_01_09	G6_01_03	G6	N	In	Stand	Speak	In					
G7_01_12			G7	N	In	Sit	Using	Device					
G7_02_12			G7	N	Other	Sit							
G9_02_12	Z3_01_01		G9	N	Other	Sit	Using	Device					
Z6_01_12			Z6	Y	In	Stand	Walk	Z6-Z5					
Z6_02_12			Z6	N	In	Stand	Walk	Z6-Out					
Z6_03_12			Z6	N	In	Stand	Walk	Z6-Out					
G1_01_13			G1	N	In	Sit	Speak	In					
G1_02_13			G1	N	In	Sit	Touching	Booklet					
G1_04_13			G1	N	In	Sit	Speak	In	Touching	Booklet			
G1_06_13			G1	N	In	Sit	Speak	In					
G3_01_13			G3	N	In	Sit	Using	Device					
G4_01_13			G4	N	In	Sit	Speak	In	Using	Booklet			
G4_02_13			G4	N	In	Sit	Speak	In	Using	Booklet			
G5_03_13	G5_03_06		G5	N	In	Sit	Using	Device					
G6_01_13	Z3_02_08		G6	N	In	Sit	Speak	In					
G6_02_13	Z3_01_09	G6_01_03	G6	N	In	Stand	Speak	In					
G7_01_13			G7	N	In	Sit	Using	Device					
G7_02_13			G7	N	Other	Sit							
G9_02_13	Z3_01_01		G9	N	Other	Sit	Using	Device					
Z6_01_13			Z6	Y	In	Stand	Walk	Z6-Z5					
Z6_02_13			Z6	N	In	Stand	Walk	Z6-Out					
Z6_03_13			Z6	N	In	Stand	Walk	Z6-Out					
G1_01_14			G1	N	In	Sit	Using	Device					
G1_02_14			G1	N	In	Sit	Speak	In					
G1_04_14			G1	N	In	Sit	Touching	Face					
G1_05_14	G1_05_10	Z4_02_01	G1	Y	In	Stand							
G1_06_14			G1	N	In	Sit	Speak	In					
G3_01_14			G3	N	In	Sit	Using	Device					
G4_01_14			G4	N	In	Sit	Speak	In	Using	Booklet			
G4_02_14			G4	N	In	Sit	Speak	In	Using	Booklet			
G5_03_14	G5_03_06		G5	N	In	Sit	Using	Device					
G7_01_14			G7	N	In	Sit	Using	Device					
G7_02_14			G7	N	Other	Sit							

G9_02_14	Z3_01_01		G9	N	Other	Sit	Using	Device	Touching	Face			
Z1_01_14			Z1	N	In	Stand	Walk	Z1-Out					
Z2_01_14			Z2	N	In	Stand	Walk	Z2-Z1					
Z5_01_14			Z5	N	In	Stand	Walk	Z5-Z4					
Z5_02_14			Z5	N	In	Stand	Walk	Z5-Z4					
Z6_01_14			Z6	N	In	Stand	Walk	Z6-Out					

The time taken to complete analysis of a time increment varied given the size of the space observed, the size of the population present in the sample area, and the complexity of their actions. From the data collected from a similar type of setting (although - to be clear - not at an airport gate), recording individuals and all of their attributes took approximately 1 minute per person (see *Table 4*). This can be used as a baseline for the data collection to be conducted in the airport settings from the video footage available.

Table 4: Completion times for data extraction tasks.

Time interval	Work time (mins)
12:00	19
12:01	17
12:02	21
12:03	18
12:04	18
12:05	15
12:06	14
12:07	16
12:08	18
12:09	16
12:10	22
12:11	19
12:12	18
12:13	17
12:14	21
12:15	
12:16	
12:17	
12:18	
12:19	
12:20	
12:21	
12:22	
12:23	
12:24	
12:25	
12:26	
12:27	
12:28	
12:29	

Total	269
Hours	4.48

Appendix 3C: Phase I Data Analysis

Method Adopted

A sample of the data collected during the Phase I field observations of passenger movement has been examined. The data collection results and the implication for the Phase II field observations are presented in this section. The objective of the Phase I field observations as a pilot study is not to produce a representative data-set for practical use. Instead, it is aimed to identify:

- the types of data that might reasonably be collected through manual observations,
- limitations in the data collection method,
- the limits to what might be expected of observers in the field,
- the gaps that cannot be filled by manual observation, thus informing the requirements of the video and experimental data collection.

The data described in this section represents a fraction of the data actually collected – approximately 10% of the observations during the Phase I manual field observations; however, it represents a range of locations, observers, attributes/action types (i.e., content types), data formats, and data from different levels (e.g., individual, population, aggregate, etc.). As such, it provides an overview of the passenger behavioural data that can be collected through manual observations.

Several analytical tasks have been conducted relating to the observers' ability to extract the data and the data types that might be extracted. These tasks are broadly categorized into Assessment, Method and Results Extracted:

- Assessment: Observer Actions
- Method: Passenger Direction During Flight
- Method: Passenger Status Change
- Method: Passenger Actions
- Results Extracted: Gate - Seating Area (waiting for boarding)
- Results Extracted: Gate - Boarding Analysis
- Results Extracted: Jetway Flow Analysis
- Results Extracted: Inflight Analysis
- Results Extracted: Mapping and Narrative Data

Assessment: Observer Actions

The purpose of the data collection is to identify certain passenger actions that may affect their respiration levels (i.e., minute ventilation) and to estimate the duration of these actions. There are two methods of data collection, manual and video observations. Manual observations require several carefully positioned observers (seated along with passengers) to monitor the passengers and manually record their actions using formatted template. Video observation utilizes automated action extraction from video footage recorded from the CCTV cameras positioned to monitor the passenger areas in the terminal. While video analysis can continuously monitor the situation, its accuracy is sensitive to the environmental conditions, and has additional restrictions regarding confidentiality and anonymity (e.g., there will be no camera coverage on flight). Manual observations can produce relatively quick results and ensure anonymity in the data collected, but it also has limitations. Although some time discretization will be required in either manual or automated data extraction, the former is particularly sensitive to the selected time step. The interval between observations, i.e., the frequency of sampling, can have an impact on the accuracy of the estimation of the duration. The accuracy is also influenced by the characteristics of the actions: the typical duration and occurrence of different actions. In general, a higher sampling frequency provides more accurate estimates of the duration as it reduces the likelihood of missing events and provides more data points for analysis. However, there are practical constraints that cap the sampling frequency. These include the limited number of observers, the number of passengers observed, the necessary time to take note, the level of attentiveness and the restricted view of the observers. As such, there is a trade-off between time-step and sample size.

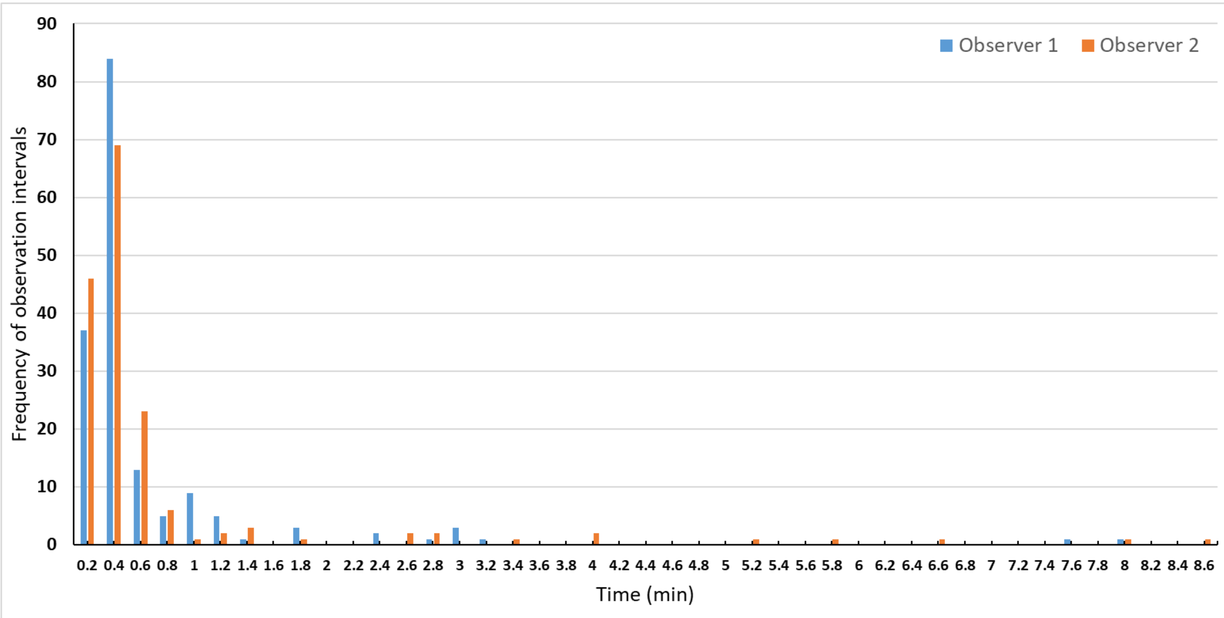


Figure 1. The frequency distribution of the onboard manual observation intervals.

The frequency of observation is analysed for the pilot manual observation conducted on the flight from Airport#1 to Airport#2 on the 3rd of May 2023. Two observers were sitting in the aircraft and monitored 17 passengers around them. Observer 1 made 167 observations on nine passengers in 93.12 minutes and Observer 2 made 164 observations on eight passengers in 105.57 minutes. Table 1 shows the statistics of the two sets of observation intervals and Figure 1 shows the frequency distributions of the observation intervals. Most observations were made by the two observers with an interval between 0.2 and 0.4 minutes and the two frequency distributions are largely similar to each other. **Therefore, 2.5 to 5 observations per minute was the observed frequency seen onboard during the pilot study.** This frequency might be used as a benchmark for the planned manual observations in Phase II of the work.

Table 1. The duration of the two observers' observation intervals.

Observer	Number of observations made	Min/Max (min) of observation interval	Mean ± STD (min) of observation interval
1	167 observations on 9 passengers	0.12/7.93	0.56 ± 0.97
2	164 observations on 8 passengers	0.05/8.40	0.65 ± 1.27

The frequency of observation is also compared with the frequency of major actions observed onboard to decide whether the method is sufficient for observing the number of passengers and capturing their actions. Table 2 lists the total number of each of the five major actions, the greatest number of actions from any individual during the flight, and the average interval of observing such an action from that person. The greatest number of actions from any individual during the flight is 11, and the shortest average interval of observing such an action from that person is 8.2 minutes. Note that since the two observers monitored multiple passengers, each of the 17 passengers were observed 19.2 times on average with a mean interval of 4.94 minutes. Apparently, the interval of observations is much shorter than the average interval of the most frequent action demonstrated by any of the 17 passengers. The observers were also focusing on capturing the start-end of action to enhance the fidelity of the observations of passenger actions. This shows that the arrangement of the manual observations (17 passengers monitored by 2 observers with a frequency of 2.5 to 5 observations per minute) is broadly sufficient to capture the most frequent actions demonstrated by the passengers during the flight in the pilot study.

Table 2. The number of five major actions overserved onboard and the average interval of observing such an action.

	Change of facing direction	Standing	Speaking	Touching	Using
Total number of actions	70	5	10	58	27
The greatest number of actions from any individual	11	2	3	11	11
Average interval of observing such an action from the person with the most observed actions (min)	8.2	45.3	30.4	9.5	9.4

Key findings:

- A frequency of 2.5 to 5 observations per minute per observer (an interval between 0.2 and 0.4 minutes) was used during the onboard manual observations in the pilot study.
- The arrangement of the onboard manual observations (17 passengers monitored by 2 observers with the frequency of 2.5 to 5 observations per minute per observer) is sufficient to capture the most frequent actions demonstrated by the passengers during the flight.

Method: Passenger Direction During Flight

In this section, the method for assessing the change of passenger direction during the flight from the observational data is introduced, including the analysis for both the frequency of change and the duration of facing a particular direction. A set of assumptions were made to extract data related to the direction passengers faced while on board:

- Direction is recorded at 90-degree level of accuracy: **up**, **left**, **right** and **down**.
- Every passenger has a direction that they typically face during the period examined. This is deemed to be **up** (i.e., facing forward when seated). This assumption allows the absolute direction to be established and the changes in relation to the normal position to be recorded.
- Other possible facing directions exist – **left, right and down**.
- It is assumed that the passenger remains facing the same direction recorded in the previous time-step until a new direction is noted.

The number of changes in passenger direction observed during the flight is identified and recorded, including the last change back to the prevalent direction, i.e., the normal position. This allows a narrative of direction change to be established, but it can also be compared against other activities (e.g., food service).

An example sequence of one passenger's facing direction observed during the flight is shown in Table 3. There are five changes in facing direction recorded from the series of observations.

Table 3. An example sequence of one passenger's facing direction observed during the flight.

Observation	1	2	3	4	5	6	7	8	9	10

Time of observation	06:50:18	06:55:40	06:59:07	**06:59:56**	07:03:35	07:09:50	**07:13:37**	07:18:01	**07:23:28**	**07:28:45**
Direction	Up	Up	Up	Right	Left	Left	Up	Up	Left	Up
Change of direction	-	-	-	**Yes**	**Yes**	-	**Yes**	-	**Yes**	**Yes**

It is possible to record the number of times someone changes direction from the assumed norm. The probability of observing the person facing a direction other than the normal position can be estimated from the example sequence as follows:

$$Probability\ of\ facing\ other\ direction = \frac{Number\ of\ facing\ other\ direction\ observed}{Number\ of\ observations} \times 100\%$$

For instance, four direction changes (1 right and 3 left directions) are recorded from the series of observations on one passenger in Table 3, and the probability of facing other direction from this sequence of observations is 40%.

The time spent in a specific direction can be added up to estimate the ratio of people facing other direction than the norm as follows:

$$Ratio\ of\ facing\ other\ direction = \frac{Cumulated\ period\ of\ facing\ different\ direction\ oberved}{The\ entire\ observation\ period} \times 100\%$$

Each period is counted from the first observed deviation until the next direction change back to the norm. For instance, there are two such periods in the example shown in Table 3, a duration of 13.7 minutes between Observations 4 and 7, and a duration of 5.3 minutes between Observations 9 and 10. The ratio of the person facing other direction than the norm is 49.3% during the observation period of 38.5 minutes. These measures might be represented on an individual, a type of person, by dyad, or across the population.

It is possible for inaccuracies in the duration times (e.g., an observation made after a passenger had already changed direction) and the frequencies (e.g., direction changes missed). However, it is not expected that these errors will bias the results in a particular direction.

Method: Passenger Status Change

In this section, the method for assessing the change of passenger seated status during the flight from the observational data is introduced, including the analysis for both the frequency of change and the duration of remaining in a particular status. A set of assumptions were made in order to extract data related to the passenger status change (i.e., standing / sitting) while on board:

- Every passenger has a prevalent seated status – **Sitting**.
- Other possible status – **Standing**.
- Upon an observed change of status, it is assumed that the passenger remains the same status recorded from previous observation.
- The observer notes when there is a change in status.

The number of seated status changes observed per passenger during the flight is recorded. For instance, ten observations (two standing and eight sitting) were recorded from the series of passenger observations shown in Table 4. This allows the duration spent in any status, the probability of changing, etc. and allows this to be related to external events.

$$Probability\ of\ standing = \frac{Number\ of\ standing\ observed}{Number\ of\ observations} \times 100\%$$

Table 4. An example sequence of one passenger's seated status observed during the flight.

Observation	1	2	3	4	5	6	7	8	9	10
Time of observation	06:26:29	**06:27:48**	**06:47:18**	06:50:18	06:55:40	06:59:07	**06:59:56**	**07:03:35**	07:09:50	07:13:37
Seated status	Sitting	**Standing**	Sitting	Sitting	Sitting	Sitting	**Standing**	Sitting	Sitting	Sitting

The observed durations of a passenger remaining in a seated/standing status can be summed. Each period is counted from the first change of observed status till the moment when the status was changed again. For instance, there are two periods of standing in the example shown in Table 4, between Observations 2 and 3, and between Observations 7 and 8.

$$Ratio\ of\ standing = \frac{Cumulated\ period\ of\ standing\ observed}{The\ entire\ observation\ period} \times 100\%$$

Method: Passenger Actions

Example passenger actions will be described to demonstrate the method of extracting passenger actions.

We focus on observed talking, touching or using an object actions. The probability of observing the corresponding action and the duration of each occurrence of the action can be estimated.

$$Probability\ of\ speaking = \frac{Number\ of\ speaking\ observed}{Number\ of\ observations} \times 100\%$$

$$Ratio\ of\ spreaking = \frac{Cumulated\ period\ of\ speaking\ observed}{Entire\ observation\ period} \times 100\%$$

$$Probability\ of\ touching/using = \frac{Number\ of\ touching/using\ observed}{Number\ of\ observations} \times 100\%$$

$$Ratio\ of\ touching/using = \frac{Cumulated\ period\ of\ touching/using\ observed}{Entire\ observation\ period} \times 100\%$$

Results Extracted

Data analysis has been conducted for the observational data collected during the FAA Phase 1 pilot study. The data sets include the observations made on the passengers waiting for boarding, boarding/deplaning, and inflight (see Table 5). Results are introduced below.

Table 5. the original source of data and index of analysis conducted on the data.

Date	**Observer**	**Location / Process**	**Data source file**
01-05	AHS	Seating area (Gate 5) /waiting for boarding	Test_2023-5-1_12_9_21.txt
03-05	AHS	Seating area (Gate 28) / waiting for boarding	Test_2023-5-3_5_30_17.txt
03-05	SH	Gate/ Boarding	Test_2023-5-3_5_50_21.txt
		Jetway / Boarding and deplaning	

03-05	SG, AHS	Inflight	Test_2023-5-3_7_57_5.txt (Seat9A) Test_2023-5-3_XXXXXX.txt (Seat10E)

Results Extracted: Gate - Seating Area (waiting for boarding)

In this section, the behaviour of the passengers waiting for boarding in a selected seating area is analyzed (see Figure 2).

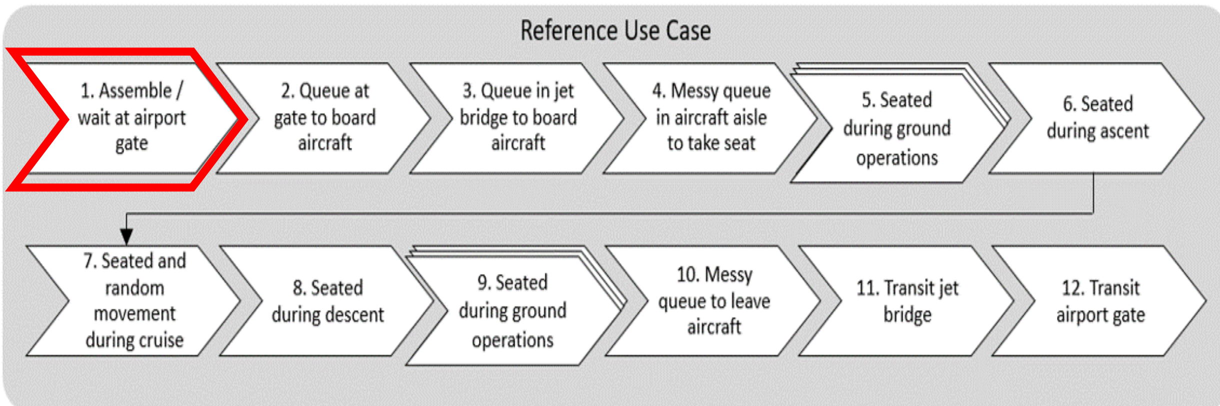


Figure 2: Phase of Passenger Experience examined.

The insights include:

- **Grouping**: Passenger group formations (number of groups, the number of passengers in each group).
- **Seating**: Seat occupation.
- **Actions**: Actions passengers performed and how grouping/seating related to these actions.

The sample seating area for people waiting for boarding consists of four groups of six seats in two rows – 24 seats in total (see Figure 3). These seats are number from 1A to 1L in the first row and 2A to 2L in the second row.

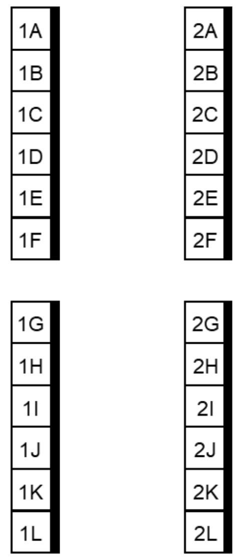


Figure 3. Seat plan of the observed waiting area for passengers waiting for boarding.

A seating plan or gridded location is required in order for these assessments to take place. The seating schematic was identified during a pre-observation visit allowing data to be assigned to a pre-determined location. Manual observation data was collected on 1st and 3rd of May 2023 from this area. The results are presented in the following sections.

Observations of passenger behaviour in the seating area (before boarding) were made on 01/05/2023 from 11:53:42 to 12:09:21 for a duration of 15.7 minutes. In total, 51 observations were made of 12 people in the seating area. Of the 12 people, there is one group of two people and ten individuals. All 12 passengers were adults.

Table 6. Passenger grouping in seating area.

Group	**Number of people**	**Adult**	**Child**
Group A	2	2	0
Individuals	10	10	0
Total	12	12	0

Of the 24 seats, 10 (41.7%) were occupied and 14 (58.3%) were empty (see Table 7). All 12 people, including the single group, consisting of two people, were sitting in the first row (one changed seat from 1J to 1H).

Table 7. Occupied and empty seats during the observation.

1A	Y	**2A**	
1B		**2B**	
1C	Y	**2C**	
1D	Y	**2D**	
1E	Y	**2E**	
1F	Y	**2F**	
1G		**2G**	
1H	Y	**2H**	
1I	Y	**2I**	
1J	Y	**2J**	

1K	Y	**2K**	
1L	Y	**2L**	

Figure 4 and Figure 5 show the frequency and percentage of different actions from the 51 observations. The most frequent action was “Use/touch phone”, which accounts for 52.9% (27) of all observations, followed by “No action” (13.7% or 7), “Touch luggage” (9.8% or 5) and “Speaking to passenger” (7.8% or 4). The four “Speak to passenger” actions occurred between the two group members and two individuals. The other individuals did not have any actions that interacted with any other passengers.

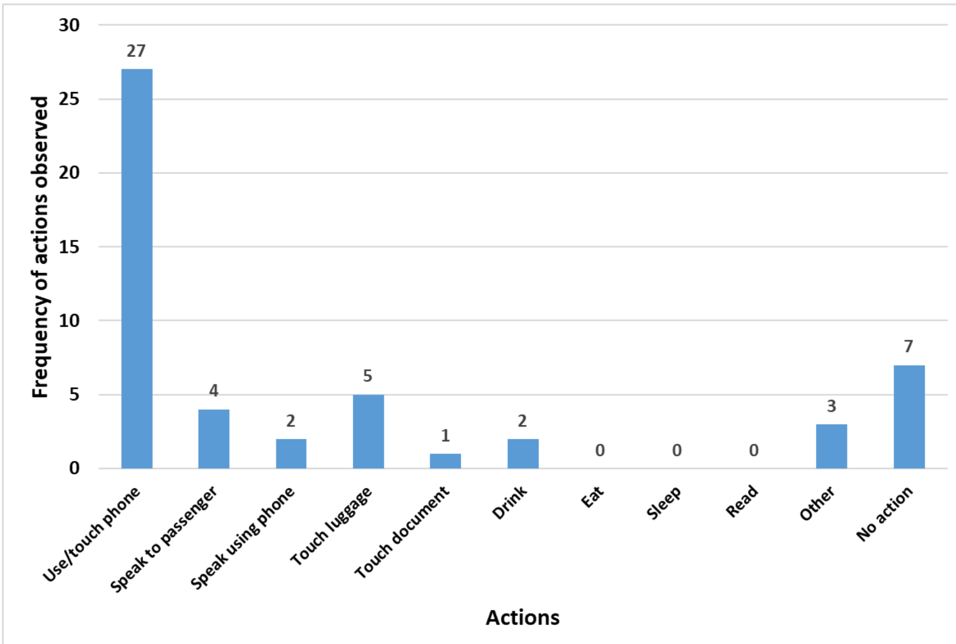


Figure 4. Frequency of actions observed in the waiting area (01 May 2023).

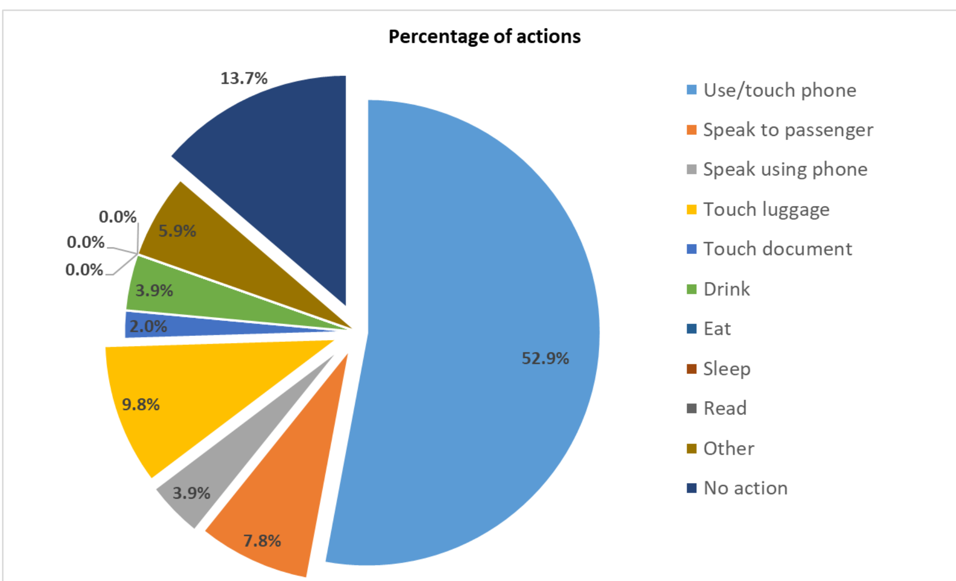


Figure 5. Percentage of actions observed in the waiting area (01 May 2023).

Passenger behaviour in seating area before boarding: The observations were made on 03/05/2023 from 05:18:03 to 05:30:17 for a duration of 12.2 minutes. In total, 32 observations were made on 16 people. Of the 16 people, there are four groups of people (ten passengers were observed to be in one of four groups) and six individuals (deemed not to be in a group). Two groups of people included one or two children, and the other two groups consisted of adults. All six individual passengers were adults (see Table 8).

Table 8. Passenger groups in seating area.

Group	Number of people	Adult	Child
Group A	2	2	0
Group B	3	2	1
Group C	3	1	2
Group D	2	2	0
Individuals	6	6	0
Total	16	13	3

Of the 24 seats, 14 (58.3%) were occupied and 10 (41.5%) were empty (see Table 9). Of the four groups of people, three were seated together and one group of two people were seated one seat apart. Of the six individuals, four were seated at least one seat apart from other people, and two were seated next to other people. There were a few people (all children) changing seats during the observation.

Table 9. Occupied and empty seats during the observation.

1A		**2A**	
1B	Y	**2B**	
1C	Y	**2C**	Y
1D	Y	**2D**	
1E	Y	**2E**	Y
1F		**2F**	Y

1G		**2G**	
1H	Y	**2H**	Y
1I		**2I**	Y
1J	Y	**2J**	
1K		**2K**	Y
1L	Y	**2L**	Y

Figure 6 and Figure 7 present the frequency and percentage of different actions from the 32 observations. As before, the most frequent action was “Use/touch phone”, which accounts for 34.4% (11) of all observations. However, since there were more people in groups during the current observation, the second most frequent action was “Speak to passenger” (25.0% or 8). All eight “Speak to passenger” actions occurred between group members – people in groups appeared more likely to talk to each other (8) than to use a phone (6). All six individuals did not have any actions that interacted with any other people.

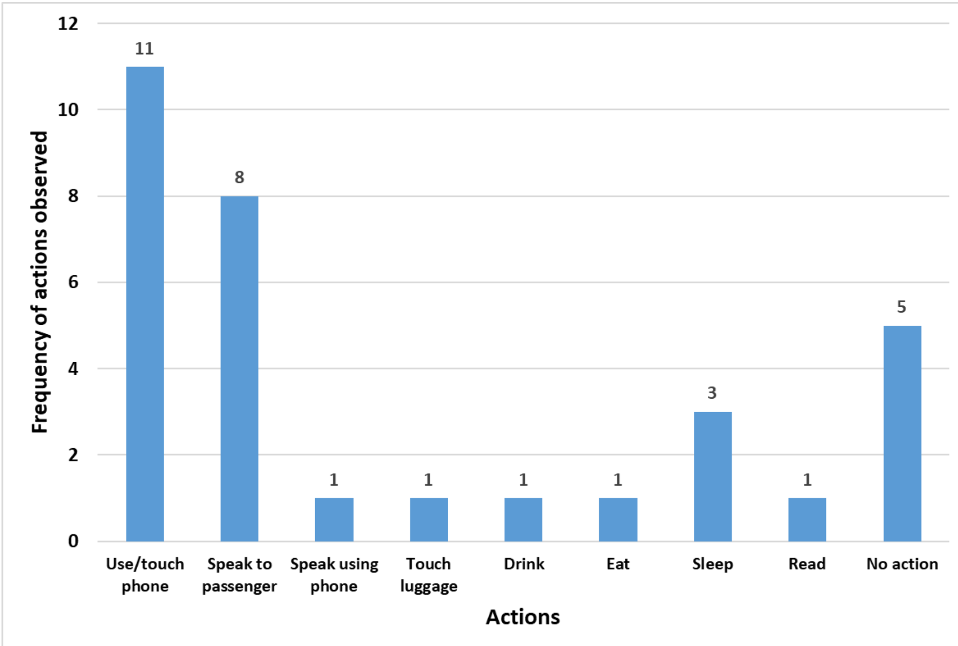


Figure 6. Frequency of actions observed in the waiting area (03 May 2023).

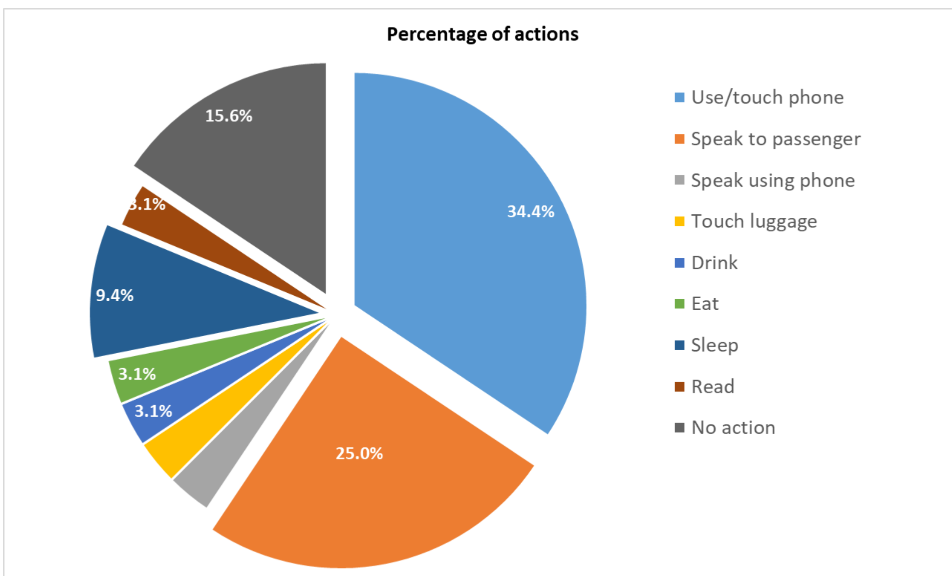


Figure 7. Percentage of actions observed in the waiting area (03 May 2023).

The key insights obtained through the two manual observations on the seating area include:

- It was possible to extract data from observations made on different days. These observations were able to take into account group affiliation, action type, objects affected.
- **Grouping**: Passengers may form small groups of two to three people. Where there are more than two people in a group, the likelihood increases of these additional passengers being children.
- **Seating**: Passengers in a group tend to sit together. In the first observation on 1st May, individuals clustered in the front row of seats, while in the second observation on 3rd May, individuals scattered in two rows of seats.

- **Actions**: The most frequent action observed was "Use/touch phone" (later referred to as 'Use/Touch Mobile_Device'), among all passengers (34.4% - 52.9%). However, passengers in a group tend to talk to each other more than to use phone. Individual passengers seldom interact with other passengers.

Results Extracted: Gate - Boarding Analysis

The observations of the boarding queue are presented below (see Figure 8).

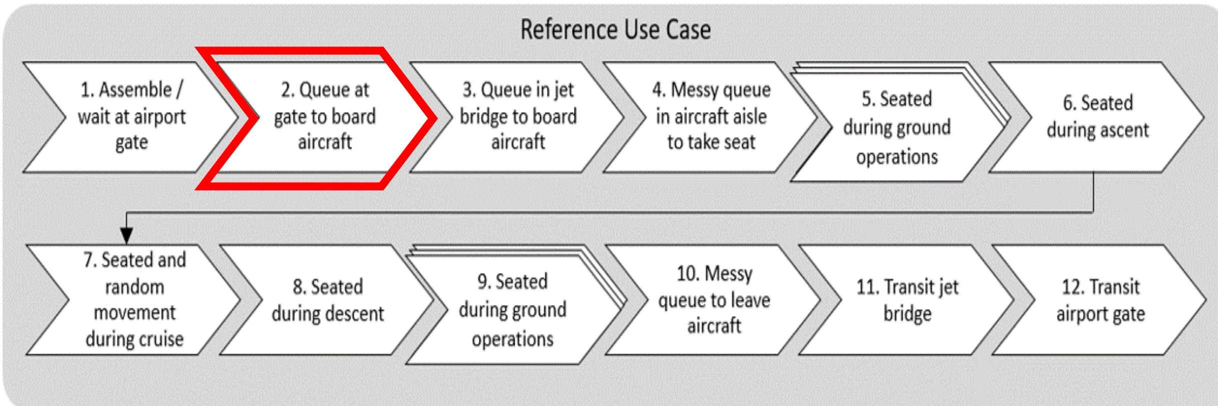


Figure 8: Phase of Passenger Experience examined.

There are a total of 48 observations made for the boarding queue at Counter A on the 3rd May. The first observation was made at 05:23:45 (t_S), and the last at 05:50:21 (t_e) – a total duration of 26.6 minutes. The observations were split into two periods: a pre-boarding period and the actual boarding period. The pre-boarding period includes nine observations from 05:23:45 to 05:28:39. As no group had been called, lower demand was observed, producing short queues of up to six people. The actual boarding period includes 39 observations from 05:36:32 (t_c) to 05:50:21 (t_e), producing queues of up to 29 people. Each of the 39 observations was made when the person at the front of the queue completed their boarding process and left the queue. Both the queue length and the processing time for the 38 people (*N=38*) at the desk were recorded. Note the boarding time of the last person was not recorded as the observation ended at the queue length of one at the end of the boarding process.

Assuming all the 38 passengers joined the boarding queue at t_c and the boarding time forms a normal distribution, in theory the total waiting time of the passenger population is

$$T_{q1} = \frac{N \times (t_e - t_c)}{2} = \frac{38 \times 13.82}{2} = 262.52\ (minutes),$$

i.e., the area of the triangle area ABC (see Figure 9). Given that some passengers may not join the queue from the beginning of boarding, the actual total waiting time can be estimated by

$$T_{q2} = \sum_{i=1}^{N=38} (t_{i+1} - t_i) \times \frac{Q_{i+1} - Q_i}{2} = 261.10\ (minutes),$$

where t_i is the observation time and Q_i is the length of the queue observed at t_i. The total waiting times estimated by the two methods are almost equal and this is supported by visual examination, i.e., the data points of the observed queue length fall along line AC (i.e., most of the passengers started queuing from the beginning of check-in at t_c). The average waiting time (including check-in time) is estimated to be 261.10/38=6.87 (minutes).

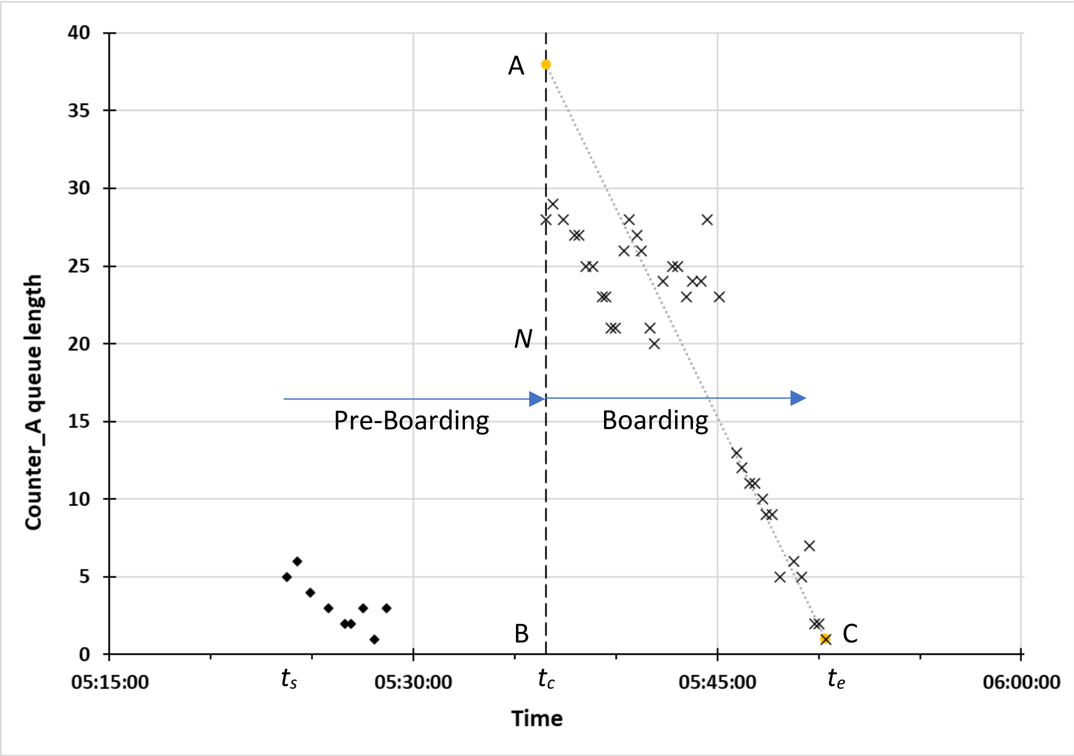


Figure 9. Queue length observed at Counter A during check-in.

The touch and use actions of **the person at the front of the queue** during the boarding process are also analyzed. Table 10 shows the frequency and duration of people touching/using one of three common objects during boarding: luggage, document, mobile device. Most people (48.7% or 19) held their mobile device, followed by holding nothing (30.8% or 12) and holding a document (20.5% or 8). While most people (51.3% or 20) did not use any objects, followed by using document (38.5% or 15) and mobile device (10.3% or 4). Luggage was hardly touched or used during check-in. The duration of holding or using an object or no object is about the same.

Table 10. The frequency and time of touching and using an object during passenger check-in process.

Object	**Touch**		**Use**	
	Frequency	**Time (s)**	**Frequency**	**Time (s)**
Luggage	0 (0%)	-	0 (0%)	-
Document	8 (20.5%)	24.8 ± 4.6	15 (38.5%)	21.5 ± 11.3
Mobile device	**19 (48.7%)**	21.0 ± 10.6	4 (10.3%)	22.5 ± 0.9
None	12 (30.8%)	21.1 ± 7.1	**20 (51.3%)**	21.9 ± 7.1
All	39 (100%)	21.8 ± 8.7	39 (100%)	21.8 ± 8.7

The queue analysis therefore produces two key metrics - (each of which can be interrogated according to a number of factors and levels (see Table 11): queue time (for individual or for the population) and process time (by touch actions at the counter, etc.).

Table 11. Passenger boarding process time and queue time.

Metrics	**Min / Max (Unit)**	**Mean ± STD (Unit)**
Passenger boarding queue time	0.35 / 13.82 (min)	6.87 (min)
Passenger boarding process time	0.17 / 0.88 (min)	0.36 ± 0.15 (min)

	10.0 / 53.0 (sec)	21.8 ± 8.7 (sec)

Results Extracted: Jetway Flow Analysis

The flow rates of both boarding and deplaning on the jetway were analysed from the five datasets collected (see Figure 10).

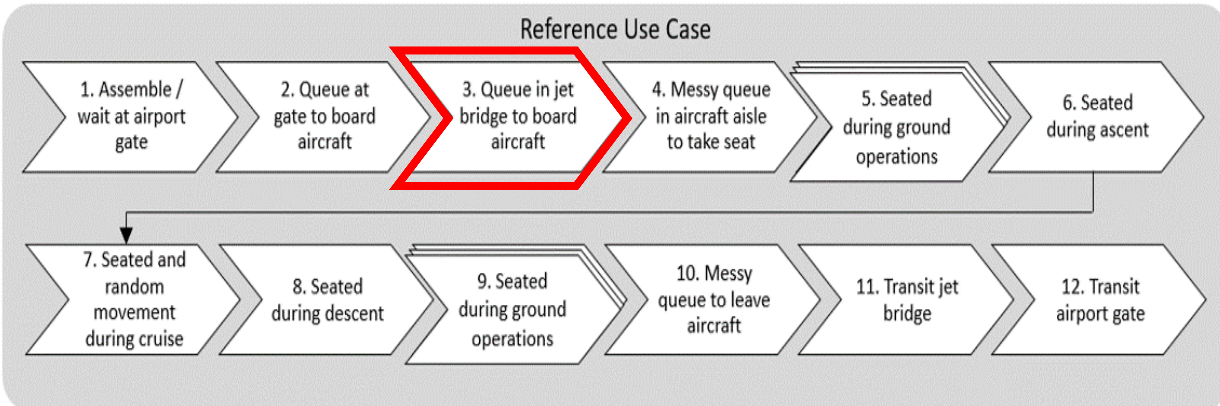


Figure 10: Phase of Passenger Experience examined.

Data was extracted representing the flow rates of passengers as they passed the observer who was located at the aircraft door (see Table 12); however, he carefully positioned himself such that he did not distract or hinder passenger movement or luggage access (to the extent that no passenger delayed their movement or approached the observer).

Table 12. Flow rate analysis of the data collected from five flights.

Date	Type & location	Duration (min)	No. of Pax	Flow rate pers/min)	Figure
01 May	Boarding to Airport#2	17.83	109	6.1	Figure 11
01 May	Deplaning in Airport#1	7.98	93	11.7	Figure 12
03 May	Boarding to Airport#1	1.75	16 *	9.1	Figure 13
03 May	Boarding to Airport#2	18.02	99 **	5.5	Figure 14
03 May	Deplaning in Airport#1	12.05	79	6.6	Figure 15
03 May	Deplaning in Airport#2	4.26	51	12.0	Figure 16

* There were 149 passengers on this flight, but only 16 were recorded during boarding.
** About 10 passengers had already boarded before the manual observation started.

To generalize the estimate, the boarding and deplaning flow rates are weighted by the number of passengers on each of the flights observed:

$$Weighted\ flow\ rate = \sum_i \frac{Pax_i}{\sum Pax_i} * \frac{Pax_i}{D_i}$$

Pax_i – The number of passengers boarding or deplaning on the i^{th} flight observed.

D_i – The duration of boarding or deplaning of the i^{th} flight observed.

The weighted results are presented in Table 13. The arrival curves produced for the six aircraft boarding and deplaning activities are shown in Figure 11 - Figure 16.

Table 13. The weighted flow rates and range during boarding and deplaning.

	Flow rate (pers/min)		
	Weighted average	Min	Max
Boarding	6.1	5.5	9.1
Deplaning	9.9	6.6	12.0

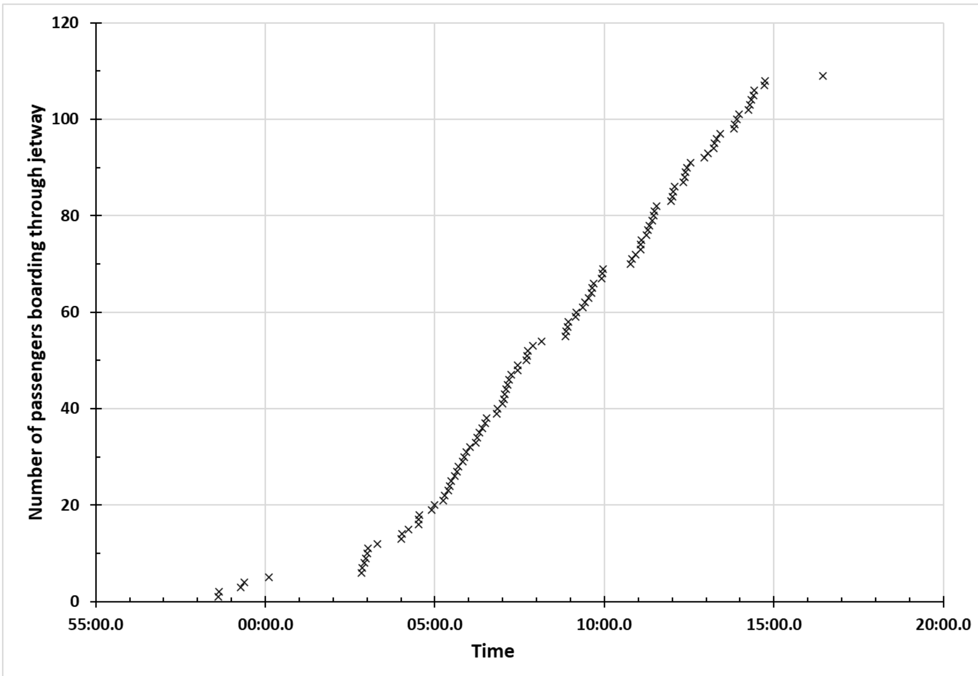


Figure 11. 1/5/23 Boarding to Aiport#2.

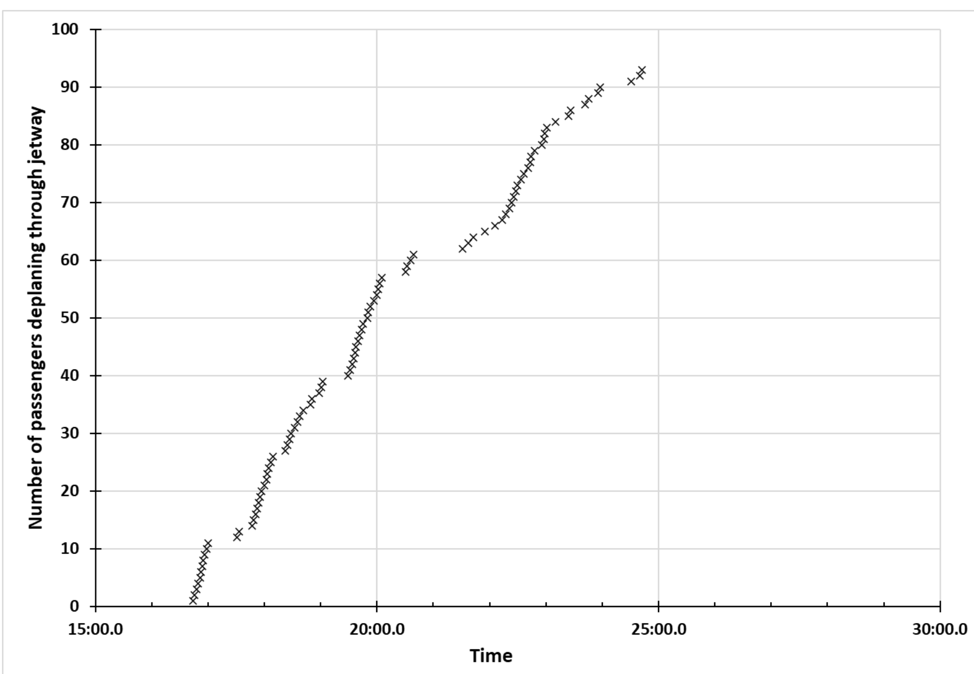


Figure 12. 1/5/23 Deplaning in Airport#1.

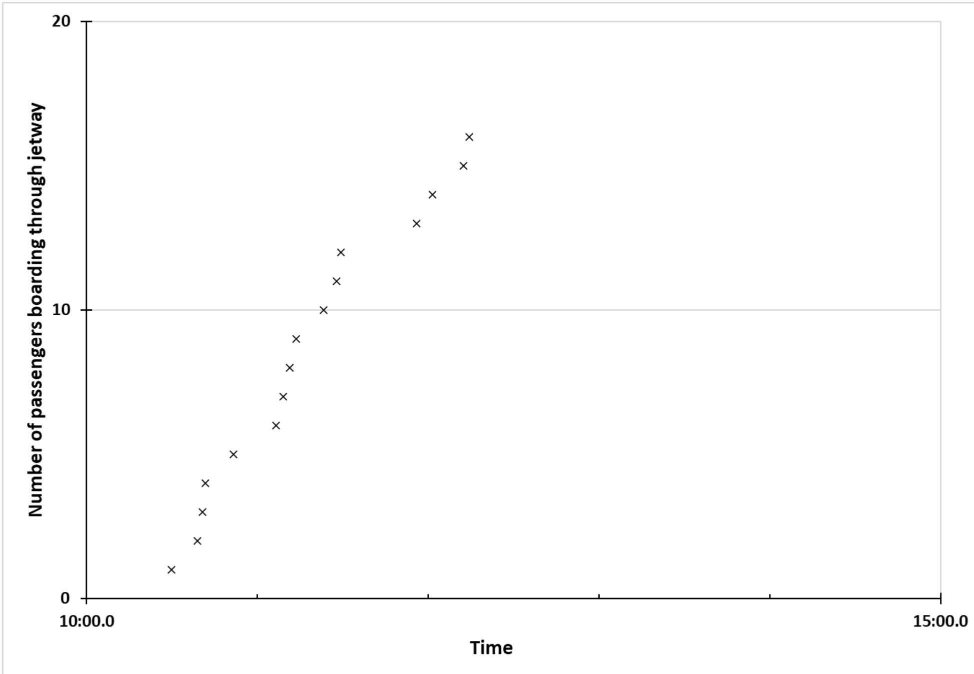


Figure 13. 3/5/23 Boarding to Airport#1.

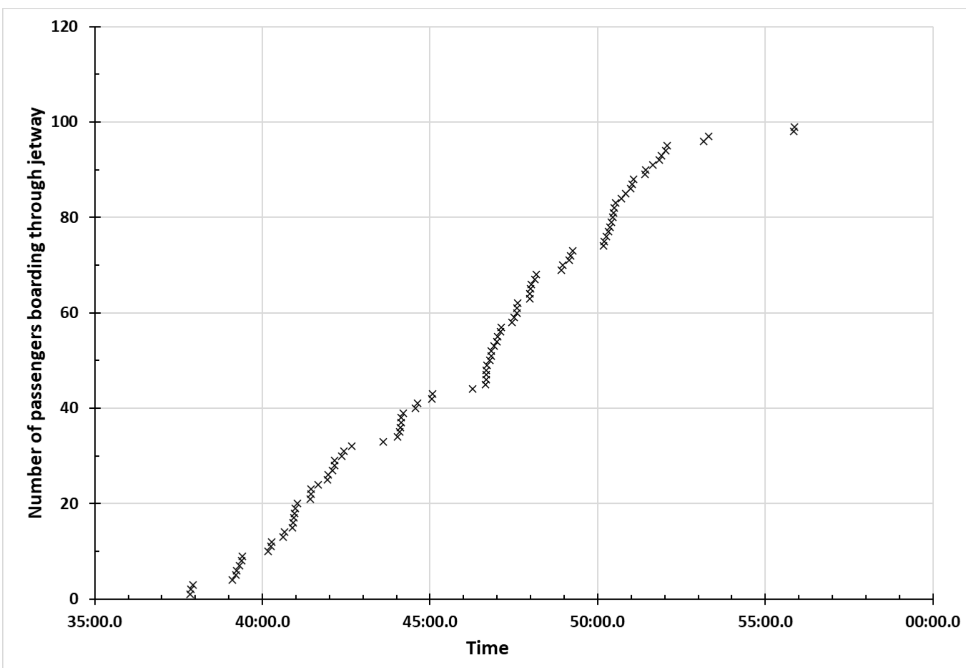


Figure 14. 3/5/23 Boarding to Airport#2.

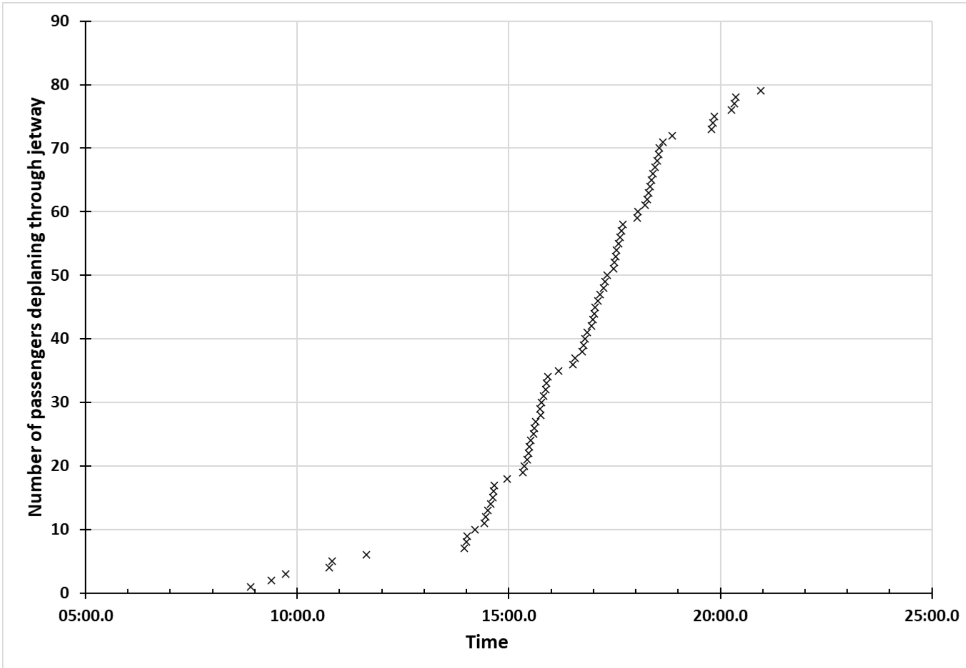


Figure 15. 3/5/23 Deplaning in Airport#1.

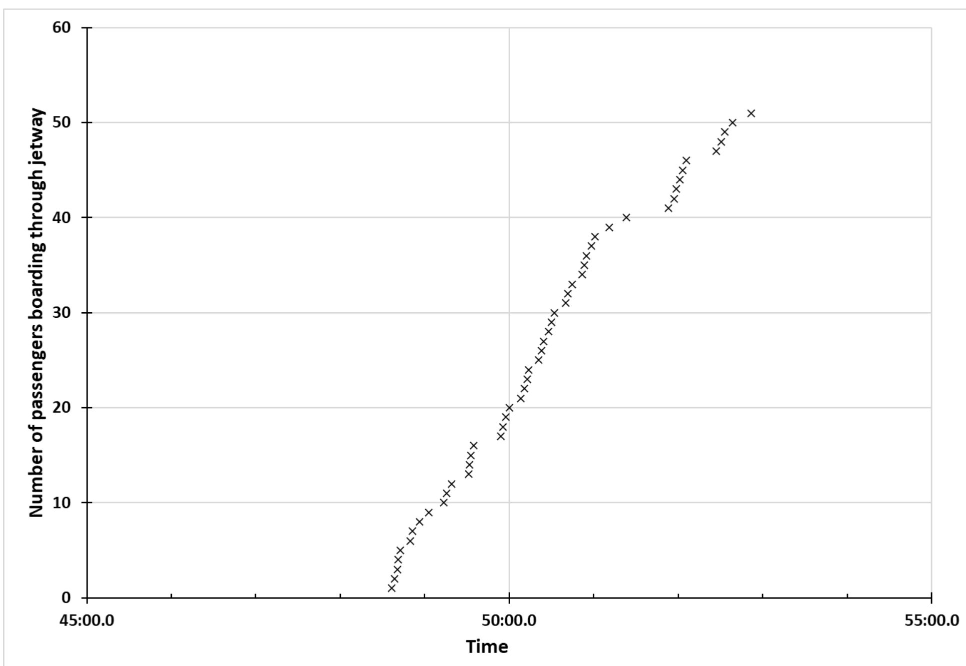


Figure 16. 3/5/23 Deplaning in Airport#2.

Results Extracted: Inflight Analysis

The actions and status of 17 passengers were observed by two observers on a flight from Airport#1 to Airport#2 on the 3rd May 2023. There are 326 observations made on these passengers for an average observation period of 95 minutes. Each passenger was observed 19 times on average with a mean interval of 5 minutes between noted changes. Two example data-sets are derived: direction faced and seating status.

Of the 17 passengers in the sample, four (23.5%) made no change in facing direction, the other 13 (76.5%) passengers made between 1 to 11 changes during the observation period. **On average, each passenger made 4.1 changes of direction during the flight, or 0.65 changes of direction per 15 minutes.** Figure 17 displays the cumulative changes of direction during the observation period, while Figure 18 displays the number of changes recorded along the timeline.

Of the 326 observations, the probability of the 17 passengers being observed facing a direction other than the default direction is **18.3%**, and the ratio of the duration of them facing a direction other than the default direction to the whole observation period is **17.9%**.

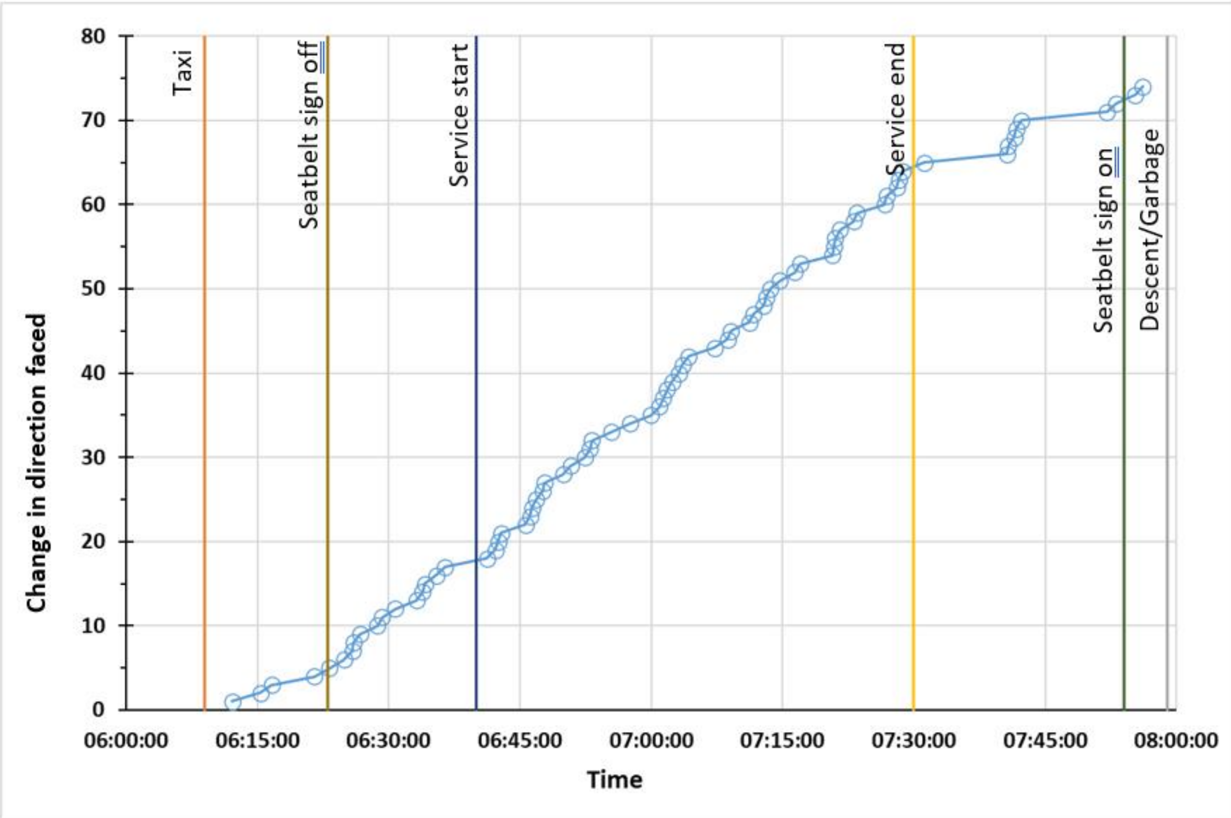


Figure 17. Cumulated change of direction faced during the flight from Airport#1 to Airport#2.

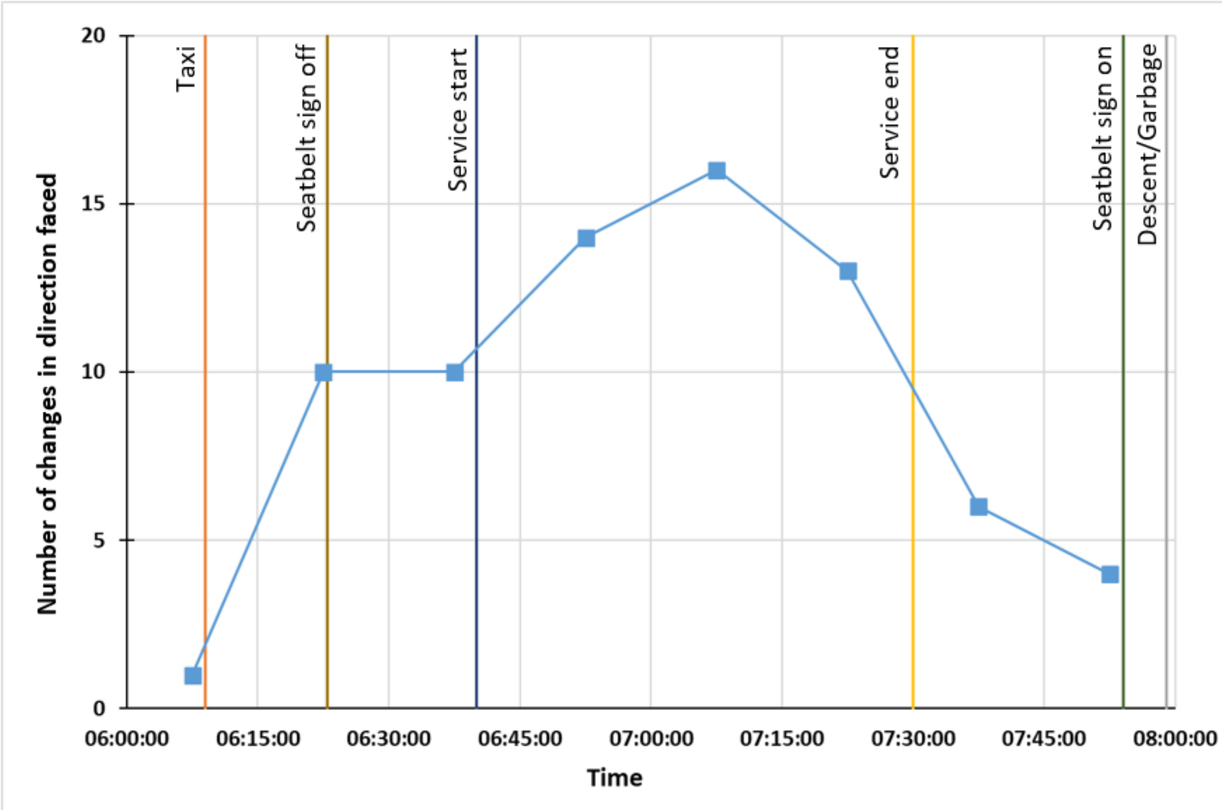


Figure 18. Number of changes in direction faced during the flight from Airport#1 to Airport#2.

Of the 326 observations made, the probability of the 17 passengers being seen standing is **1.4%**, and the ratio of the duration of them standing to the whole observation period is **2.4%**. **Note: only 3 (17.6%) passengers were observed standing - either once or twice during the observation period**, the other 14 (82.4%) remained seated during the whole observation period. This may have been related to the timing of the flight; however, of more interest is the potential for capturing such information rather than the results produced here.

Table 14 also includes a summary of some of the observed passenger actions discussed above.

Table 14. Key insights on the flight from Airport#1 to Airport#2 on the 3rd of May 2023.

Metrics	Insights	Min / Max (Unit)	Mean ± STD (Unit)	Probability or ratio
Direction Faced	Number of changes in direction made by individuals during the flight	0 / 11 (No. of changes made during the flight*)	4.1 ± 3.3 (No. of changes/person/flight*)	-
	Frequency of observed changes in direction	0 / 1.83 (No. of changes/15 min)	0.65 ± 0.55 (No. of changes/person/15 min)	-
	Probability of observing a person facing in direction other than the prevalent direction at a sampling event during the flight	-	-	18.3%

	Duration of individuals facing direction other than the prevalent direction	0.00 / 72.60 (min)	16.46 ± 21.15 (minutes/person/flight*)	-
	Ratio of a person facing direction other than the prevalent direction against the observation period	-	-	17.9%
Standing	Probability of observing a person standing during the time/space sampled during the flight	-	-	1.4%
	Duration of individuals standing	0.00 / 23.15 (min)	2.17 ± 5.71 (minutes/person/flight*)	-
	Ratio of a person standing against the observation period	-	-	2.4%
Speaking	Number of speaking actions made by individuals during the flight	0 / 3 (No. of speaking during the flight*)	0.6 ± 1.0 (No. of speaking/person/flight)	-
	Speaking to other pax Speaking to crew	4 (40%) 6 (60%)		
	Duration of individuals speaking	0.00 / 18.78 (min)	3.21 ± 5.96 (minutes/person/flight*)	-
	Ratio of a person speaking against the observation period	-	-	3.5%
Touch	Number of touching actions made by individuals during the flight	0 / 11 (No. of touching during the flight*)	3.4 ± 2.5 (No. of touching/person/flight)	-
	Duration of individuals touching	0.00 / 58.48 (min)	14.92 ± 14.55 (minutes/person/flight)	-
	Ratio of a person touching against the observation period	-	-	15.5%
Use	Number of using actions made by individuals during the flight	0 / 11 (No. of using during the flight*)	1.6 ± 2.7 (No. of using/person/flight)	-
	Duration of individuals using	0.00 / 23.15 (min)	2.17 ± 5.71 (minutes/person/flight)	-
	Ratio of a person using against the observation period	-	-	8.5%

* An observation period of 95 minutes during the flight.

Results Extracted: Mapping and Narrative Data

Results were also extracted in a more qualitative format - to provide insights into the types of behaviours performed across populations and- locations, and a narrative understanding of individual performance. Examples are shown in Figure 19- Figure 21.

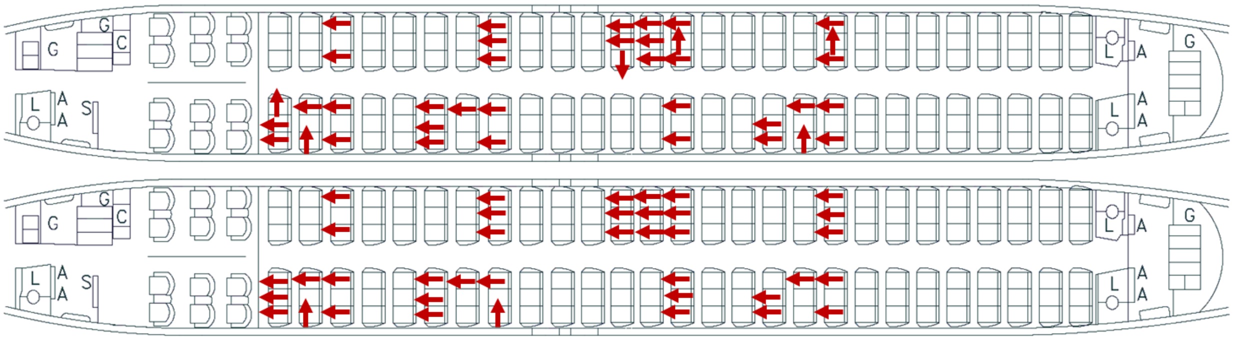


Figure 19: Mapping conditions across the population.

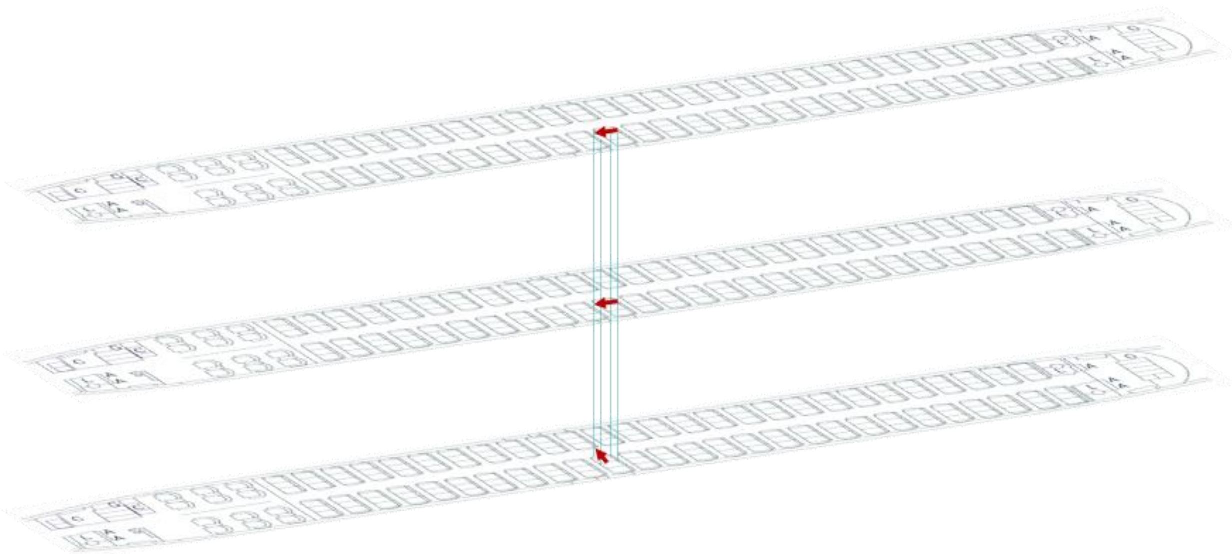


Figure 20: Charting experiences of an individual.

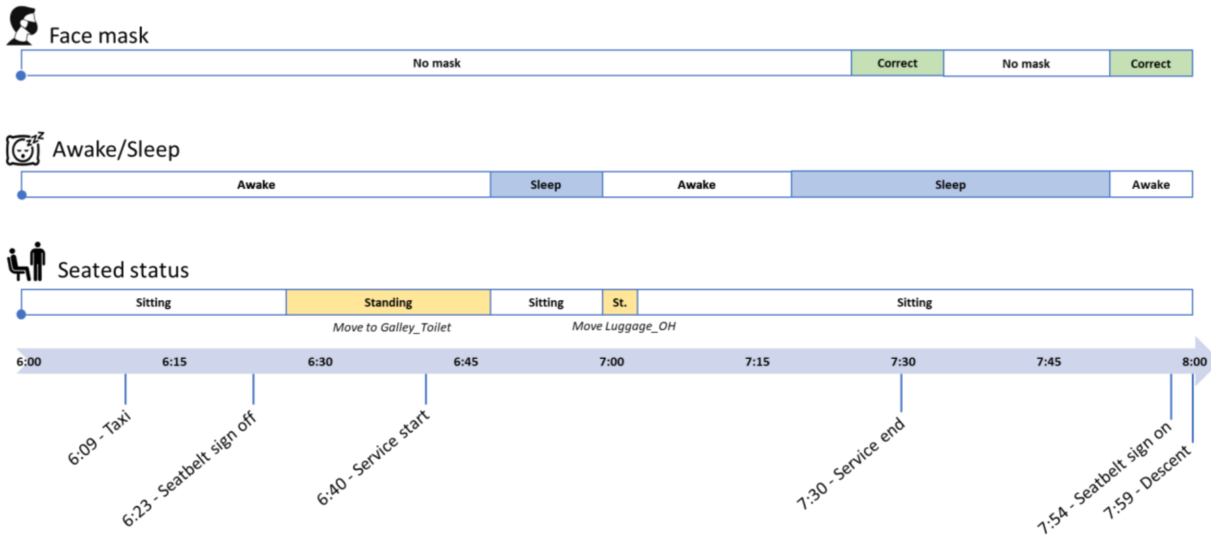


Figure 21: Comparison of individual narrative according to different attributes with aircraft procedure.

Appendix 4: Field Observation - CCTV / Video Extraction

The field observations provided additional insights into the types of behaviour that might be expected during passenger observations at the gate around. This in turn led to iterations of the video extraction template. Although intended for the field observations, it will also have an impact on the data extraction process from the CATR trials – given that the primary source of data produced during the trials will be from camera footage.

The following text outlines the main tasks involved in using the template (shown in Appendix 5).

Video Data Extraction Guide

This provides brief instructions for GHD/NRC staff to extract data from third party footage and then store for later analysis. This guidance also makes reference to a set of other documents – especially the [FAA Video Analysis Template] which will be used to store video data. This guidance is broken down into a set of assumptions [1-8] listed as pre-requisites of subsequent video analysis tasks [9-24].

1. **ASSUMPTION**: Requested access to CCTV footage or permission to install own cameras for survey. It is assumed access to video footage is allowed – whether it is from existing CCTV cameras or temporary cameras installed by our team.
    a. If only third-party footage is available, then all locations / actions / group membership will be manually extracted by the operator.
    b. If bespoke (stereoscopic) cameras can be introduced this will (at a minimum) automatically locate (identify coordinates for each person in the frame), assign a direction, and timestamp the event. Actions / grouping will still likely need manual extraction.
2. **ASSUMPTION:** Data extractors are assigned to the task with which they were previously involved in Phase 1 data collection activities, Phase 1 analysis / template design, and/or who have been trained by someone who was involved in Phase 1 data collection activities. All data extractors are assumed to be intimate with the project's goals, the dyads examined, the actions of interest and the data being collected.
3. **ASSUMPTION:** All those extracting data from video footage will have read this document.
4. **ASSUMPTION:** All those extracting data from video footage will have read the behavioural dictionary (outlining definitions of observable behaviours to be recorded – see Appendix 6).
5. **ASSUMPTION**: All those extracting data from video footage will have reviewed the spreadsheet template.
6. **ASSUMPTION**: We will have previously investigated and observed the gate in operation during a real pre-boarding and boarding scenario to ascertain the survey area(s) – as part of Pilot in Phase 2. This will include
    a. Establishing catchment areas of individual cameras (be they CCTV or installed)
    b. Expected activities within each area (e.g. seating, desk, general movement).
    c. Establishing actions / interactions that can reasonably be captured from the camera positions – allowing lists embedded within spreadsheet to be prioritized.
    d. Identifying data metrics that can collected relating to these actions / interactions.
7. **ASSUMPTION**: Equivalent onsite assessment conducted to determine starting point of data collection. Given previous analysis, it is assumed that this will be up to a maximum of 60 minutes before boarding to boarding complete (will other film relating to the arrival of passengers at the gate after arrival). This period will be aligned with the period adopted in manual observations allowing direct cross-referencing between results collected.
8. **ASSUMPTION:** Prior to data collection, NRC/GHD staff will have produced and installed a grid system on the floor in survey areas for calibration and reference. This will be overlaid and then photograph from the perspective of the observer / camera position. This will be essential if stereoscopic cameras are NOT in place – requiring manually locating people. In this approach, grid densities will be used as a proxy for establishing distances between people. Images of grid system will be used as overlay for manual assessment.

a. If manual counting is required, then gridding is the primary means of establishing local densities and will be used to structure the data extraction activities outlined below.

b. If automated counting used, then coordinates/derived distances between passengers will be logged. However, gridding might still be used as secondary (manual) means of deriving local densities and will be used to structure to data extraction activities outlined below.

9. The first task is for the operator is to scan the entire video footage (e.g. from 60mins before boarding to boarding complete) to establish the target period in which the area is used for the flight being analyzed (to avoid lulls and times of inactivity). This scan may be conducted at speed (2x, 5x actual speed) to save time while still allowing time periods, group calls, passenger movement and anomalies to be established – some judgement will be required to ensure decisions regarding observation timelines are credible and consistent. Periods where the target location is not in use by the flight population should be avoided.

   a. **Output: Data Extraction Start – End Time.**

10. Identify time increments to be adopted when extracting data as outlined in Tasks 12-24 below. Data will be collected at pre-determined time intervals. These increments will be selected to minimize double-counting of passenger activities, and to get a representative sample of action likelihood and action times across the period in question. This will be somewhat driven by the size of the catchment area being observed. Time intervals should allow for someone passing across the space – to reduce likelihood of double-counting. A default time-step of 60s is assumed; although, this might be reduced to 30s for smaller catchment areas.

   a. **Output: Time Step.**

11. Refer to spreadsheet template (see Appendix 5). This template will be populated with the data extracted from the video footage. It includes several tabs used as part of this work:

   a. *General Population Insights*: Summary observations including number of groups and population size by cell/location.

   b. *Individual Data:* information related to each person in the location and time period. This includes the time step, area code (cell number), the event phase (pre-boarding, group calls, etc.), the person being observed (e.g. ID number cell_timestep_ID), aliases (reflecting previous times when they have been observed and the ID given them - cell_timestep_ID, group membership ID), person type (e.g. staff, crew, passenger), demographic (e.g. adult, child, elderly), mask status (e.g. worn correctly, not worn, etc.), status (e.g. sitting, standing, reclining, etc.), and then the action in which they are engaged at that point in time (action, modifier, and object).

12. **Data Extraction Activities (1).** Record in General Population Insights. **Output: Number and size of group in cell**

13. These initially refer to each gridded location/fixed location in the video frame and describe population insights. The data extractor will sweep across grid cells counting number present.

   a. Identify snapshot indicated by time increment. Record Time Increment. **Output: Time** (General Population Insights - Col.A).

   b. Sweep for groups and population sizes in each grid.

   c. Pick a grid cell and the way in which you will cycle through cells. Document cycle pattern adopted. Start from same cell each time.

      i. Record number of people present in each cell **Output: Population Size** (General Population Insights - Col.C – Col.XXX depending on number of cells present).

      ii. Record the number of groups present. Use the guide below for considering whether groups are present. Groups – constitutes one or more of the following

         1. Deliberate contact with another person
         2. Either when facing or lasting more than one time increment
         3. Deliberate contact with shared object

4. Deliberate movement towards another passenger within 1m radius (more than one step)
5. Communication when facing someone while static and across more than one time increment.

iii. Record number of groups: **Output: Groups Present** (General Population Insights - Col.B).
iv. Return to [c] and select the next cell.

14. **Data Extraction Activities (2).** Cycle through individuals in frame associated with each grid cell or location (eating seating area). Record in Individual Data. **Output: Individual Attributes and Actions**
15. These initially refer to each gridded location or definable location in the video frame. The data extractor will sweep across each one - identifying the individuals associated with that location and their attributes.
16. These tasks refer to each individual observed for that time increment and relate to their activities. Cell location or definable location will still be recorded to enable densities to be easily established and provide an easy means to track data extraction; however, an option for automatically extracted coordinates is also included. For key performative elements (direction, mask status, individual actions), a comparison will be made with an individual's previous record and detailed information recorded only if the situation is deemed to have changed from the previous completed record. This will increase the efficiency of the data extraction process while allowing more detailed timing assessments to be made.
17. Identify snapshot indicated by time increment. Record Time Increment. **Output: Time** (Individual Data - Col.A). *Also note actual time at which work on this time increment begins.*
18. Record cell/location under examination (e.g. gate seating, desk, general). **Output: Area Code** (Individual Data - Col.B)**.** Some areas will be gridded allowing grouping while others provide a static location or natural grid (e.g. seats).
19. The extractor will cycle through the following for the individuals in the location being examined. **Output: Record for an individual completed.**

a. Record data extractor ID (for inter rater comparisons). **Output Observer** (Individual Data - Col.C).

b. Record event phase (e.g. before call, standby), from dropdown. **Output: Event Phase** (Individual Data - Col.D)**.**

c. Create unique ID of person being observed. **Output: Person ID** (Individual Data - Col.E)**.**

e. Record individual coordinates. This will be determined automatically should stereoscopic cameras be in place. **Output: X-Coord, Y-Coord** (Individual Data - Cols.G/H)**.** Otherwise, it will be left blank.

f. Record whether person in shot was previously identified in an earlier timeframe. An alias can be assigned to persons who can be identified as having returned to the sample area. This will be established by recording the Person ID (e.g. location_timestep_ID) identified in the previous time-step – to associate the two individuals together. This will likely not be easy to discern manually, especially if an absence from the recording of an individual is lengthy. **Output: Previous Alias** (Individual Data - Cols.I/J). To help with this, a non-exhaustive list is below:

i. Distinctive clothing, including any shoes, headwear or mask
ii. Height, body shape, gait
iii. Return to interaction with an identified group
iv. Noticeable mannerisms/actions

g. Record the type of person, from dropdown. **Output: Person Type** (Individual Data - Col.K). This is to establish whether the person is a member of the public of airport/aircraft staff.

h. Record the age of the person, from dropdown. **Output: Demographic** (Individual Data - Col.L). Use the definitions listed below as a guide to classification:

i. Child – someone who appears under 16 and who is accompanied by an adult or elderly person,

ii. Elderly – someone who appears over 65,
iii. Adult – everyone who appears to not be a child or an elderly person.

i. For the following entries (Direction, Mask, Status, Action/Object) the detailed record should only be included if changes are noted – through comparison with the previous entry for that individual (*time increment – 1*). If any changes are noted, then the full entry should be completed, with new timings associated with the recorded changes captured. This will require the analyst scan the footage to note the start / endpoints of the change.

j. Record direction that the individual is facing, from dropdown. This will be contextual – likely relative to an object (e.g. seat) or the direction of the camera. This will be recorded on a four point scale (N,E,S,W), with precise definitions produced after camera perspective established in Tasks 6-9. **Output: Direction (Individual Data - Col.F).**

k. Record mask status – whether it is worn and whether it is worn correctly, from dropdown. **Output: Mask** (Individual Data - Col.M). Use the definitions listed below as a guide to classification:

i. Correct – mask present and covers mouth and nose
ii. Incorrect – mask present but either mouth and/or nose is not covered
iii. Not present – no mask observed.

j. Record individual's posture, from dropdown. **Output: Status** (Individual Data - Col.N).

k. Record the individual's *action*, *modifier* and *object* – what they are doing, how they are doing it and what external object is being affected. It should be noted that the entries in the dropdown list will be reordered according to the video being captured – to reduce operator effort.

l. If an accurate start/end time is required for the action (e.g. delay experienced standing at desk), then scan footage and record in Updated Start Time and End Time (Cols. Y-Z). This may also allow multiple actions to be identified for a person within and between time increments.

20. Continue until all individuals associated with the current location/cell have been recorded. **Output: Record for a grid cell/location completed.**

21. Sweep across those in the cell/location and identify which of the individuals are in groups (see Task 13 for definition). For those identified, assign them to the group by including the group name (e.g. cell_timestep_GroupID). Where groups cross cells, include cells involved in label, highlight label and revisit group definition when those cells are reached (e.g. [cell1_cell2]_timestep_GroupID). **Output: Group Identify** (Individual Data – Col.X).

22. Once the individual and group attributes are recorded for that location for that cell, return to [18]) and move onto next location.

23. Once all cells and locations have been examined, move to the Work time per interval tab and record time spent on extracting data for that time step (making reference to [17]). Return to [17]) and move to next time increment.

24. Travel speeds at the gate will be established from examining the consecutive coordinates of individuals (either in Cols. G-H and Cols.AA-AB or making reference to earlier records where an alias is matched) – given that these coordinates have been time-stamped and produced from stereoscopic camera. This is automatic if stereoscopic cameras in use. If this is not possible, then an additional task will be included. This will involve an extractor identifying locations where movement is observed (e.g. in the gate area away from the desk and seats), and identifying sample movement across records. If movement falls within a single record and overlaps with other observations these can be added to existing entries. Otherwise:

a. Record Cols.E-H, K-N as above, select Move in Col.O and then determine the final coordinate locations of the individual in Cols.AA-AB. The distance travelled will be determined by comparing start and end coordinates, and then the speed calculated by determining elapsed time over distance. It should be noted that this movement should occur within the time increment.

b. Surrounding density conditions will have been established in General Population Insights for the time step, allowing the density/speed conditions to be established.

The time taken to complete analysis of a time increment will vary given the size of the population present in the sample area. From data collection testing at a similar type of setting (during previous observations during a pandemic, although not at an airport gate), recording individuals and all of their attributes took approximately 1 minute per person.

A set of data was extracted from the material collected during the field observations. This data was extracted purely to test the data collection and extraction methods rather than to produce credible estimates of passenger performance.

Appendix 5 - General Population Insights

Time	Groups Present (including more than 1)	Pop Size – Loc G1 (people at each table)	Pop Size – Loc G2	Pop Size – Loc G3	Pop Size – Loc G4	Pop Size – Loc G5	Pop Size – Loc G6	Pop Size – Loc G7	Pop Size – Loc G8	Pop Size – Loc G9	Pop Size – Loc Z1 (people in each path zone)	Pop Size – Loc Z2	Pop Size – Loc Z3	Pop Size – Loc Z4	Pop Size – Loc Z5	Pop Size – Loc Z6

Appendix 5 - Individual Data

Time	Area Code	Observer	Event Phase	Person ID	Direction	X-Coord	Y-Coord	Previous Alias?	Previous Alias? (2)	Person Type	Demographic	Mask	Status	Action (1)	Modifier (1)	Object (1)	Action (2)	Modifier (2)	Object (2)	Action (3)	Modifier (3)	Object (3)	Group Identity	Updated Start Time	End Time	End X	End Y	Distance (m)	Speed (m/s)

Appendix 5 - Dropdown List

Event Phase*	People	Demographic	Mask	Status	Action	Modifier	Object	Direction
Before call	Pax	Adult	Correct	Sitting	Touch	Loudly	Armrest	N
Priority call	Staff/Crew	Child	Incorrect	Standing	Use	Sharing	Seatbelt	E
Pre-boarding/standby		Elderly	No Mask	Reclined	Speak	Quickly	Tray	S
Group calls				Bending	Sleep		Shared_Document	W
Late arrivals to gate				Nothing	Eat/Drink		Seat_Pocket	
Individual passenger call					Read/Watch		Power_Outlet / USB	
					Cough/Sneeze		Window/Fuselage	
					Yawn		(Window) Blind	
					Move		PSU	
					Face		Overhead_Locker	
					Hold		Luggage	
					Deposit		Luggage (Overhead)	
					Unknown		Luggage (Floor)	
					None		Luggage (Carried)	
					Collect		Overclothes	
					Wait		Overclothes (Overhead)	
					Other		Face/Mask	
					(Crew) Serve		Mobile_Device	
					Turn		Personal_Document	
					Sit		Mobility_Aid / Movement_Device	
					Stand		Pushchair/Car_Seat	
					Exchange		Staff/Crew	
					Don		Pax - Adult	
					(Crew) Sanitize		Pax - Baby	
							Pax - Child	
							Lavatory (Location)	
							Aisle	
							Seat	
							Pay_Device	
							Trolley	
							Call Switch	
							Galley	
							Ticket Swipe	
							Desk/Counter	
							Wall / Fuselage	
							Earphone Socket	

*Event Phase will be modified to fit the dyad in question.

Time Interval	Work Time (mins)

TOTAL (mins)	0
Hours	0

Appendix 6: Action and Object Definitions

Definitions of actions			
Action (Passenger and Crew, unless stated)	**Definition**	**Metric [#/s]**	**Modifier / Associated Attribute**
Touch	Hand/fingers in contact with object or body.	#	n/a
Use	Hand/fingers in contact with object or body.	#/s	n/a
Speak	Verbal communication (mouth moving) with either a person or device (being held near mouth, ear, or via headphones).	#/s	Loudly Direction
Sleep	Resting with eyes closed; immobile.	#/s	n/a Direction
Eat/Drink	Bringing either foods or a fluid vessel to mouth.	#/s	Sharing Direction
Read/Watch	Eyes fixed on an object, though object not necessarily in contact with hand/fingers (might be set / balanced).	#/s	
Cough/Sneeze	(In)voluntary, sudden expulsion of air from one's mouth/nose – associated jolt to body.	#	n/a Direction
Yawn	Involuntary opening of one's mouth to inhale deeply	#	n/a Direction
Move (use modifier if necessary)	Becoming locomotive (agent movement) or manipulating an object's location (object movement)	#/s	Quickly Direction
Face	Change in direction of person's head and shoulders	#/s	n/a Direction
Hold (specific to outerwear and luggage)	Carrying an item in one's hand(s) or over arm / shoulder.	#/s	n/a
Deposit	Place an object in a static position.	#	n/a
Unknown	Action not able to be discerned	#	n/a
None	No action taking place	#	n/a
Collect	Person picks up (Touches it) an object and takes it with them (Hold).	#	n/a
Wait	Person remains in situ delaying movement until a particular time/event/other action is completed	#/s	n/a Direction
Other	(If a novel action not represented by former definitions)	#	n/a
(Crew) Serve	Restricted to Crew Activity during service. Entails the picking up a food/drink object and passing to a passenger after communication.	#/s	n/a Direction
Turn	Rotation requiring modification of direction status.	#	
Sit	Change status from Standing to Sitting.	#	n/a

Stand	Change status from Sitting to Standing.	#	n/a Direction
Exchange	Passes object to another agent.	#	n/a Direction
Don	Wears garment or mask.	#	n/a
(Crew) Sanitize	Crew cleans surface (e.g. tray, armrest, galley, toilet door handle, etc.)	#/s	n/a

Definitions of objects	
Objects	**Definition**
Armrest	Seat divider designed to support arms/hands.
Seatbelt	Strap designed to secure person to a seat.
Tray	Foldable table attached to the back of a seat.
Shared_Document	Airline owned non-electronic written/printed paper(s) (e.g. safety briefing card).
Seat_Pocket	Elasticated fabric storage located on the back of a seat.
Power_Outlet / USB	Electrical receptacle that provides a power supply to connected equipment.
Window/Fuselage	Opening in the wall of the cabin or the surrounding wall.
(Window) Blind	Screen designed to cover a window.
PSU	Overhead control for ventilation, service call and lighting.
Overhead_Locker	Overhead locker (inner/outer surface and handle).
Luggage	Bag.
	Overhead – located in overhead locker.
	Floor – located on floor.
	Carried – being held by person.
Overclothes	Removable item of clothing.
	Overhead – located in overhead locker.
Face/Mask	Front part of a person's head or protective covering for the nose and mouth.
	Correct – mask present and covers mouth and nose
	Incorrect – mask present but either mouth and/or nose is not covered

	Not present – no mask observed.
Mobile_Device	Portable computer (e.g. phone, tablet, laptop).
Personal_Document	Passenger owned non-electronic written/printed paper(s) (e.g. passport).
Mobility_Aid / Movement_Device	Device used to assist a person with moving (e.g. walking stick).
Pushchair/Car_Seat	Seat for babies to be transported in.
Staff/Crew	Person working for airport/airline.
Pax - Adult	Passenger aged 17 or above.
Pax - Baby	Passenger aged under 2.
Pax - Child	Passenger 3-16
Lavatory (Location)	Lavatory - contact with lavatory door with intention to enter lavatory, with indication of location within aircraft. (from Herz)
Aisle	Passage between rows of seats.
Seat	Furniture intended to be sat on (includes every surface of the seat).
Pay_Device	Card payment machine.
Trolley	Device used to provide service by cabin attendants
Call Switch	Switch above seated passenger onboard to get crew attention
Galley	Area next to partitions where crew prepare and provide service.
Ticket Swipe	Device allowing passengers to present tickets - usually digital or paper tickets.
Desk/Counter	Location at gate where passengers board and interact with staff
Wall / Fuselage	Wall in airport/fuselage in aircraft.
Earphone Socket	Port between seats.

General Definitions:

- Group – constitutes one or more of the following:
  - Deliberate contact with another person - either when facing or lasting more than one time increment
  - Within 1m of another person while static and across more than one time increment
  - Deliberate contact of more than one person with shared object
  - Movement towards another passenger (more than one step)
  - Communication when facing someone while static and across more than one time increment

Appendix 7: Overview of Data Types by Dyad.

Table 1: Gate Data Types by Data Collection Mode.

[B]oarding / [U]se/ [D]eplaning	**Behavioural Dictionary – Core Actions to Observe**	**Qualitative Insights**	**Aggregate Results**	**Individual Results**	**Sample**	**Expected Actions/Objects/Modifiers** (All entries involve counts. (s) indicates that entry has time measure)
Manual Observations [B]	**General:** Define mask use and demographic attributes across all locations. Requires access to site / prior video prior to final field observations. List of aggregate conditions.	**General:** General patterns of movement and behaviours across gate areas. Pathways used (desire lines) between seating / gate / jetway, locations of interaction and congestion.		**General:** Requires observer position in standing position >10m removed from seat.	**General:** Area deemed to be observable. Must be noted / mapped with results.	
	Desk: List of actions observed from 1st person at desk – type – define start and end points (see **[G1]**). Actions observed of staff at desk (see **[G1]**).	**Desk:** Action selection of first person in queue / type of queue structure.	**Desk**: Queue length over time in gridded area (#) Queue processing time (s) Map – Direction / Action– Object-Person-Group over time. Frequency of items/objects touched (by individual). Frequency of items/objects	**Desk:** *Requires observer position perpendicular to desk.* Time spent at desk (s) by 1st person (filtered by sub-set of action / object combinations – see **[G1]**). Narrative of actions of 1st person.	**Desk:** Queue location monitored based on pre-determined gridded area.	**[G1] Desk:** Touch/Mobile_Device Touch/Personal_Document Touch/Luggage Hold/Luggage Touch/Face/Mask Touch/Overclothes Touch/Mobility_Aid Touch/Pushchair/Car-Seat Touch/Baby Touch/Desk Touch/TicketSwipe Hold/Baby Touch/Pax Speak/Staff Speak/Pax Speak/Mobile_Device Eat Drink Cough Sneeze

			touched (by object).			Yawn Turn / Direction Change *All associated with time recorded at desk – so no additional time recordings necessary.*
	Seat: Actions observed of those in seat – type, when it starts and ends. Definition of groups (see [G2]).	**Seat:** Direction / Actions performed by those in seats. Grouping of people in seats. Profile of those in seats (demographic, mask status, etc.).	*Aggregate of individual data summarised during post-observation analysis.*	**Seat:** Number (#) / Direction / Direction Changes / Standing / Actions / Actions – Object-Group v Time (filtered by sub-set of action / object combinations – see **[G2]**). Delay (s): Direction / Direction Changes / Standing / Actions / Actions – Object -Group Membership (filtered by sub-set of action / object combinations – see **[G2]**).	**Seat:** Pre-determined seating area (<12)	**[G2] Seat:** Touch/Mobile_Device Touch/Personal_Document Touch/Luggage Hold/Luggage (s) Touch/Face/Mask Touch/Overclothes Touch/Seat Touch/Mobility_Aid Touch/Pushchair/Car-Seat Touch/Baby Touch/Pax Hold/Baby (s) Speak/Staff/Crew (s) Speak/Pax (s) Speak/Mobile_Device (s) Face/Pax Face/Staff Sleep (s) Eat (s) Drink (s) Cough Sneeze Yawn Stand / Status Change Sit / Status Change Turn/ Direction Change

Video [B/D]	Depending on access (e.g. to control room, blurred images, etc.), this might occur after manual observations and so may not contribute.	**General:** General patterns of movement and behaviours across gate. Pathways used (desire lines), locations of interaction and congestion	**General:** Object touch points – number of times objects are touched (extracted from individual interactions with objects) Occupancy over time. Population distribution over time.	**General:** Travel speed (m/s). Number (#) / Direction / Direction Changes / Standing / Actions / Actions – Object-Group Membership v Time (filtered by sub-set of action / object combinations – see **[G3]**) Delay (s): Direction / Direction Changes / Standing / Actions / Actions – Object -Group Membership (filtered by sub-set of action / object combinations – see **[G3]**)	**General**: Observable Area	**<u>[G3] General:</u>** Move (s) Touch/Mobile_Device (s) Touch/Personal_Document Touch/Luggage Hold/Luggage (s) Touch/Face/Mask Touch/Overclothes Touch/Mobility_Aid Touch/Pushchair/Car-Seat Touch/Baby Touch/TicketSwipe Hold/Baby (s) Touch/Pax Touch/Staff/Crew Touch/Desk Speak/Staff/Crew (s) Speak/Pax (s) Speak/Mobile_Device (s) Face/Pax (s) Face/Staff (s) Eat (s) Drink (s) Cough Sneeze Yawn Turn/ Direction Change
	Desk: Add actions observed from those in the queue – not just at front of queue. Develop definition of groups in queue (see [V1]).	**Desk**: Action selection of those in queue. Grouping of those in queue. Narrative of actions of those in queue (sample).	**Desk:** Queue length over time (#) Queue processing time (s) Map – Direction / Action– Object-Person-Group over time. Frequency of items/objects touched (from	**Desk:** Time spent at desk (by action / object - filtered by sub-set of action / object combinations – see **[G4]**). Time spent in queue (s) Number (#) / Direction / Direction Changes / Standing /	**Desk:** Entire queue.	**<u>[G4] Desk:</u>** Touch/Mobile_Device (s) Touch/Personal_Document Touch/Luggage Hold/Luggage (s) Touch/Face/Mask Touch/Overclothes Touch/Mobility_Aid Touch/Pushchair/Car-Seat Touch/Baby Hold/Baby (s) Touch/Pax Touch/Staff/Crew Touch/Desk Touch/TicketSwipe

			individual / from object) Densities/contact distance (ppm^2) of those in queue. Time in queue.	Actions / Actions – Object-Group Membership v Time When in queue (-filtered by sub-set of action / object combinations – see **[G4]**).		Speak/Pax (s) Speak/Staff/Crew (s) Speak/Mobile_Device (s) Face/Pax (s) Face/Staff (s) Eat (s) Drink (s) Cough Sneeze Yawn Turn/ Direction Change
	Seat: Add actions observed by those in seat. Add actions by staff at desk (see [V2]).	**Seat:** Direction / Actions performed by those in seats. Grouping of people in seats. Profile of those in seats (demographic, mask status, etc.).	**Seat:** Total number of people seating / standing – over time. Total time people standing/seated. Occupied % - over time. Avg. Dwell Time (s) – time pax in seating area. Frequency of items/objects touched. Densities/contact distance (ppm^2)	**Seats:** Number (#) Direction Changes / Standing / Actions / Actions – Object-Group Membership (-filtered by sub-set of action / object combinations – see **[G5]**). Delay (s): Direction Changes / Standing / Actions / Actions – Object-Group Membership (-filtered by sub-set of action / object combinations – see **[V2]**).	**Seat:** Seating area associated with gate.	**[G5] Seat:** Touch/Mobile_Device (s) Touch/Personal_Document Touch/Luggage Hold/Luggage (s) Touch/Face/Mask Touch/Overclothes Touch/Seat Touch/Mobility_Aid Touch/Pushchair/Car-Seat Touch/Baby Hold/Baby (s) Touch/Pax Speak/Staff/Crew (s) Speak/Pax (s) Speak/Mobile_Device (s) Face/Pax (s) Face/Staff (s) Sleep (s) Eat (s) Drink (s) Cough Sneeze Yawn Stand Sit Turn (s) – [Direction Change]
CATR [B/D]	No actions derived from CATR – actions applied from field observations.		For comparison with video.	**General:** For model configuration.	**General:** CATR	-

				Travel Speed (m/s)		
		Desk: Action selection of entire queue. Grouping of those in queue. Interactions between crew and passengers (e.g. handling passports/boardin g passes, speaking)	**Desk:** Queue length over time (#) Queue processing time (s)	**Desk:** Time (s) spent at desk (by action / object - filtered by sub-set of action / object combinations – see **[G6]**). Time spent in queue (s) - (by action / object - filtered by sub-set of action / object combinations – see **[G6]**) Time spent on action/object when in queue (by action / object - filtered by sub-set of action / object / group membership combinations – see **[G6]**). Number (#) / Direction / Direction Changes / Standing / Actions / Actions – Object-Group Membership v Time when in queue (by action / object - filtered by sub-set of action / object combinations – see	**Desk:** CATR.	**<u>[G6] Desk:</u>** Touch/Mobile_Device (s) Touch/Personal_Document Touch/Luggage Hold/Luggage (s) Touch/Face/Mask Touch/Overclothes Touch/Mobility_Aid Touch/Pushchair/Car-Seat Touch/Baby Touch/TicketSwipe Hold/Baby (s) Touch/Pax Speak/Staff/Crew (s) Speak/Pax (s) Speak/Mobile_Device (s) Face/Pax (s) Face/Staff (s) Eat (s) Drink (s) Cough Sneeze Yawn Turn/ Direction Change

				[G6]).Narrative of actions of those in queue (sample).		
		Seat: Direction / Actions performed by those in seats. Grouping of people in seats. Narrative view of pax. actions (sample – by seat).	**Seat:** Avg. Dwell Time (s) – time pax in seating area. Densities/contact distance (ppm^2)	**Seat:** Number (#) Direction Changes / Standing / Actions / Actions – Object-Group Membership (by action / object - filtered by sub-set of action / object combinations – see **[G7]**) Delay (s): Direction Changes / Standing / Actions / Actions – Object-Group Membership (by action / object - filtered by sub-set of action / object combinations – see **[G7]**)	**Seat:** CATR	**[G7] Seat:** Touch/Mobile_Device (s) Touch/Personal_Document Touch/Luggage Hold/Luggage (s) Touch/Face/Mask Touch/Overclothes Touch/Seat Touch/Mobility_Aid Touch/Pushchair/Car-Seat Touch/Baby Hold/Baby (s) Touch/Pax Speak/Staff/Crew (s) Speak/Pax (s) Speak/Mobile_Device (s) Face/Pax (s) Face/Staff (s) Sleep (s) Eat (s) Drink (s) Cough Sneeze Yawn Stand Sit Turn/ Direction Change

Table 2: Jetway Data Types by Data Collection Mode

[B]oarding / [U]se/ [D]eplaning	**Behavioural Dictionary – Core Actions to Observe**	**Qualitative Insights**	**Aggregate Results**	**Individual Results**	**Sample**	**Expected Actions/Objects/Modifiers** (All entries involve counts. (s) indicates that entry has time measure)
Manual Observations [B]	Ground Staff/Pax Activities	Passenger actions at front of queue (deposit /collect luggage)	Flow Rate (p/s) Number of luggage present v. time	1st Person Delay time at aircraft exit (s).	1st person in queue (filtered by **[J0]**)	**[J0]** Deposit/Luggage

Video [B/D]	Add to Ground Staff/Pax Activities derived from Manual Observations	Passenger actions at front of queue (deposit /collect luggage) Ground staff actions at front of queue (deposit / collect luggage) Grouping of passengers in queue.	Object touch points (extracted from individual interactions with objects) Flow Rate (p/s) Number of luggage present v. time Densities/contact distance (ppm^2) in observable area. Queue length in observable area Number of bags removed by crew (vs. time). Time to remove bags / crew. Number of bags deposited by pax (vs. time) Time to deposit bags / pax.	1st Person in queue Actions / Delay@Exit / Luggage Deposit Delay / Number of bags left by each pax (by action / object - filtered by sub-set of action / object combinations – see **[J1]**)	Observable area (measured beforehand)	**[J1]** Collect/Luggage (s) Deposit/Luggage (s) Collect/Mobility_Aid (s) Deposit/Mobility_Aid (s) Collect/Pushchair/Car-Seat (s) Deposit/Pushchair/Car-Seat (s) Touch/Mobile_Device (s) Touch/Personal_Document Touch/Luggage Hold/Luggage (s) Touch/Face/Mask Touch/Overclothes Touch/Mobility_Aid Touch/Pushchair/Car-Seat Touch/Baby Hold/Baby (s) Touch/Pax Touch/Crew Touch Fuselage Speak/ Crew (s) Speak/Pax (s) Face/Pax (s) Face/Crew (s) Speak/Mobile_Device (s) Eat (s) Drink (s) Cough Sneeze Yawn Turn/ Direction Change
CATR [B/D]	No actions derived from CATR – actions applied from field observations.	- Passenger actions at front of queue (deposit /collect luggage) Ground staff actions at front of queue (deposit / collect luggage) Grouping of passengers.	**For comparison with video:** Object touch points (extracted from individual interactions with objects) Flow Rate Queue length in observable area	1st Person in queue Actions / Delay@Exit / Luggage Deposit Delay / Number of bags left by each pax / Time spent in queue (by action / object - filtered by sub-set of action / object	CATR	**[J2]** Collect/Luggage Deposit/Luggage Collect/Mobility_Aid Deposit/Mobility_Aid Collect/Pushchair/Car-Seat Deposit/Pushchair/Car-Seat Touch/Mobile_Device (s) Touch/Personal_Document Touch/Luggage Hold/Luggage (s) Touch/Face/Mask Touch/Overclothes Touch/Mobility_Aid

			Densities/contact distance (ppm^2) Number of bags deposited by pax (vs. time) Time to deposit bags / pax Number of bags removed / crew.* Time to remove bags / crew.* * Only if ground crew represented	combinations – see [J2])		Touch/Pushchair/Car-Seat Touch/Baby Hold/Baby (s) Touch/Pax Touch/Crew Touch Fuselage Speak/ Crew (s) Speak/Pax (s) Face/Pax (s) Face/Crew (s) Speak/Mobile_Device (s) Eat (s) Drink (s) Cough Sneeze Yawn Turn/ Direction Change

Table 3: Onboard Aircraft - Data Types by Data Collection Mode

[B]oarding / [U]se/ [D]eplaning	**Behavioural Dictionary – Core Actions to Observe**	**Qualitative Insights**	**Aggregate Results**	**Individual Results**	**Sample**	**Expected Actions/Objects/Modifiers** (All entries involve counts. (s) indicates that entry has time measure)
Manual Observations [B/U]	**Seat:** (Sub-set of) Actions observed of those in seat row (by dedicated Observer 1-4).	**Seat:** Direction / Actions performed by those in seat rows by groups (by dedicated Observer 1-4). Narrative view of pax. actions – by a sample of those in particular seats with actions sequenced over time. Map – Direction / Action– Object-Person-Group over time.	**Seat:** % of pax seating/standing v time % of pax facing a direction v time % of pax eating/sleeping/ speaking. #Object touch points (extracted from individual interactions with objects)	**Seats: *Rows Ahead*** Number (#) Direction / Direction Changes / Standing v Time Time (s): Direction / Direction Changes / Standing **Seats: *Same Row*** Number (#) Location /	**Seat:** Observer 1-4: 6 seats ahead, 5 seats in row.	**[A1] Seat:** Move (s) Touch/Armrest Touch/Seatbelt Touch/Tray Touch/SeatBack Touch/Window/Fuselage Touch/Blind Touch/PSU Touch/Overhead_Locker Touch/Pay_Device Touch/Pax Touch/Staff/Crew Touch/Mobile_Device Touch/Personal_Document Touch/Luggage Hold/Luggage (s) Touch/Face/Mask Touch/Overclothes

			% of pax engaging in specific action.	Direction / Direction Changes / Actions / Actions – Object-Group v Time (filtered by sub-set of action / object combinations – see **[A1]**) Time (s)*: Location / Direction / Direction Changes / Actions / Actions – Object-Group (filtered by sub-set of action / object combinations – see **[A1]**) *Many of the times here are derived estimates rather than observed.		Touch/Mobility_Aid Touch/Baby Hold/Baby (s) Speak/Crew Speak/Pax Face/Pax (s) Face/Crew (s) Speak/Mobile_Device (s) Sleep Eat Drink Cough Sneeze Yawn Stand/Status Change Sit/Status Change Recline /Status Change Turn / Direction Change
	Aisle (Cruising): (Sub-set of) Actions observed of crew (by dedicated Observer 6).	**Aisle/Galley(Cruising):** Crew/Pax activities in aisle during cruise/service (Observer 6)	**Aisle(Cruising):** Number of crew in aisle v time. Number of crew serving v time. Service time window. Avg.Crew Time in Aisle. Avg.Crew Time Serving.	**Aisle(Cruising):** Number (#) Direction / Direction Changes / Actions / Actions – Object-Group v Time (filtered by sub-set of action / object combinations – see [A2]) Time (s): Location / Direction / Direction	**Aisle(Cruising):** Observer 6: Crew/Pax Activities & Toilet Activities (during different periods)	**[A2] Aisle(Cruising):** Move/Aisle (s) Hold/Baby (s) Touch/Overhead_Locker Touch/SeatBack Touch/Pax Touch/ Crew Touch/FaceMask Speak/Crew Speak/Pax Face/Pax Face/Crew Touch/Mobile_Device Cough Sneeze Yawn Move/[Galley/Toilet] (s)

			Number of pax in aisle v time. Avg.Pax Time in Aisle.	Changes / Actions / Actions – Object-Group (filtered by sub-set of action / object combinations – see [A2])		Collect/Overhead_Locker Deposit/Overhead_Locker Wait (s) Turn (Crew) Serve (s)
	Between Seat and Target: (Sub-set of) Actions observed of pax movement between seat & toilet/galley (by new dedicated Observer 5).	**Between Seat and Target:** Narrative – paths / movement of pax from seat to toilet/galley via aisle (by new dedicated Observer 5).	**Between Seat and Target:** Map - Paths adopted from seats to aisle / galley. Number of pax moving between seat / toilet – seat/galley. Pax time out of seat. % Population out of seat #Object touch points (extracted from individual interactions with objects)	**Between Seat and Target:** Number (#)/ Actions / Actions – Object v Time (filtered by sub-set of action / object combinations – see **[A3]**) Time (s): Location / Direction / Direction Changes / Actions / Actions – Object-Group (filtered by sub-set of action / object combinations – see **[A3]**) Probability of a passenger leaving seat per unit time.	Observer 5: Pax Movement from seats to target – Economy.	**[A3] Between Seat and Target:** Move/Aisle (s) Hold/Baby (s) Touch/Overhead_Locker Touch/SeatBack Touch/Pax Touch/Crew Touch/FaceMask Speak/Crew Speak/Pax Face/Pax Face/Crew Touch/Mobile_Device Cough Sneeze Yawn Move-Galley/Toilet (s) Collect/Overhead_Locker Deposit/Overhead_Locker Turn / Face Stand Sit
	Aisle – Boarding / Deplaning: Pax standing in aisle during boarding. Preparatory Actions observed		**Aisle – Boarding / Deplaning:** Flow during boarding/ deplaning (Number of pax passing at time increment).	Number (#)/ Actions / Actions – Object v Time (filtered by sub-set of action / object combinations – see **[A4]**)	Observer 4: 5 rows ahead. Observer 6: Crew Activities & Toilet Activities	**[A4] Aisle – Boarding / Deplaning** Touch/Overhead_Locker Touch/SeatBack Turn Sit Stand Sanitize (Crew Action)

	of crew boarding and deplaning movement (by new dedicated Observer 6).		Number of pax present in aisle section vs. time.			Touch/Galley (Crew Action)
	Toilet / Galley: Actions of those observed waiting.	**Toilet / Galley:** Activities adopted in and around toilet, footprint occupied.	**Toilet/Galley:** Pax queue length vs time. Pax number in galley vs. time Number of crew in galley v time.	**Toilet/Galley:** Time pax spent waiting for toilet. Time pax spent in toilet. Time pax spent in galley. Crew Time in Galley Number(#)/ Actions / Actions – Object v Time (filtered by sub-set of action / object combinations – see **[A5]**) Time (s): Actions / Actions – Object (filtered by sub-set of action / object combinations – see **[A5]**)	Observer 6: Crew Activities & Toilet Activities	**[A5] Toilet / Galley:** Touch/Mobile_Device Touch/Face/Mask Touch/Overclothes Touch/Mobility_Aid Touch/Baby Hold/Baby (s) Touch/Pax Touch/ Crew Touch/Toilet~~l~~ (Door) Touch/Galley Speak/Crew Speak/Pax Face/Pax Face/Staff Cough Sneeze Yawn Turn / Face Wait (s)
Video	-	-	-	-	-	

CATR [B/U/D]	No actions derived from CATR – actions applied from field observations.		**For comparison with manual observations:** Object touch points (extracted from individual interactions with objects)		CATR	
		Seat: Direction / Actions performed by those in observable seats (by Object/Group). Narrative view of pax. Actions – by a sample of those in particular seats with actions sequenced over time.	**Seat:** Pax states / actions across population % of people seating/standing v time Object touch points (extracted from individual interactions with objects) Map – Direction / Action– Object-Person-Group over time.	**Seat:** Detailed insight into touch point per action (e.g. object and frequency of touch when getting out of window seat) Number (#) Direction / Direction Changes / Standing/ Actions / Actions – Object-Group v Time (filtered by [C1]) Time (s): Direction / Direction Changes / Standing / Actions / Actions – Object-		**[C1] Seat** Touch/Armrest Touch/Seatbelt Touch/Tray Touch/Shared_Document Touch/Seat_Pocket Touch SeatBack* *[May not be a valid indicator given lack of turbulence]. Touch/Power_Outlet Touch/Window/Fuselage Touch/Blind Touch/PSU Touch/Overhead_Locker Touch/Pay_Device Touch/Pax Touch/Staff/Crew Touch/Mobile_Device (s) Touch/Personal_Document Touch/Luggage Hold/Luggage (s) Touch/Face/Mask Touch/Overclothes Touch/Mobility_Aid Touch/Pushchair/Car-Seat Touch/Baby Hold/Baby (s)

				Group (filtered by [C1]) Refined pax interactions with seat area (sensed) – tray, OH, seatback. Crew: Number (#) Direction / Direction Changes / Actions / Actions – Object- Group v Time (filtered by [C1]) Time (s): Location / Direction / Direction Changes / Actions / Actions – Object-Group (filtered by [C1])		Speak/Staff/Crew (s) Speak/Pax (s) Face/Pax (s) Face/Crew (s) Speak/Mobile_Device (s) Sleep (s) Eat (s) Drink (s) Cough Sneeze Yawn Move/Galley/Toilet (s) Move/Aisle (s) Sit Stand Turn Recline
		Aisle(Cruising): Crew: (Although set according to scenario, recorded as if independent variable) Crew activities in aisle during cruise/service. Narrative view of crew actions. Narrative – movement of pax from seat to toilet/galley via aisle.	**Aisle(Cruising):** Flow during boarding /deplaning. Number of pax in aisle v time Pax time in aisle Service time window. Number of crew in aisle v time. Number of crew serving v time	**Aisle(Cruising):** Number (#) Direction / Direction Changes / Actions / Actions – Object-Group v Time (filtered by sub-set of action / object combinations – see **[C2]**) Time (s): Location / Direction / Direction Changes / Actions / Actions – Object-		**[C2] Aisle(Cruising):** Move/Aisle (s) Hold/Baby (s) Touch/Overhead_Locker Touch/SeatBack Touch/Pax Touch/Staff/Crew Touch/Face/Mask Speak/Crew (s) Speak/Pax (s) Face/Pax (s) Face/Crew (s) Touch/Mobile_Device (s) Cough Sneeze Yawn Move/[Galley/Toilet] (s) Collect/Overhead_Locker Deposit/Overhead_Locker

			Avg. Crew Time in Aisle Avg. Crew Time Serving Number of pax in aisle v time. Avg. Pax Time in Aisle [May not be relevant as crew will be scripted – of main use when compared with other data, such as passenger movement.]	Group (filtered by sub-set of action / object combinations – see **[C2]**)		Wait (s) Turn
			Between Seat and Target: Map - Paths adopted from seats to aisle / galley. Avg. Number of pax moving between seat / toilet – seat/galley. Avg.Time of pax moving between seat / toilet – seat/galley. Densities/contact distance (ppm^2) Pax time out of seat.	**Between Seat and Target:** Number (#) Direction / Direction Changes / Actions / Actions – Object-Group v Time (filtered by sub-set of action / object combinations – see [C3]). For instance, number of times a passenger visits the toilet. Time (s): Location / Direction / Direction Changes / Actions		**[C3] Between Seat and Target:** Move/Aisle (s) Hold/Baby (s) Touch/Overhead_Locker Touch/SeatBack Touch/Pax Touch/Crew Touch/Face/Mask Speak/Crew (s) Speak/Pax (s) Face/Pax (s) Face/Crew (s) Touch/Mobile_Device (s) Cough Sneeze Yawn Move/Galley/Toilet (s) Collect/Overhead_Locker Deposit/Overhead_Locker Turn Stand Sit

			% Population leaving seat	/ Actions – Object-Group (filtered by sub-set of action / object combinations – see [C3]) Probability of a passenger leaving seat per unit time.		
				Aisle Boarding / Deplaning: Number (#) Direction / Direction Changes / Actions / Actions – Object-Group v Time (filtered by sub-set of action / object combinations – see [C4]) Time (s): Location / Direction / Direction Changes / Actions / Actions – Object-Group (filtered by sub-set of action / object combinations – see [C4])		**[C4]Aisle – Boarding / Deplaning:** Move/Aisle (s) Hold/Baby (s) Touch/ Overhead_Locker Collect/Overhead_Locker Deposit/Overhead_Locker Touch/Luggage Hold/Luggage (s) Collect/ Luggage Deposit/Luggage Cough Sneeze Yawn Turn Sit Stand Sanitize (Crew Action) Touch/Galley (Crew Action)
			Toilet/Galley: Pax queue length vs time Avg.time spent waiting for toilet.	**Toilet/Galley:** Queueing – Number (#) Direction / Direction Changes / Actions / Actions		**[C5] Toilet / Galley:** Touch/Mobile_Device (s) Touch/Face/Mask Touch/Overclothes Touch/Mobility_Aid Touch/Baby Hold/Baby (s)

			Avg.time spent in toilet. Avg.number in galley. Avg.time spent in galley. Time toilet in use. Number of crew in galley v time Avg. crew Time in Galley	– Object-Group v Time (filtered by sub-set of action / object combinations – see **[C5]**) Queueing - Time (s): Location / Direction / Direction Changes / Actions / Actions – Object-Group (filtered by sub-set of action / object combinations – see **[C5]**) Time spent waiting for toilet. Time spent in toilet. Time pax spent in galley. Time Crew in Galley		Touch/Pax Touch/ Crew Touch/Toilet Door Touch/Galley Speak/ Crew (s) Speak/Pax (s) Face/Pax (s) Face/Staff (s) Cough Sneeze Yawn Turn

Appendix 8: Parameter Types (Post-August 2023 Workshop)

Below is a description of the parameters to be captured during the field observations and/or CATR trials. A few points:

- The team commits to collecting parameters in **Tables 1-3** that have been shaded gold. Parameters not shaded were deemed less important (by client modellers and stakeholders) however may still be collected dependent on resourcing, budget, and timeline and will be assessed at a later date.
- In **Table 3**, parameters shaded in **peach** are related to high frequency touch points in the air cabin. The touch frequency of each area is currently being investigated. Once information is collected it will be presented to the greater team (FAA, NRC, Boeing, and stakeholders). At this time a decision will be made regarding the subset of parameters to be included in data collection in the CATR.
- Parameters will be collected in either CATR and/or the field. There will be cases where there is overlap, with one parameter being collected in both environments (Field and CATR), allowing for validation. Such overlap might allow model configuration and/or benchmarking depending on the model approach, etc.

Table 1: Parameters for Gate area

Type	**Data description**	**Units**
Movement	Facial direction.	Binary [Expected / Deviation]
Speech	Speech detected crew-pax	Binary [Yes / No]; Time (s)
Speech	Speech detected pax-pax	Binary [Yes / No]; Time (s)
Movement	Movement (in and out of seat, time spent etc.)	Time (s)
Movement	Number of people that have carry-on luggage (roll / backpack / handbag). Might be derived from reviewing the queue.	#
Movement	Number of people that use the counter **<u>prior</u>** to boarding - may be covered by [10] if it is started early enough in the process. Including those with mobility needs. As opposed to visit to the bathroom, etc.	#
Movement	Distance between people	m
Speech	Speech detected crew-crew	#
Close contact	Kiosk counter (after boarding commences) - moves from [7] to [10] after boarding	#
Movement	Processing time at counter (delay time experienced by individual)	Time (s)
Movement	Queue length (across time)	#
Event	Length of gate dyad	Time (s)
Movement	Time spent in queue	Time (s)

Action	Time spent eating/drinking	Time (s) / #
Action	Mask - on/off	Binary [On/Off]
Touch -shared	Shared kiosk items - desktop, pens, boarding pass, phone, luggage	#
Touch -shared	Touch body (crew-pax)	#
Movement	Type of queue structure	Description
Physiology of crew	Proshirt (n=2)	TBD
Physiology of pax	Proshirt (n=6)	TBD
Touch	Face touch	#
Movement	Length of time boarding passes are scanned (Service time)	Time (s)
Speech	Speech detected - cough	#
Speech	Speech detected - sneeze	#

.

Table 2: Parameters for Jet-bridge.

Type	**Data description**	**Units**
Movement	Delay experienced at interface between jetway / aircraft (derived flow)	Time (s)
Shared touch	Touch - shared items - luggage (ramp handlers-pax)	#
Speech	Speech detected crew-pax	Binary [Yes / No]; Time (s)
Speech	Speech detected pax-pax	Binary [Yes / No]; Time (s)
Movement	Direction facing	Binary [Expected / Deviation]
Speech	Speech detected crew-crew	Binary [Yes / No]; Time (s)
Event	Time of first person arrival	Time (s)
Event	Length of jet-bridge dyad	Time (s)
Event	Time of last person departure	Time (s)
Movement	Density / distance of those in the queue	p/m2 OR m
Movement	Queue length (across time)	#
Touch	Mask - on/off	Binary [On/Off]
Movement	Type of queue structure	Description
Physiology	Physiology of pax	TBD
Physiology	Physiology of crew	TBD
Shared touch	Fuselage	#

Action	Time spent eating, drinking	Time (s)
Touch	Face touch	#
Speech	Speech detected - cough	#
Speech	Speech detected - sneeze	#
Boarding/deboarding	# close contacts or shared occupancy with staff (non-crew)	#

Table 3: Parameters for Cabin.

Phase of Flight	**Data description**	**Units**
All	Seat Back Touches	#
All	Speech detected crew-crew (comparable to Herz)	#
All	Speech detected crew-pax (comparable to Herz)	#
All	Speech detected pax-pax (comparable to Herz)	#
All	Face Touching	#
Cruise - Service	# of touches between crew-pax	#
Cruise - Service	Time service takes per monument	Time (s)
All	LAV use queue	#
Deboarding	Deboarding - queue + Baggage collection	p/s
Deboarding	Lagging during deboarding (head count)	#
All	LAV external doorknob	#
All	LAV internal doorknob/lock	#
All	LAV flush button	#
All	LAV Faucet	#
Cruise - Service	# of people who refuse service	#
All	PSU - instrumentation	#
All	Direction facing	Binary [Expected / Deviation]
All	LAV use time	Time (s)
Cruise - Service	Garbage collection - # of shared items touched	
All	LAV use #	#
All	Time out of seat	Time (s)
All	%Pax out of seat	#
All	# Pax in aisle	#
Boarding, Deboarding	Length of boarding/deboarding time	Time (s)
Cruise - Service	Length of service	Time (s)
Cruise - Service	Length of garbage collection	Time (s)
All	Mask on/off	Binary [On/Off]

Cruise	Duration of crew - crew contact (in aisle / galley)	Time (s)
Cruise	Duration of crew - pax contact (in aisle / galley)	Time (s)
Cruise	Window Touch	#
Cruise	Window blind Use	#
Cruise	Recline button Touch	#
Cruise	Fuselage Touch	#
Cruise	Tray table Touch	#
Cruise	Seat back (top of seat as people walk aisle) Touch	#
Cruise	Seat pocket Touch	#
Cruise	Seatbelt Touch	#
Cruise	Armrest Touch	#
Cruise	Barriers Touch	#
Cruise	Use of hand sanitizer/wipes (on receipt of wipe or at later time – use on hands/on tray). Note in field whether it is passed out and use.	# of people using and when
All	Physiology of pax	TBD
All	Physiology of crew	TBD
Cruise	Field: Capture movement when out of row and identify what people do, with whom (i.e. those remote from individual) and how long it takes for them to return to seat.	#
All	Time spent eating/drinking	Time (s)
Boarding	Time to enter each seat (permutations with pax in seats already)	Time (s)
Deboarding	# close contacts or co-occupancy with cleaning staff	#
All	Speed of movement /queue in aisle/personal spacing	m/s
Boarding	Time to board (enter through to seated)	Time (s)
All	Overhead bin	#
All	Time 2 crew members were in galley	#
All	Number of people with luggage in cabin	#