430

Applying Flow simulation framework to model passenger behaviour in an airport terminal in North America

GÖZDE UYAR 1, ÅSMUND IZAKI 1, FREYAAN ANKLESARIA 1, RICHARD SPENCER 2

ERA-CO, LONDON, UNITED KINGDOM 1,

WOODS BAGOT, SAN FRANCISCO, USA 2

ABSTRACT

‘Strong programme’ buildings are defined in space syntax theory as those where diverse groups of people and activities come together in a well-defined manner. Airports are one such functional typology of complex buildings with strong programmes, where passenger movement is highly defined by spatio-temporal factors such as operational flight schedules and designated spaces for different user groups. In addition to their primary functions as transport hubs other uses can include retail units, leisure, and service spaces. To pre-empt issues with the circulation system, thereby improving passenger experience, agent-based models are required to assess flows in the preliminary stages of airport designs. This case study demonstrates the application of an extended simulation framework called Flow, to airside activities in an airport terminal extension project in North America.

Given the lack of data, predicting, and simulating movement patterns in an unbuilt project usually requires a large set of assumptions as input for modelling. Due to its well-defined programme, modelling assumptions in this project were built up from various data sources including detailed passenger surveys and flight schedules from recent years (2015 and 2019). The proposed design option was assessed during the peak three-hour scenario, on a Friday evening (7pm-10pm). The journeys of 9,000 passengers with eight unique profiles and itineraries were simulated. Business and leisure passengers were further categorised as originating, arriving, or connecting passengers where each passenger was assigned a journey that included shopping, eating, using a restroom, and visiting terraces with a pre-assigned dwelling time. The originating and destination flights were paired using a routing dataset and distributed between gates. All destination units were weighted by their area, frontage visibility from the floor, proximity to decision-making points and the shortest detour to destinations.

In summary, the case demonstrates how a sophisticated agent-based model along with spatial analysis provided critical insights, thus informing the design process. The extended framework Flow enabled the simulation of complex itineraries of different user groups in a strong programme building. Outputs helped inform designers to enhance passenger experience by improving legibility and wayfinding early in the design process. Also, ideal locations for concessions were identified to increase benefit from footfall as well as to minimise travel time between gates and facilities. Though dealing with a specific case here, this process of evidence-based-design demonstrates potential for applicability in the design of complex buildings in general.

KEYWORDS

Agent-based modelling, Evidence-based design, Space Syntax, Airport Terminal Design, Movement simulation

1 INTRODUCTION

Operational efficiency and passenger experience are the key drivers of performance in airport terminal buildings. Understanding potential passenger movement early in the design process helps to make better informed decisions before the design is realised. Agent-based models in space syntax first derived from the findings of cognitive studies by Dalton R.C. (2001) and developed as Depthmap software by Turner et al. (2001) aimed to replicate pedestrian movement through design computation in the built environment. Over the last two decades, these models have been widely used in consultancy to inform design strategies by predicting and assessing movement flows in various buildings and cities. Expanding from key space syntax principles, the case study presented here shows the application of an extended simulation framework developed in an airport terminal extension project in North America.

Passengers have distinct itineraries and movement behaviour in airport buildings. Circulation patterns depend on many factors including multiple check points, passenger boarding times, passenger's purpose of travel, gate locations, itineraries shaped by individual choices as well as desire to visit a shop before departure. These types of buildings where user behaviour is strongly affected by the programme of the building are defined as Strong Programme Buildings in Space Syntax theory (Hillier, B. 1996). In strong programme buildings, movement is not exploratory but heavily influenced by its functional and operational requirements. To account for a diverse and complex visitor behaviour in agent-models, a refined simulation methodology is required.

There are agent-based modelling software packages where complex itineraries can be simulated, where the agent is taken from point A to point B such as in Legion and MassMotion. Agent-based models are also used in space syntax for consultancy work using the Depthmap software to assess potential movement flows at the early stages of design projects. The user needs to input a pre-calculated origin-destination matrix where the number of people expected in each destination is manually inserted by the user prior to the analysis. The agent then follows the most visible and the most direct path to its destination. Even though the crucial spatial qualities such as visibility and distance are considered in Depthmap, it lacks complex and temporal behaviour that might arise from the programme of the building. The proposed Flow framework here offers a more sophisticated method to account for the complex passenger behaviour combined with spatial qualities derived from the space syntax theory (Izaki Å., Uyar G., Jones S. 2022 forthcoming). It enables agents to have the autonomy to choose their activities and destinations with individual itineraries, walking speeds and dwell times in the building. This method allows for a less assumption-based model without the need for a pre-defined origin-destination matrix input from the user, as required in earlier space syntax studies.

Another key advantage of the Flow software is that the algorithm allows for temporal data to be simulated. During the peak three-hour period, each passenger has a different walking speed, dwell time, boarding time and therefore different entry and exit times in the simulation. As a result, the flow rates between points A and B change every second of the selected scenario. This dynamic algorithm enables to capture details such as walking speeds or dwell-times of each persona and passenger during the simulation. Also, flight schedules, and landing times are all crucial factors of the microsimulation of this strong programme building.

The case study presented in this paper reflects on a consultancy project undertaken by ERA-co in collaboration with Woods Bagot as the project lead and commissioned by LAWA in 2019. The brief included the design of a new two-storey terminal extension building, Midfield Satellite Concourse South (MSC-South), at Los Angeles International Airport (LAX) to accommodate eight gates for domestic flights, concession units, viewing terraces, service rooms and circulation spaces. (MSC-South) is directly connected to the Tom Bradley International Terminal's West Gates satellite which is served by a foot tunnel as well as by shuttle buses to other LAX terminals. The key intent for the spatial analytics and the consultancy work undertaken by ERA-co was to ensure that the placement of the gates and the units was carefully planned to eliminate any potential conflict points, maximise passenger experience, increase legibility and operational efficiency as well as maximise benefit from high footfall for retail units.

Flow agent-based modelling software was used to achieve the project goals through its algorithm built to describe spatial relationships objectively and quantitatively, in a measurable way. The outputs of the software were used to assess potential human behaviour and natural movement patterns which led to a set of design recommendations for an iterative design process in collaboration with the design team. Prior to running the agent-based model, other spatial metrics such as visibility and metric catchment were calculated to identify the best corridor alignment for wayfinding as well as allocate restrooms to be accessible from boarding gates. Starting with the building as a tabula rasa and testing initial metrics enabled for an iterative process and not only testing different design options at the end of the project.

The next chapter elaborates on the research on strong and weak programme buildings in space syntax theory as well as some of the current agent-based modelling tools that are used to test these buildings. Chapter 3 presents the case study as well as the methodology and the assumptions used to apply the Flow framework. In Chapter 4, the results are explained under two parts for both spatial and Flow analyses. Lastly, Chapter 5 discusses the advantages and limitations of the framework by suggesting paths for further study.

2 THEORY

Transport buildings are highly functional spaces with complex operational systems. Passenger movement is dependent on many spatial factors such as the location of security checkpoints, the division of restricted vs. unrestricted areas and other procedures that one needs to go through until reaching their destination. Architectural decisions are constrained to meet these requirements to allow for passenger movement to flow within a specific time and space. Validating the success of a building through post-occupancy studies can be costly if issues were found after its construction. However, spatial analytical tools and techniques can help early in the design process to identify and eliminate any potential issues.

2.1 Agent based models

Spatial layout of buildings and cities has been researched and analysed for decades in the field of space syntax to understand how built environment may have influence on human behaviour. Studies have shown that people move in straight lines, gather, and interact in convex spaces (Hillier and Hanson 1984) and experience space through visual perception that changes as we move, defined as “isovists” (Tandy 1967, Benedikt 1979). Using these key principles space can be represented mathematically, and movement potentials can be estimated in the built environment. Isovists approach was applied to spatial systems using Depthmap software and were further developed as Visibility Graph Analysis (VGA) to measure the visibility of complex environments (Turner et. all, 2001). The central role and influence of visual perception on people' s movement choices and patterns, has been unambiguously demonstrated by decades of research from Gibson (1960s Ecological Psychology) to ongoing work at ETH (Emo 2014) and UCL, Koutsolampros on office buildings an Pachilova on hospitals.

Derived from cognitive studies of Dalton R.C. (2001) and combined with early visibility studies, agent-based models were created as a set of analytic tools to simulate more dynamic and complex movement behaviour in spatial systems (Turner and Penn, 2001). In Depthmap, the movement principle of an agent is based on a defined visual field derived from visibility graph analysis. In addition to testing random exploratory movement behaviour, agent models were further extended with a new toolkit to incorporate origin-destination based algorithm (Ferguson, Friedrich, Karimi, 2012). This technique allowed for agents to move between its predefined origin and destination whilst still being able to use visibility metrics as key parameters for movement choices.

Other crowd simulation software such as Legion and MassMotion are also widely applied on transport buildings to model congestion and evacuation scenarios. In rail transport, applying MassModel software, Ikukenthiran, Fisher, Shalaby, and King (2013) showed that adjusting train arrival patterns at interchange stations could have as much as a 63% reduction in passenger congestion. Nevertheless, useful in modelling extreme congestion scenarios by moving crowds from point A to B, these software packages do not account for natural behaviour nor experiential qualities in the same way as space syntax models which show high correlation with observed passenger movement in existing transport buildings (Orellana and Sayed 2013, Kalakou, Filipe and Valério. 2015).

2.2 Strong and Weak programme buildings

In space syntax theory, buildings are classified under two categories in terms of their strength of programme: Strong and Weak Programme buildings (Hillier, Hanson and Peponis 1984, Hillier, 1996). Much of the early development of the space syntax agent models were tested and correlated with observational data from buildings where movement is exploratory and relatively undirected by predetermined destinations, namely Weak Programme buildings, such as in museums and art galleries. Movement in these buildings are not dictated by its programme as the space allows for random, exploratory social activities to take place. In contrast, buildings like airports, railways and hospitals are classified as Strong Programme buildings, a term used for spaces where the movement is strongly determined by their functions and where diverse groups of people and activities come together in a well-defined manner (Hillier, 1996). Even though origin-destination based agent models can be used in Strong Programme buildings, the current methods are not sufficient to capture complex movement behaviour that emerges from operational constraints. Therefore, a new framework is needed to build on to the complexity generated from strong programme buildings like airport terminals.

2.3 The need for a new framework

Described in his 1995 book Non-Places: An Introduction to Supermodernity, French anthropologist Marc Augé uses the term “non-place” to describe airport buildings where there is lack of a feeling of place as opposed to spaces like homes, cafes, and vibrant parks, to which people relate themselves to with history and identity. In contrary to “places” where there is a sense of community and culture, in “non-places” large numbers of people pass through as anonymous individuals. The movement is mainly enforced to be continuous and within directionality with a specific destination goal of the user. This framework is useful to understand the social dynamics of how airports work.

Analysing spatial environments help to understand movement possibilities that the spatial configuration can offer. However, human activities are highly social and movement behaviour varies based on the particularity of users as well as events and spaces. One of the sophisticated frameworks that account for these variables are the Event-Based modelling where various use scenarios are created to simulate human behaviour using different Actors, Activities and Spaces where the event takes place (Simeone and Kalay 2012, Sopher, Schaumann, Kalay 2016). This gave the flexibility to include social, cultural and psychological parameters to the model where interaction between multiple user groups, spaces and activities were simulated. Similarly, Kielar and Borrmann (2016) proposed a new mathematical function to present psychological factors to improve pedestrian destination choices in simulations. According to these models and frameworks, individual behavioural choices were not static, and they constantly changed with their surroundings.

The key argument suggested in this paper is that movement behaviour is inseparable from their spatial, social, and operational settings and therefore should be both included in the simulation modelling, especially in complex buildings with strong programme. Even though the passenger origins and destinations are physically predetermined in an airport building through operational schedules, the intermediary destinations and the experience navigating between these points are still influenced by the spatial layout of the building and the visual perception of the passenger. Similarly, studying two hospital buildings that are typically considered as strong programme buildings; Sailer and colleagues (2013) found that buildings may not need to be strictly classified as either weak or strong as they might still have a degree of both in them. The case study presented here also showed patterns of both strong and weak programme buildings. Some passengers only followed the programme to go to departure gates whereas others had more exploratory behaviour where they visited restrooms or shops before going to departure gates. More importantly, the Flow framework enabled both behaviours to be simulated within the same scenario.

In this paper we demonstrate how we can simulate complex movement behaviour in strong programme buildings using a new framework that combines space syntax methodology with a more sophisticated event-based approach. Using an airport terminal as a case study it shows how this approach can be useful in analysing movement within similar organisational, social, and spatial settings. The application of Flow methodology presented in the next chapter shows how passengers were modelled as dynamic actors that performed predefined itineraries based on varying temporal factors such as dwell times, flight schedules and walking speeds. It acknowledges the need to factor in the strong influence of various aspects of programme such as:

various attractor functions, multiple modes of vertical connections, operational flight schedules, varied propensity to visit the attractors based on the user profiles.

3 DATASETS AND METHODS

3.1 Data collection and general modelling assumptions

Various inputs were required to run the Flow microsimulation. These inputs varied from aircraft specifications to passenger surveys and to flight schedules to be able to account for specific operational requirements of the building's programme. The flow assessment is used to test the busiest scenario to ensure that the level of passenger flows would not be disrupted at any other times. Therefore, the modelling was done for a peak time which aimed to capture the worst-case scenario with the highest possible levels of movement. As a design day flight schedule, or even specific airline users for this new concourse, had not been defined by LAWA, the team identified the Southwest Airlines flight schedule for LAX Terminal 1 as a useful example of high intensity operation. July is typically the busiest month at LAX and analysis of the actual schedule from July 2019 showed that the busiest time of the week was on a Friday between 7pm and 10pm. We therefore used a three-hour peak period for our flow assessment with a two-hour extension period on both ends which also gave us the opportunity to test the overlap of multiple flights and different types of passenger movement.

To calculate the peak numbers, in consultation with LAWA, maximum passenger capacity of each flight was derived from Airplane Design Group (ADG) III specifications as 189 seats with a 90% load factor. Passenger numbers during the busy period were distributed to eight domestic gates using a flight schedule created for the microsimulation, described under the Operational assumptions section.

To access the two-storey building from outside, there were two options: shuttle bus or foot tunnel from Tom Bradley International Terminal. Both modes arrive in the same area of the West Gates building. Since there was not enough information on the passenger choice between the two, we assumed an equal 50% split for each to access the terminal building. The study boundary was set to the building envelope; therefore, agents were not simulated outside the boundary until they reached the building. Movement on the vertical connections were assumed to have a split of 10% for the lifts, 10% for the stairs and 80% for the escalators derived from previous lift consultants' studies.

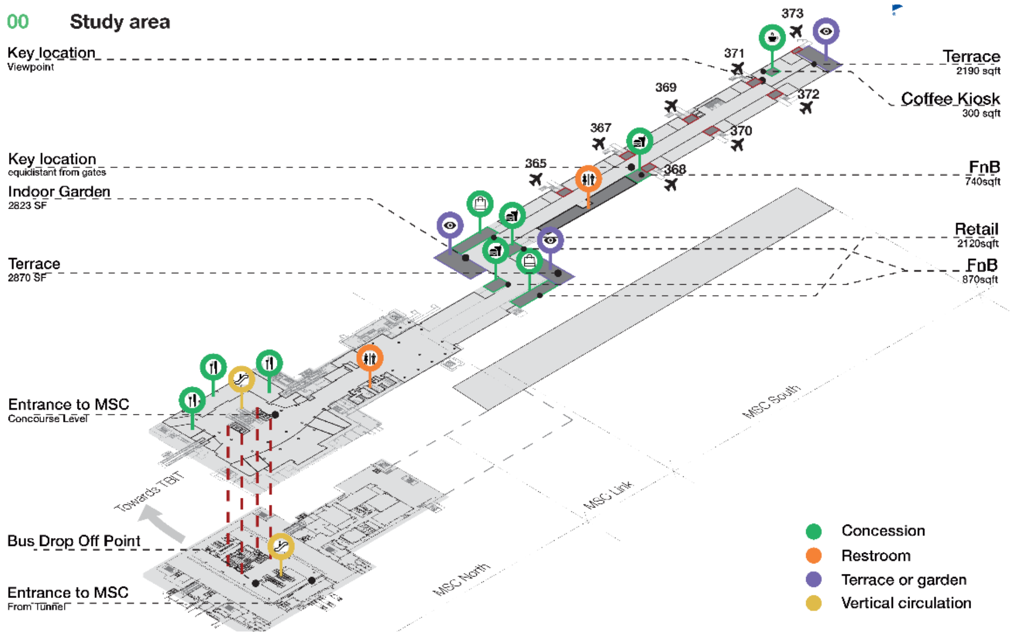


Figure 1: Study area and origin-destination points

3.2 Passenger profile and itinerary assumptions

The inputs for the microsimulation were planned with high complexity to account for a variety of users and choices that could be made on a busy day where the terminal was visited by originating, destination and connecting passengers. Before reaching their final destinations such as boarding gates or leaving the terminal, passengers visited other intermediary destinations such as restrooms, viewing terraces as well as shops and restaurants.

All originating, destination and connecting passengers were also divided under two main profiles based on their purpose of travels: Leisure and Business. The percentage split between the two was collected from 2019 LAX International Airport Air Passenger Survey which showed that 72% of passengers were travelling for leisure and 28% for business purposes. One of the key assumptions made was that there were behavioural differences between the two profiles on time spent in leisure activities including the number of concession units visited, and the duration spent. Among the ones who shopped before departure, Leisure passengers were assumed to spend more time on leisure activities than Business passengers.

To account for personal choices and other differences, the two passenger profiles were further split into four categories each with a unique itinerary and dwell time in their multiple destinations. The itinerary types, the percentage splits and average dwell times in each destination have been extracted from the 2016 Customer Survey Report of San Francisco International Airport (Corey, Canapy & Galanis, 2016). According to the survey, almost a third of the departure passengers for both profiles were directly headed to their departure gates after the security checks. Around 17 to 18% of passengers had either grab-and-go or seated food or drinks before departure and spent between 10 to 35 minutes in each unit. Another 24 to 32% of passengers were assumed to visit at least one shop spending about 10 minutes in each unit. Finally, the fourth itinerary type included a trip to both Food and Beverage (F&B) and at least one shop before departure. In addition to concession uses, 50% of passengers in all categories were assumed to use the restrooms up to twice with about 5 minutes dwell time each time and 40% of passengers visited viewing terraces for about 15 minutes before boarding.

To calculate average passenger dwell times at the airport, 2015 Los Angeles International Airport Air Passenger Survey Results were used. According to the survey results, 81% of passengers spend less than 3 hours in an airport (Unison Consulting, 2015). Using this data as a benchmark we assumed a range between 50 – 180 minutes in our modelling to be able to capture a diversity of passengers. Also, the passengers were assigned varying walking speeds between 2.95ft/s and 3.60ft/s (0.9m/s – 1.1m/s) slightly slower than average normal speeds where carrying hand baggage was accounted for.

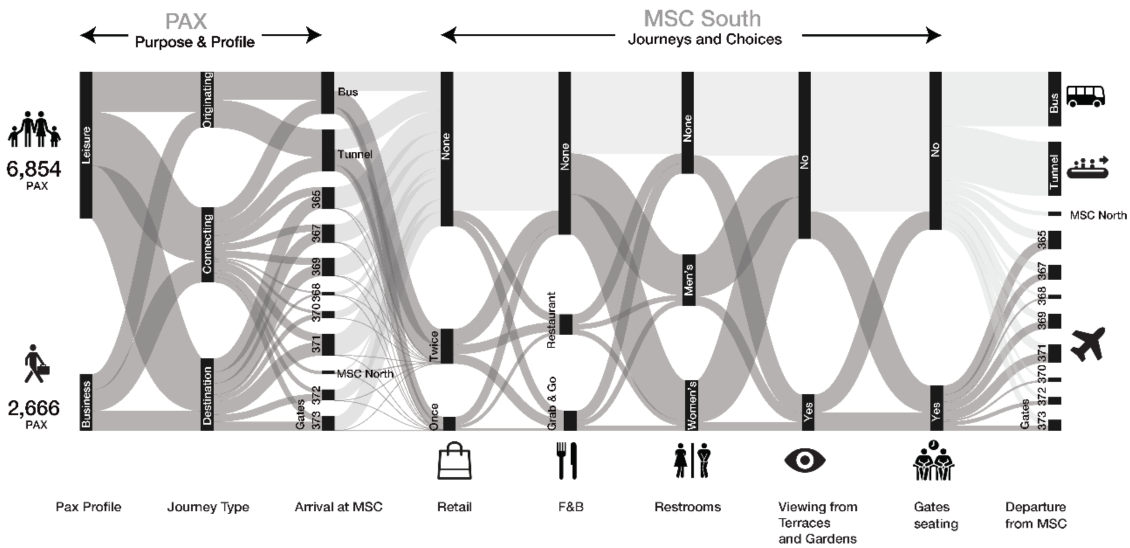


Figure 2: Passenger Journey Summary Sankey Diagram

3.3 Passenger travel assumptions

Departure passengers included the ones who originated in the terminal as well as those who connected from another flight to depart from the same terminal building. Once the departure passengers arrived at the concourse level, half of them were assumed to find their gates before going to retail units, restrooms, or the terraces. During the departure time, 75% of passengers were assumed to be already waiting in the seating area while the remaining 25% directly headed to the boarding area from concession units (Figure 3).

According to previous passenger surveys, 63% of destination passengers who arrive at the terminal end their journey at LAX. The remaining 37% passengers would transfer to another flight within the same airport. Of those 37%, only 5% were assumed to be connecting to another flight within the same terminal. Until their next flight, we assumed they would have similar itineraries to departure passengers in terms of visiting various concession units. For the ones leaving the terminal we assumed that 50% of them would visit a restroom before leaving the terminal.

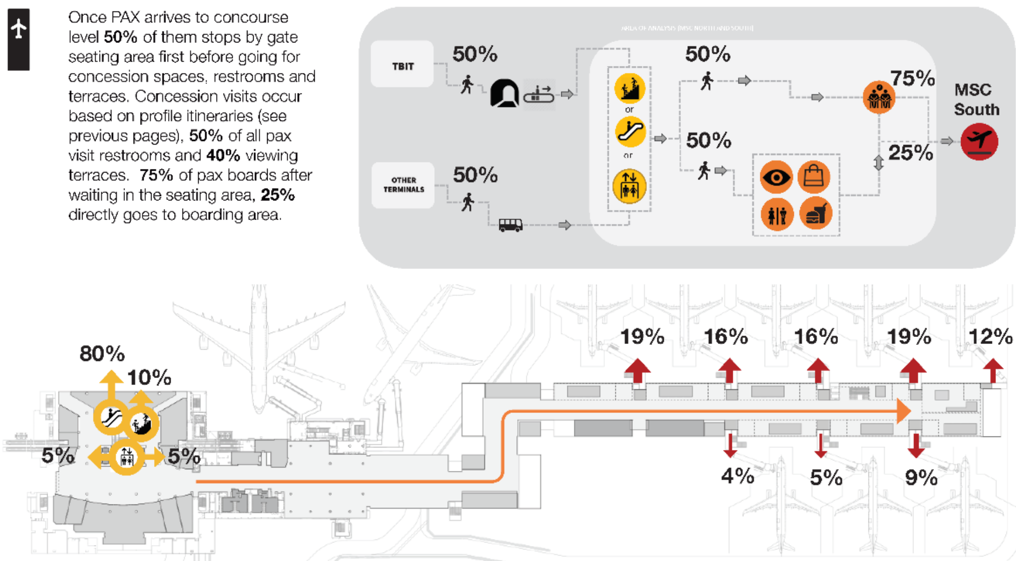


Figure 3: Departure passengers journey assumptions

3.4 Operational assumptions

Flight schedules and operational assumptions were key to simulate passenger flows during the peak three-hour period. The use of temporal factors was crucial to capture the programme of the terminal building as well as to replicate natural passenger behaviour close to real-time scenarios. As it was the early stages of the design, there were no flight schedules for the proposed gates in our study area. To create an estimate flight schedule, we used an existing schedule of a similar size domestic terminal with similar aircraft sizes within the same airport and used a filtering system to adapt it to our study area. As a result, LAX Terminal 1, Southwest Airlines, July 2019 flight schedules for 12 gates were used as a proxy to generate MSC South assumptions. Original LAX flight data was filtered three times to obtain the peak three-hour period of the week. Two hours on both end of the peak was also included to capture all potential overlaps in the microsimulation. Therefore, the microsimulation was produced for a total of seven hours, but the gate counts were only extracted during the peak three-hour period. Boarding ended 10 minutes before departure and for arrival passengers deplaning ended 15 minutes after landing times.

All originating and destination flights have been paired using the routing information provided in Terminal 1. The schedule for 12 gates was adjusted for 8 gates by removing every third flight to match the MSC South capacity. Finally, the paired flights have been distributed across the gates with at least 15min gap between each arrival and departure times and with more weight given to the eastern side of the concourse as requested by the client (Figure 4).

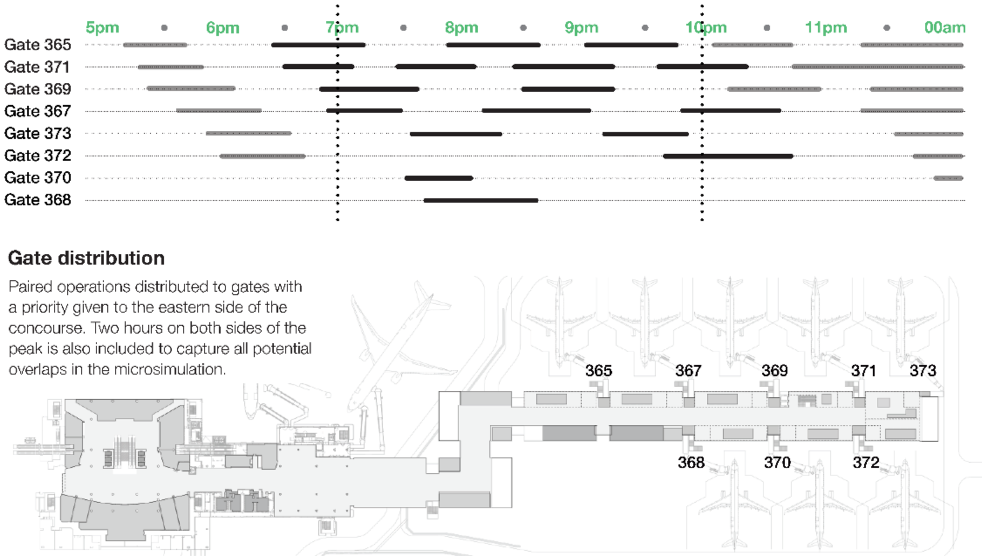


Figure 4: Flight schedule per gate during the peak three hours

3.5 Movement assumptions

Movement assumptions in the algorithm are mainly divided under three principles:

Passenger Itinerary: Each passenger has a pre-assigned a profile and a type of itinerary that define their journeys and activities including shopping, eating, using restroom, and visiting terraces. Each activity has a pre-assigned range of dwell time.

Unit selection: All units within each four categories: retail, food and beverage (F&B), restrooms, terraces are weighted by their area, frontage visibility from the floor, proximity to decision making points and shorter detour to destinations.

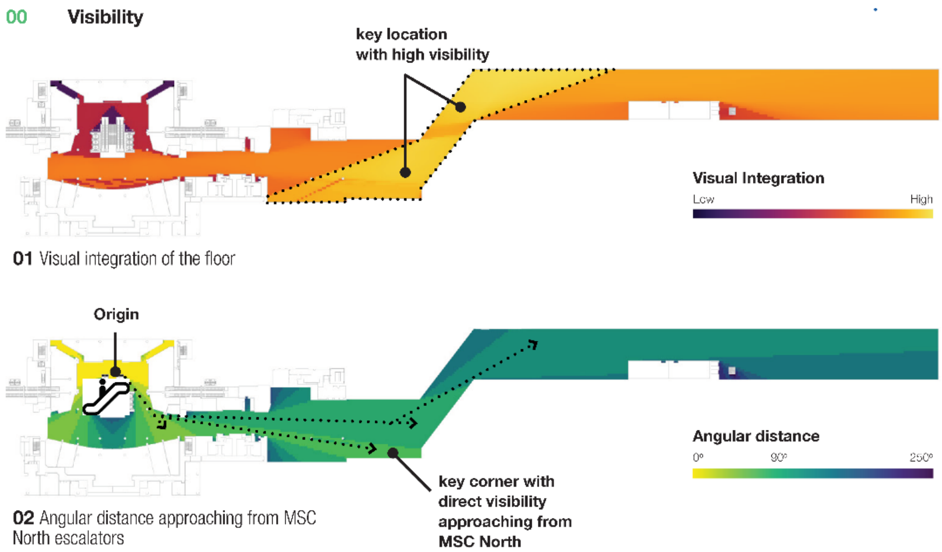
Circulation principles: Passengers decide their routes based on their pre-assigned itinerary types and final destinations. The most visible, closest and direct routes (with least angular deviation) are preferred.

The software requires other intermediate datasets to be input in addition to the assumptions. These include the simplification of CAD Plans, placement of origin and destination points, table for individual passenger profiles and journeys. For this study, in addition to flow analysis, other spatial analyses were also conducted to answer some of the strategic questions around the placement of concession. The outputs included general floor visibility, concession visibility, metric catchment from gates and escalators. Flow analysis outputs included flow density, flow paths, gate counts on key locations and level of services based on both TfL and Fruin standards.

4 RESULTS

4.1 Spatial Analysis

Prior to Flow Analysis, the layout was analysed through other spatial metrics to identify key locations for concession units. These metrics included space syntax Visibility Graph Analysis (VGA) applied to the circulation area, the angle of visibility approaching from the escalators and the lifts as well as the walking times to get to proposed restroom locations within selected key locations (Figure 5). The VGA showed that, the two diagonal corners were visually the most integrated locations on the plan. However, the geometry of this diagonal corridor blocked direct visibility towards the gates approaching from the escalators as picked up in the angular distance analysis. This initial study enabled us to give strategic recommendations early in the design process before any design option was proposed. As a result, the design team allocated concession units in the most visible and accessible locations including restrooms accessed within two minutes of walking distance from the furthest point in the layout.



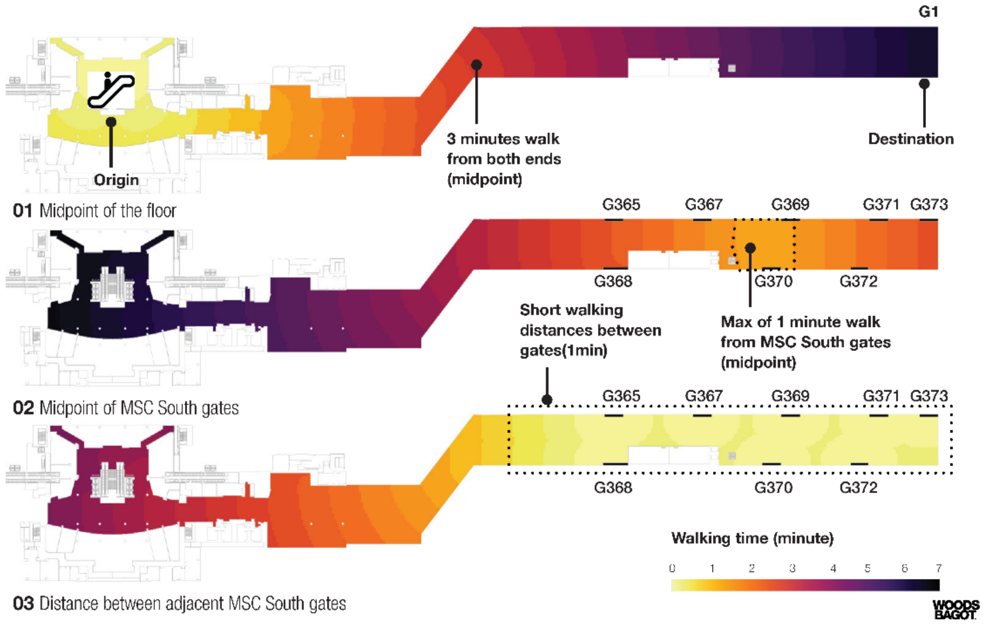


Figure 5: Space syntax analysis showing VGA, Angular distance and metric catchment from selected key locations

4.2 Flow Analysis

After an initial design option was proposed by the design team, the drawings were simplified and input to the software. During the Flow Analysis, approximately 9,000 passenger flows were simulated between the three-hour peak scenario in the proposed design option. The results were presented in the form of recommendations informed by cumulative flow density maps and paths. Extracted numbers from selected key locations were also assessed against Transport for London (TfL) as well as Fruin level of service standards to ensure that there were not any potential conflict points in the floor. There were five key output maps that showed the results of the Flow Analysis.

1- Flow density
2- Flow paths
3- Gate counts
4- Level of service for both TfL and Fruin standards
5- Visitor density

Flow density measured the passenger density in the circulation area which showed key desire lines in the form of a heat map. Flow paths of all passenger groups showed movement levels increasing in the middle of the floor plan and dropped towards the end of the terminal. Four locations were highlighted as potential conflict points between the arrival and departure passengers (Figure 6).

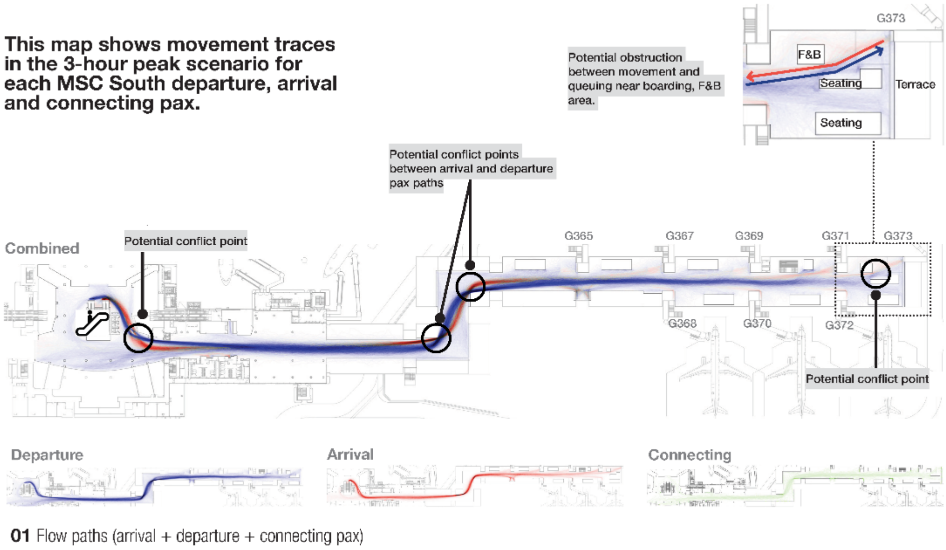


Figure 6: Flow paths per passenger type

The gate counts map showed bi-directional passenger counts per five-minute peak period on selected key locations. According to that the busiest gate location had 71 passengers moving on both directions (Figure 7). These numbers were converted into a peak minute period and were divided by corridor widths to measure the Level of Service using both Fruin and TfL (Transport for London) standards. Compared to Fruin standards, TfL suggests stricter thresholds for calculating the comfort levels for circulation. Therefore, TfL was selected for the purpose of this study. This analysis enabled us to understand how comfortable it would be to circulate within the proposed layout and identify any potential issues before finalising the design. The results showed that all corridor widths were adequate to support the simulated movement levels between A and B+ except for one location near the lift lobby which was calculated as C+ which meant it might be more uncomfortable compared to other locations in the layout (Figure 8).

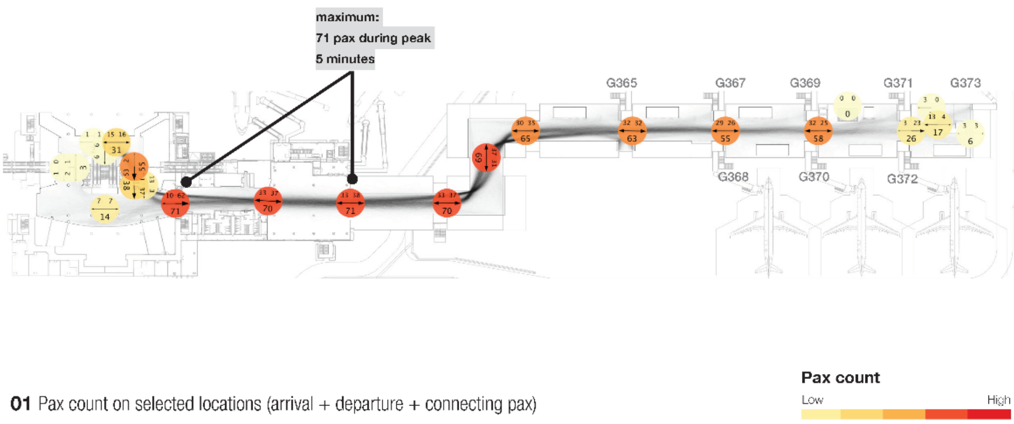


Figure 7: Passenger count on selected locations (pax/5min)

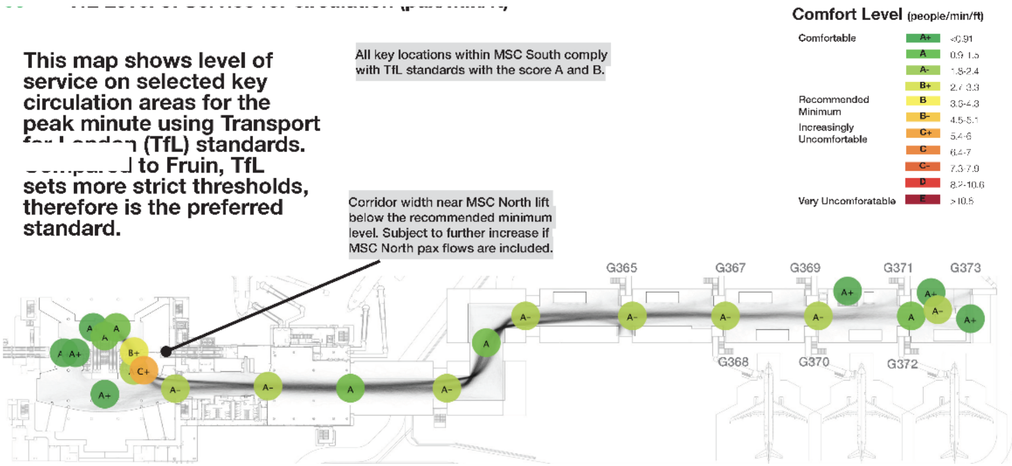


Figure 8: TfL Level of service for circulation (pax/min/ft)

Lastly, the Visitor Density map was produced to capture the potential performance of each concession unit. Concession units were grouped under three categories: Retail, Food and Beverage (F&B) and Viewing Terraces. The visitor density in each unit was grouped per category and the proportional comparison were shown by pie charts (Figure 9). To calculate their potential performances, visitor densities in each unit were compared as percentage below or above average (–% or +%) against the three-hour period within the same category (Figure 9). For example, if a retail unit had 10 passengers per square feet during the peak-period and if the average was 5 in other retail units during the same period, then that unit would have a +100% higher performance above the average. The reason for this relative comparison was that the results were only specific to the peak scenario, and they could not be extrapolated for movement behaviour across other time frames.

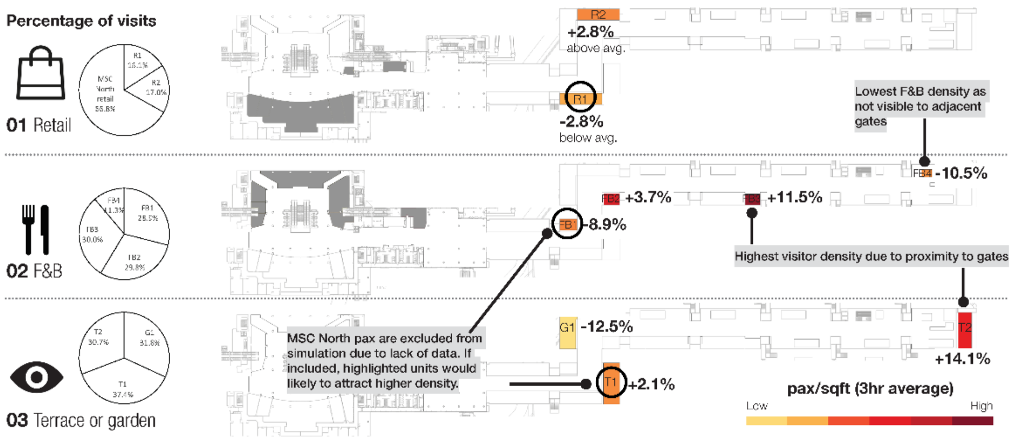


Figure 9: Three-hour average visitor density per concession unit (pax/sqft)

As a summary, Flow analysis found that all key locations within the proposed terminal layout complied with both TfL and Fruin Level of Service standards. However, some potential conflict points were identified between arriving and departure passenger flows near the lift lobby and the link bridge. Also, some concession units were placed in good proximity to gates but required to be more visible from them to attract more footfall. Recommendations were given on key locations for signage as well as for increasing performance of some F&B units and terraces (Figure 10).

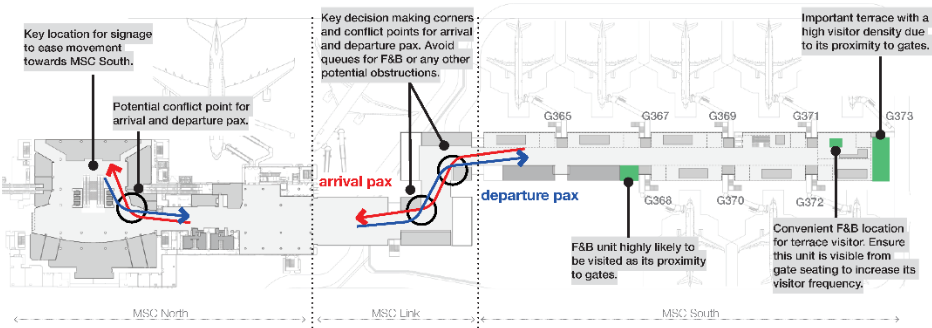


Figure 10: Summary and recommendations

5 CONCLUSION AND DISCUSSION

5.1 Advantages of Flow Framework

Flow framework showed the use of a sophisticated methodology and a complex set of assumptions to simulate movement behaviour within a selected period in a strongly programmed airport terminal building. The modelling included datasets from previous passenger surveys and flight schedules as well as sets of assumptions made in the absence of relevant data. One of the complexities of the simulation was the creation of unique passenger profiles with different dwell times, walking speeds and itinerary types traveling for both leisure and business purposes. All originating, arriving, or connecting passengers were also modelled including their varying origin and destination points. Combining a sophisticated algorithm with key space syntax movement principles using spatial configuration of the building resulted in a unique approach which allowed for a more nuanced agent-based model compared to similar software used in the industry.

One of the key strengths of this approach was to incorporate temporal factors to the microsimulation which enabled us to account for the building's operational requirements and its influence on passenger movement. Every second, new passengers were released to the system with unique itinerary and profiles. Time-based inputs such as flight schedules, boarding times at gates, passenger walking speeds, total dwell times spent in activities made it possible to calculate overlapping passenger flows during the peak times generated through the algorithm. This automated method allowed for a more rigorous approach in identifying potential congestions during the peak time, compared to other software where manual calculations might be needed.

5.2 Limitations and future potentials

The complexity of assumptions and the bespoke algorithm allowed for an increased range of possibilities and parameters to be used for simulating numerous options and scenarios. However, this also resulted in some challenges and limitations. Firstly, the methodology could not be used as a quick design tool due to the amount of input and time required to build the first model with complex assumptions. It also required proposed design option to be drawn before running the analysis which made it harder to give quick insights early in the design process. Therefore, to be able to guide strategic decisions early in the design process, other spatial analytical metrics and tools were used such as the Visibility and Catchment from selected locations.

Secondly, the simulation results were heavily influenced by the set of assumptions made prior to the analysis. For example, passengers' selection of concession units was dependent on the unit's visibility, its proximity, capacity, and whether it was on the way to passengers' ultimate destination. These assumptions affected their choices of shops to visit. Also, the scenario was simulated for the worst-case scenario to capture potential congestion points. This prohibited the results to answer questions around the popularity of proposed shops for non-peak times as the results could not be extrapolated for movement behaviour across other time frames. Therefore, no findings could be given on retail performance for other non-peak times as the popularity of shops may depend on various other factors. As a result, only relational comparison on visitor density was made between each unit and other units with the same type of use. However, in the future new scenarios can be redesigned to assess the popularity of shops, and the number of customers in each concession unit using annual averages of similar existing retail spaces.

Overall, as intended at the start of the project, Flow software helped answer some of the key questions such as identifying potential pinch points and congestion areas in holdrooms and circulation areas. It allowed for assessing level of services on key locations as well as identifying best location for concession uses to minimise travel time between gates and facilities. The outputs were used to shape design to maximise passenger experience by improving legibility and wayfinding in circulation spaces and new gates. Due to its sophisticated algorithm and the possibilities of modelling complex inputs, the software has great potential to test future scenarios and the results could be validated by post-occupancy study.

REFERENCES

Augé M., (1992) Non-Lieux, Introduction à une anthropologie de la surmodernité, translated as Non-Places: Introduction to an Anthropology of Supermodernity (1995).I. Buchanan 'Non-Places: Space in the Age of Supermodernity' in R. Barcan and I. Buchanan (eds.)Imagining Australian Space (1999).

Benedikt, M. L. (1979) 'To Take Hold of Space: Isovists and Isovist Fields', Environment and Planning B: Planning and Design, 6(1), pp. 47–65. doi: 10.1068/b060047.

Corey, Canapy, Galanis (2016), BART Customer Satisfaction Study, BART Marketing and Research Department

Dalton R. (2001), The Secret is to Follow Your Nose: Route Path Selection and Angularity, 3rd International Space Syntax Symposium Atlanta

Emo B. (2014), Seeing the Axial Line: Evidence from Wayfinding Experiments, Behavioral Sciences 4, no. 3: 167-180. https://doi.org/10.3390/bs4030167

Ferguson P., Friedrich E., Karimi K. (2012), Origin-destination weighting in agent modelling for pedestrian movement forecasting, 8th International Space Syntax Symposium, Santiago

Fruin J. (1987) Pedestrian Planning and Design

Gibson J. (1960), The Ecological Approach to Visual Perception: Classic Edition, Psychology Press & Routledge Classic Editions

Hillier, B. (1996, 2007), Space is the Machine: A Configurational Theory of Architecture. Space Syntax: London,UK. P197

Hillier, B. and Hanson, J. (1984) The Social Logic of Space. Cambridge: Cambridge University Press. doi: 10.1017/CBO9780511597237.

Hillier, B.; Hanson, J.; Peponis, J.; (1984) What do we mean by building function? In: Powell, J.A. and Cooper, I. and Lera, S., (eds.) Designing for building utilisation. (pp. pp. 61-72). E & F.N. Spon Ltd: London, UK.

Ikukenthiran S., Fisher D., Shalaby A., King D. (2013), Pedestrian Route Choice of Vertical Facilities in Subway Stations. Transportation Research Record: Journal of the Transportation Research Board. 2351. pp.115-123.

Izaki Å., Uyar G., Jones S. (2022, forthcoming), Flow: Agent Simulation Framework with Spatial Choice for Multilevel Buildings, Proceedings of the 13th Space Syntax Symposium, Bergen

Kalakou, S., Moura F., Medeiros V. (2015), Analysis of airport configuration and passenger behaviour.

Kielar P, Borrmann A. (2016), Modeling pedestrians' interest in locations: A concept to improve simulations of pedestrian destination choice Simulation Modelling Practice and Theory 61, pp. 47–62

Koutsolampros, P., Sailer K., Varoudis T., Haslem R. (2019). Dissecting Visibility Graph Analysis: The metrics and their role in understanding workplace human behaviour.

Orellana N., Al Sayed K. (2013), ON SPATIAL WAYFINDING: Agent and human navigation patterns in virtual and real worlds, Proceedings of the Ninth International Space Syntax Symposium, Ed. by Y O Kim, H T Park and K W Seo, Seoul: Sejong University

Pachilova R., Sailer K. (2015), Size and complexity of hospitals matter for quality of care: A spatial classification of NHS buildings. 10.13140/RG.2.1.2766.0646.

Penn A., Turner A. (2001). Space Syntax Based Agent Simulation. Penn, Alan and Turner, Alasdair (2002) Space Syntax Based Agent Simulation. In: Schreckenberg, Michael and Sharma, Som Deo, (eds.) Pedestrian and Evacuation Dynamics. Springer-Verlag, Berlin, Germany, pp. 99-114. ISBN 3540426906.

Sailer, K; Pachilova, R; Kostopoulou, E; Pradinuk, R; MacKinnon, D; Hoofwijk, T; (2013) How strongly programmed is a strong programme building?: A comparative analysis of outpatient clinics in two hospitals.

Simeone D., Kalay Y. (2012). An Event-Based Model to Simulate Human Behaviour in Built Environments. Proceedings of the 30th eCAADe Conference. 1.

Sopher H., Schaumann D., Kalay Y. (2016). Simulating Human Behavior in (un)Built Environments - Using an Actor Profiling Method. International Journal of Computer, Electrical, Automation, Control and Information Engineering. 10. 2030 - 2039.

Srikukenthiran, S. et al. (2013) 'Pedestrian Route Choice of Vertical Facilities in Subway Stations', Transportation Research Record, 2351(1), pp. 115–123. doi: 10.3141/2351-13.

Tandy, C. R. V. (1967). ‘The isovist method of landscape survey’. In: Murray, H. C. (ed.), Methods of Landscape Analysis, Landscape Research Group: London.

Transport for London (2010) Mayor of London, Pedestrian Comfort Level Guidance First Edition, Version 2 (2019)

Unison Consulting, (2015), Final Report, Los Angeles International Airport 2015 Air Passenger Survey Results and Findings, presented to: Los Angeles World Airports

Unison Consulting, (2019), 2019 Passenger Survey, Los Angeles International Airport, prepared for Los Angeles World Airports, pp.64.