AITPM
Leadership in
Traffic and Transport

PEDESTRIAN MODELLING GUIDELINES

About AITPM

The Australian Institute of Traffic Planning and Management Ltd (AITPM) is the central point of reference for practitioners in traffic and transport planning and management.

AITPM has a vision for a sustainable, efficient, safe and accessible transport system. We are focused on leading our members to connect, collaborate, and participate to advance their skills, capability, and knowledge in order to support a good transport system.

As a member driven organisation, we are focused on collaboration and engagement across the industry to influence better outcomes, and in growing industry capability through sharing and developing knowledge and experience.

The AITPM Pedestrian Modelling Guidelines are an exemplar of our ethos. Collaboratively developed by our members and volunteers, it represents the depth of knowledge and experience in our transport and land use modelling community.

AITPM and its members gratefully acknowledge the voluntary commitment of the Editorial Team to growing the body of knowledge.

Australian Institute of Traffic Planning and Management Ltd
PO Box 107, LUTWYCHE QLD 4030
www.aitpm.com.au
aitpm@aitpm.com.au

TABLE OF CONTENTS

EDITORIAL TEAM 3

EDITION HISTORY 3

1 INTRODUCTION 4

1.1 Purpose 4

1.2 Guideline objectives 4

1.3 Target audience 4

1.4 Document limitations 5

2 ASSESSMENT SPECIFICATIONS AND NEED 6

2.1 What is pedestrian modelling? 6

2.1.1 Static or spreadsheet modelling 6

2.1.2 Dynamic modelling 7

2.2 Why model? 7

2.3 Questions typically answered through modelling 8

2.4 Expectations of model results and appropriateness for use 8

2.5 Model Quality Assurance / Quality Control 10

3 UNDERSTANDING THE ASSESSMENT ENVIRONMENT 11

3.1 Common areas for assessment 11

3.2 Consideration of other modes 14

4 TYPES OF ANALYSIS 17

4.1 Introduction 17

4.2 Static analysis 17

4.2.1 Semi-Dynamic spreadsheet modelling 18

4.2.2 Time-Space Modelling 18

4.3 Dynamic microsimulation analysis 19

4.4 Summary 22

5 ASSESSMENT CRITERIA 25

5.1 Level of Service 25

5.1.1 Cumulative Mean Density (CMD) 27

5.1.2 Cumulative High Density (CHD) 27

5.2 Other Level of Service Criteria 27
5.2.1 Transport for NSW 27
5.2.2 Transport for London 28
5.3 Travel time and delay 28
5.4 Other criteria 29
5.5 Appropriateness of different criteria 30
5.6 How to define criteria 30
5.6.1 Queuing 31

6 DATA REQUIREMENTS AND MODEL CALIBRATION / VALIDATION 33
6.1 Data inputs 33
6.1.1 Manual counts 33
6.1.2 Automatic counts 34
6.2 Typical data requirements for modelling non pedestrian modes 35
6.3 Modelling calibration and validation 36
6.3.1 Calibration 37
6.3.2 Validation 39
6.3.3 What if the Environment does not yet exist? 40

7 INTERPRETING RESULTS 42
7.1 Output types 42
7.2 Static spreadsheet analysis 43
7.3 Dynamic modelling 46
7.4 Things to watch out for 55
7.4.1 Perceived Accuracy 55
7.5 Average Level of Service 55
7.5.1 What is meant by average? 55
7.5.2 A Range of Results for the Same Demand 56
7.6 Measures to Improve the Specification 59
7.6.1 Approach 59
7.6.2 Model Specification 60
7.6.3 Technical review requirement 61

8 FURTHER REFERENCE MATERIAL 62

Editorial Team

These Guidelines represents a sample of the combined wisdom and experience from many pedestrian modelling practitioners. As lead editor I thank all the contributors for their input which was provided on a voluntary basis and at no cost to the AITPM. The objective being a software agnostic and altruistic desire to raise the general standard of pedestrian modelling in the Australian market for the benefit of practitioners, clients and other interested parties.

This second edition is produced in response to comments received across a wide range of users and we thank them all for taking the time to provide feedback. The principal areas of feedback were associated with providing more guidance on the calibration / validation process, provide modelling examples and guidance on other sources of information.

John Webster MSc FAITPM - September 2023

Editorial Team: - 1st Edition	Review Team
Chapter 1: John Webster (Mott MacDonald)	John Richardson (Jacobs and AITPM editorial team)
Chapter 2: Eric Rivers (Arup)	Tom Van Vuren (Veitch Lister Consulting)
Chapter 3: Ravi Kaberwal (SCT Consulting)	Dr Meead Saberi (CityX Lab, Research Centre for Integrated Transport Innovation UNSW)
Chapter 4: Ten-Zen Guh (Mott MacDonald)	Chris Morley (Beca)
Chapter 5: Lukas Labutis (Cardno)	
Chapter 6: Federico Marcantognini	
Chapter 7: Pietro Crovato (GHD), Sarah Zhang (Aurecon) & John Webster (Mott MacDonald)	
Chapter 8: Lise Chesnais (Arcadis)	

Editorial Team: - 2nd Edition	Review Team
John Webster (Mott MacDonald) Simon Rogerson (Aurecon)	John Richardson (Jacobs and AITPM editorial team)

Edition History

This is the first edition of the Australian Institute of Traffic Planning and Management Pedestrian Modelling Guidelines. It is anticipated that the content will evolve over subsequent editions and more detail added (or superfluous content removed) as required. In part this will be influenced by feedback from readers of this document.

Edition 1 | September 2021

Edition 2 | March 2024

1 Introduction

1.1 Purpose

The purpose of these guidelines is to help elevate the quality of the modelling product resulting from a pedestrian microsimulation process and providing insights into assessing how various modelling approaches may impact the credibility and robustness of results. Generally, these guidelines are aimed at the modelling of high-capacity transport interchanges and stadia, although many of the principles are equally applicable to non-transit environments.

The guidance covers areas which can reduce the credibility and effectiveness of pedestrian microsimulation modelling. It is hoped that understanding these weaknesses will result in clients producing better specifications and in turn, receiving better advice.

This guidance is general in nature and not specific to any particular software platform, but it is hoped that by raising awareness of the components of modelling a better outcome would result for clients, practitioners and the end users of the spaces being modelled.

1.2 Guideline objectives

There are four principal objectives which this guidance hopes to deliver:

- Guidance for practitioners in order to deliver better quality models and to deter poor practices.
- Standardisation of approach so that poor practices are avoided or at least the subsequent limitation understood.
- Improved model specification from clients to make model procurement easier and fairer.
- Improve the appreciation of model limitations so that stakeholders better understand what can and cannot be expected from pedestrian models (even if they look fantastic).

1.3 Target audience

These guidelines are aimed at three target audiences:

- Model Practitioners who build pedestrian models. These guidelines will help produce better and more robust results and hopefully act as a reference for new entrants. Importantly, these guidelines can help create a more even playing field when it comes to bidding for projects.
- Clients who commission models. These guidelines will help write better specifications and assist in interrogating responses to a model brief. Clients will also be better placed to understand the implications of various methodologies which may all claim to provide credible results despite having different approaches and budgets.

These Guidelines include information specifically targeted at the client audience; this information is presented in these orange text boxes.

- Interested Parties. This can include other technical disciplines which rely on pedestrian modelling or stakeholders who are presented with modelling results. These guidelines offer an introduction to the field of pedestrian microsimulation and remove some of the mystery around interpreting results and looking beyond the impressive animations.

1.4 Document limitations

These Guidelines are provided for information purposes only and whilst it is hoped they increase the quality of specifications, methodology and output, they are not intended to represent a definitive statement on the appropriateness or otherwise of various approaches. This document is not providing advice or a commentary on the efficacy of various approaches and no liability is accepted for models created, amended, or assessed having referred to these guidelines.

Whilst this document does not provide standards, it is hoped that at some later date, criteria for calibration/validation will be proposed. Currently most models output results with little evidence that the model is able to reflect reality, validation and calibration are discussed in section 6.2.

2 Assessment specifications and need

2.1 What is pedestrian modelling?

The primary focus of this paper is dynamic pedestrian simulation, but the term "modelling" can relate to any number of analyses, from simple spreadsheets and diagrams to complex and detailed software simulations of transactions, processes and pedestrian movements. The purpose of any pedestrian modelling effort is to gain a better understanding of what people might experience in a space under a specific set of conditions, to understand how the environment can be better planned, designed and/or operated and to help improve safety, efficiency, operations, and a positive pedestrian experience.

The type of pedestrian modelling undertaken is typically driven by the project need and the types of outcomes desired and broadly falls into two types – Static (generally utilising spreadsheets) and dynamic (microsimulation) modelling.

2.1.1 Static or spreadsheet modelling

Spreadsheet (static) models are generally used to undertake deterministic or discrete event modelling:

Deterministic modelling, describes a process by which the outputs of the model, or the analysis, is completely determined by a set of inputs which yield a consistent result with every model run (due to applying pre-determined formulae to the input data to arrive at an answer). Deterministic models are usually created within spreadsheets which can be somewhat complex but are generally relatively simple. A basic example of a deterministic model in station planning would be to determine the number of escalators required to clear a platform of a detraining passenger load within a specific time period. In this case, a deterministic model would give a direct answer with relatively little effort to help determine the size and scale of vertical transportation, and thus begin to inform the station layout. A deterministic model might also be able to describe the maximum queue length, time required to clear all passengers and other performance metrics but would not be able to describe the personal interactions taking place between people. Likewise, as the environment being tested grows larger and more complex, the less a deterministic model is able to represent aspects like attenuation in flow and other pedestrian and crowd dynamics.

Discrete event modelling deals with systems consisting of numerous individual actions and variables within a series of transactions or events which influence the overall process. Discrete event modelling is common in manufacturing and industrial systems. In the pedestrian context, discrete event modelling is often employed to quickly review passengers moving through a number of environments where a series of discrete processes are undertaken which influence the subsequent pedestrian environment.

These processes may include elements such as:

- ticket gatelines
- escalators or other forms of vertical transport
- airport processes such as ticketing, bag drop, primary and security screening and gate activities.

Within each process, the analyst can adjust transaction times, capacities, and other operational variables such as number of staff on hand, and number of available resources. Outputs from discrete event modelling might yield the number of people in a queue and their average and maximum wait times, and in turn help size the number of servers or otherwise optimise the system.

Semi-dynamic models discussed further in section 4.2.1 are examples of more complex discrete event modelling.

2.1.2 Dynamic modelling

Dynamic pedestrian microsimulation modelling involves simulating individual people and the interactions that occur between individuals to inform crowd behaviours and the performance of an environment across time. Dynamic modelling can combine both aspects of deterministic and discrete event modelling and is informed by the physical layout of an environment, the pedestrian demands moving through the space, the rate at which they come and go, and operational aspects that affect pedestrian movement. Dynamic modelling outputs can be used to generate a number of metrics to describe the human experience while also providing visualisations in a way that is self-evident to an audience, and thus very powerful for describing different situations. Various off the shelf and in-house software packages are employed, each of which determines and describes pedestrian flow behaviours slightly differently due to differences in the software algorithms. The top five microsimulation packages (and their owner) commonly utilised in alphabetical order are:

- Legion (Bentley Systems)
- Mass Motion (Arup)
- Pathfinder (Thunderhead Engineering)
- STEPS (Mott MacDonald)
- Viswalk (PTV Group)

It is not the intent of this edition to provide a critique of the various packages – but each have their own strengths and weaknesses.

Pedestrian microsimulation is discussed further in Chapter 4.

2.2 Why model?

Modelling provides insights into the way a space or system might perform in the future, based on a series of observations, assumptions and behaviour principles applied through a logical methodology. It is a rigorous way of quantifying situations and thinking through a problem, rather than designing from a standard or worse, not designing for pedestrians at all. These modelling processes enable practitioners to respond to pedestrian experience design aspects with a comprehensive, interpretable, and analytical process rooted in an understanding of human behaviour and their interaction with the environment.

Pedestrian modelling methodologies help practitioners identify complexity within pedestrian environments and ultimately influence design to address pedestrian performance issues and improve comfort and safety. Design is now a collaborative process and articulating potential pedestrian problems is critical to solving them. Modelling processes that produce a visual output are particularly powerful in this regard; they are often highly engaging and clearly demonstrate potential issues to non-technical or non-specialist audiences. Finally, projects and stakeholders are placing increasing value in pedestrian performance, with the realisation that it directly influences safety and the human experience of the finished product. Clients and government are now requiring pedestrian design implications be proven by modelling processes and including model outputs in business cases and other project justifications.

2.3 Questions typically answered through modelling

Pedestrian modelling can be applied to various problems and situations. Modelling can be used to describe the pedestrian experience, to support new planning and design efforts, identify existing problems, test future scenarios, confirm and/or influence design, inform operations and/or policy. A few examples include:

- As designs are developed, modelling can check the performance of the design is acceptable during peak demand. This could be in terms of pedestrian density, wait times, finite capacity (e.g. escalators) or another reasonable assessment criteria.
- Scenarios can be developed that prove resiliency and redundancy, e.g. is the building resilient to an escalator or gate outage during a peak period.
- Test and inform operational scenarios to understand how to manage peak event pedestrian flows or other extreme events in order to identify the factors which contribute to an unacceptable level of risk.
- Emergency egress can also be modelled to review and prove a successful evacuation can occur before prolonged exposure occurs.
- Modelling can communicate the user experience. If a 3D visual medium is produced it can be used to clearly demonstrate how an individual might see what crowding looks like in first person or what sightlines look like at a decision point.

In Australia, transport planning agencies and Metro authorities now typically require pedestrian modelling as part of the design works for new station planning and design. These owners and operators understand the importance of understanding the customer experience while also right-sizing infrastructure within a set of forecasted customer demand and train timetabling conditions. The questions typically answered by pedestrian dynamic microsimulation for these projects include:

- Average passenger density across the peak 15-minutes of the AM peak hour in areas of queueing or walking
- Proportion of population experiencing each Level of Service (LoS) over time (see 5.1)
- Time spent in a queue for an escalator or a gateline
- Total journey time through a station system, with and without delays
- Maximum queue lengths at points of transaction.

2.4 Expectations of model results and appropriateness for use

Although pedestrian modelling is detailed, analytical and numeric in nature, it is a useful tool rather than "the answer." Dynamic modelling is considered the state-of-the art for the design of places across the built form, but models are a result of the intelligence of the software, the conditions created within each scenario, the ability of the modeller and the robustness of the inputs. Models reflect the inputs and assumptions of a defined scenario, rather than definitive reality. Whether a scenario will occur precisely as modelled and whether assumptions hold true are major caveats to the outcomes of modelling processes, including visual outputs, reporting and advice.

Software packages impose unseen assumptions onto the process, such as:

- Grid-based simulation platforms work mostly on spatial availability and shortest path. These packages may model only very limited behavioural effects on flow.

- Social forces models help to infer human behaviour (e.g. avoiding barriers, following other agents going in the same direction), but social forces still represents a simplification of the myriad of internal and external influences (many unperceived) which influence how people behave. Agents are still controlled by an algorithm and as such are subject to a relatively small number of influences; they do not have familiarity with spaces or emotional responses to route choice and they cannot respond to visual cues or human courtesy. Most microsimulation software struggle with the choice between shortest path but congested compared to further away but less busy. We humans perform this task almost subconsciously, but most software packages do not attempt this task at all.
- Platforms with algorithms based on studies of people within actual places might be able to replicate those studied movements very specifically and accurately. However, apply that platform in a different setting or within a different culture and the results may not be appropriate.

Similarly, the theory behind the discipline in general also has substantial implications on the results:

- Fruin (1971) forms the basis of much of the discipline, including observed human behaviours like the average size of pedestrian and the distribution of desired walking speeds. Fruin's research was undertaken in the New York during the 1960's; the cultural and urban context of the research affects the observations and is carried over to most work done in the field, often outside the original research context.
- In the late 1980s, Fruin was involved in the derivation of a new set of LoS criteria more applicable to the general footpath environment, these adopted a similar A to F grade but with different trigger points.
- Fruin's LoS performance metrics are often used. Fruin LoS relates to commuter and other environments where pedestrians have a definitive goal and a certain tolerance to crowding, rather than exploring a space or dwelling. Applying Fruin LoS in other spaces (e.g. cultural buildings) can compromise their function because crowding tolerances are probably lower for non-travel activities although it may still be useful to model the LoS and then consider which LoS criteria is deemed appropriate for that environment.
- Acceptable crowding and pedestrian behaviours are also affected by cultural preference, so default modelling parameters are not directly applicable in all contexts.
- The way results are reported seeks to summarise performance over time and space and make outputs digestible or usable (e.g. for a business case) but might not reflect actual issues: e.g. an average LoS over 15 minutes might hide 2-minutes of extreme or unsafe crowding.

There are two main risks here: clients and the public take the outputs of a model process as fact (perceived reality) without considering the need for interpretation in light of the assumptions, or they concentrate on questioning the reality and validity of a model without taking the useful lessons from it. Both outcomes are less than ideal and compromise the purpose and value of modelling, so it is important to understand and communicate what the basis of a model is, along with what is and what is not modelled.

2.5 Model Quality Assurance / Quality Control

Model development is a detailed process, often creating a complex simulation that is then relied upon for advice. Clients generally cannot interrogate model assumptions and the development process; practitioners need to undertake a quality assurance and control process themselves to give confidence in the outcomes of the modelling process. Desirable quality assurance and control approaches include:

- Origin-Destination: checks should be undertaken to ensure the model is replicating the estimated demand. This can reveal errors in model development, or the model itself, or can show unfinished trips that infer performance problems.
- Throughput checks: Some pieces of infrastructure have known capacity constraints, such as escalators, stairs, and doors (based on both behaviours as well as width). Checking throughputs against these capacities ensures that these elements do not exceed the limit of realistic operation that would occur in the place being modelled.
- Behavioural: How well do the modelled speed /flow / density relationships reflect real world measurements?
- Screenlines should be used to confirm modelled flows in a certain place replicate the observed flows.

Visual 'validation' is useful in qualitatively checking the model but just because a model looks realistic should not be taken as being realistic. Visual validation usually includes comparison to various site observations including, for example, queue sizes, general business and transaction times. It can also involve observing agent behaviours within the model for oddities and unrealistic behaviour.

As with all models, the quality of the output is directly linked to the quality of the input data and the processes undertaken to achieve the output. Pedestrian microsimulation models can produce near photo realistic results – but unless there is some demonstration of the model being able to replicate a real situation (validation), the result may look convincing but be based on virtually nothing. It is hoped these guidelines will assist clients discern the level of reliability / credibility of model output and overcome 'perceived accuracy' which is discussed further in 7.4.

Where the modelled environment does not exist the validation process is often skipped, but if the results are key to the design process, then some demonstration that the software (and modeller) are able to replicate a similar environment should be considered.

3 Understanding the assessment environment

3.1 Common areas for assessment

Pedestrian assessment can and should be undertaken anywhere there is likely to be pedestrians moving through or congregating. Though the level of detail and type of assessment required may vary dependent on the environment and pedestrian demand.

In general, pedestrian assessment would be valuable to users, designers or operators if one or more of the following considerations (or triggers) are present in an environment:

High volume (or density) of pedestrians such that congestion or activity may influence the conditions of other users.

Conflicting movements
Environment where pedestrians may potentially be moving in multiple different directions, which may restrict other pedestrians from moving freely

Mixture of pedestrian activity
Includes pedestrians moving through the environment and those who may be dwelling (staying within) or congregating for a short or long period of time.

Other transport modes
The presence of which may influence flows, spatial availability and pedestrian behaviour within the environment. Sources include:

- Public transport: rail (light, metro or suburban), bus, ferry
- Private transport: personal vehicles, taxi or rideshare
- Active and micro-mobility: including bicycles, scooters etc.

Based on the above considerations, Table 1 highlights common examples of environments where pedestrian assessment may be required.

Table 1 Common environments for pedestrian assessment

ENVIRONMENT	CONSIDERATIONS				COMMENTARY
Transport stations or stops	✓	✓	✓	✓	Includes public transport locations as well as private transport options with dedicated facilities including taxi or rideshare. Pedestrian assessment considers the interaction of pedestrians entering, exiting, or moving through the service or stop with respect to the environment and associated infrastructure (including vertical transport, gates).
International and domestic ports (including rail, air and sea)	✓		✓		Interactions consistent with local transport node, with the added complexity of: — Security checks, immigration and customs — Pedestrians spend an extended period of time within the port compared to minutes for local transport — Retail and food outlets often included with port facilities, which result in variable patterns or movements
Within buildings		✓	✓		Internal locations, including but not limited to retail, foyers or concierge environments. Though generally lower in pedestrian density, there is significantly more variability in movements (and associated conflicts), spatial restrictions and a desire to determine hotspots for retail, advertising etc.
Streetscape and Campus	✓	✓	✓	✓	Assessment generally includes interactions with: — Other modes, particularly cyclists which may share the pedestrian space — Property access (pedestrian and vehicle) — On street elements including furniture and retail (and associated queues) — Road corridor with respect to crossing opportunities and queueing

ENVIRONMENT	CONSIDERATIONS				COMMENTARY
Event Precincts and Stadiums	✓	✓			Assessment is typically based on two distinct scenarios, entry and egress. During an entry scenario, pedestrian assessment can be similar to ports, with the presence of security and ticket checks, retail and food outlets (and their associated variability) and staggered arrival times. During egress scenarios, modelling inputs are comparatively simpler with pedestrians generally leaving the stadium or precinct with minimal interactions though at a substantially higher density, which has implications for infrastructure provisions and interventions.

Across all these locations, pedestrian assessment can assist an owner, designer or developer to:

- Appropriately size key infrastructure: including stops/platforms, thoroughfares, vertical transport (stairs, escalators and/or lifts), waiting areas.
- Test positioning of key infrastructure to optimise space and throughput whilst minimising conflict and safety risks.
- Highlight risks and opportunities for capacity and throughput.
- Test physical or personnel interventions (marshalling, barriers etc).
- Test normal, degraded or special event scenarios.
    - Degraded conditions include facilities out of service, egress routes unavailable, operational service reductions etc.

Further explanation of the level of detail and type of assessment is included in Section 4. Similarly, the data and methodology required for the assessment may change depending on the environment. As illustrated in Figure 1 the amount of observed or forecast data required and complexity of methodology increases for the some of the common environments from Table 1. These changes in data requirements may include the number of locations, the frequency and medium for data collection (discussed in Section 6).

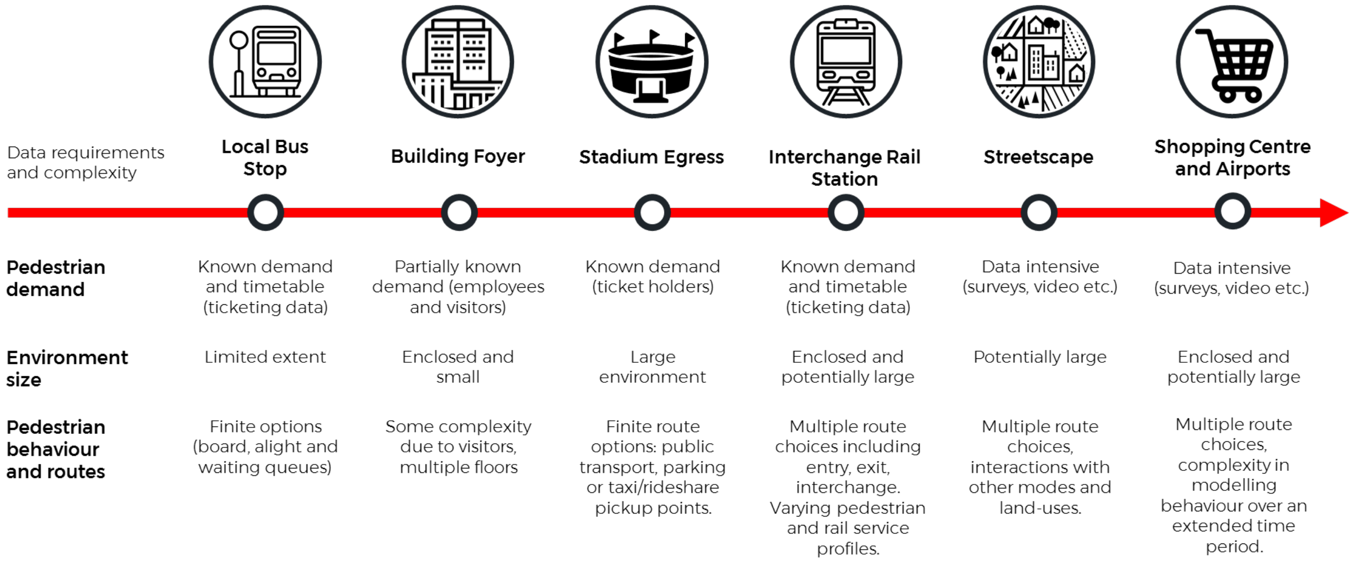
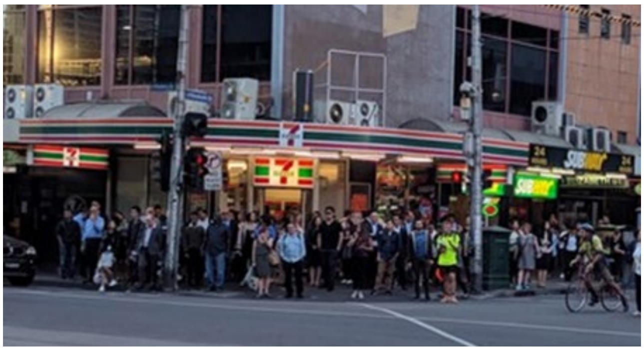


Figure 1 Comparison of data requirements and complexity for common environments

3.2 Consideration of other modes

It is important to consider other modes, as their presence may influence pedestrian flow, spatial availability, and pedestrian behaviour within the assessment environment. Examples of how other modes change the pedestrian environment are summarised in Figure 2.

Pedestrian Flow

Alighting pedestrian flow from other modes	Bunching of pedestrians at a road corridor crossing
	
Pedestrians from rail station (left) and tram service (right).	Pedestrians waiting to cross the road occupy majority of available footpath and are subsequently released in a pulse.

Spatial Availability

Pedestrians waiting for a bus service

Pedestrians waiting for bus service (highlighted) reduce the available footpath space for pedestrians walking along street which is congested in peak periods.

Figure 2 Examples of other modes interacting with pedestrian environment

The impact of other modes on the pedestrian environment is directly correlated to their proximity to the focal point (or target area) of the study, and the type of transport mode. As illustrated in Figure 3, the pedestrian flow profile following the arrival of each of the service types differs.

Comparing the profiles of these modes, it is generally apparent that:

- Suburban rail: operate less frequently compared to metro services, and hence have more passengers per service. These services may also have varying stopping patterns which may drastically change the loading of a service.
- Metro rail: operate as turn-up and go services with consistent stopping patterns. This results in relatively consistent loading between services at regular intervals, reducing the intensity of pedestrians.
- Light rail: operate with consistent stopping patterns though comparatively less capacity compared to heavy rail.

- Bus: stops may include services with numerous routes and stopping patterns, which results in differing service loading, though impact of variability is limited by the comparatively low capacity.

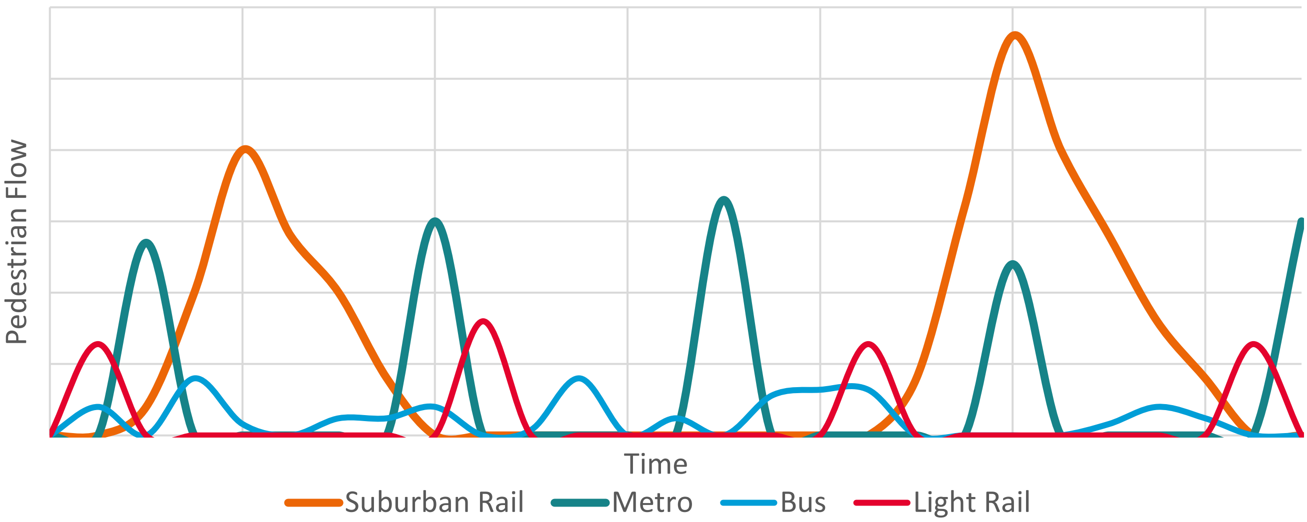


Figure 3 Comparison of indicative pedestrian profiles for common transport modes over time at node

These profiles may flatten as pedestrians move through and exit the transport node as the demand is filtered by processes such as ticket gates and queues at vertical transport.

The impact of external influences is often overlooked but factors such as the stop-start nature of crossings creates pedestrian demand pulses which may require additional pedestrian infrastructure than that suggested by adopting a more average approach profile. In such cases analysis of shorter time periods and/or adopting a more sophisticated technique may be necessary.

4 Types of analysis

4.1 Introduction

Broadly speaking, pedestrian modelling analysis is usually described as being either static or dynamic. Although both types can be referred to as a pedestrian "model" or "simulation", it is important to understand that they are two very distinct types of methodologies, each better adapted than the other for different analysis context and purposes, however neither of which are one-size-fits-all. It is therefore important that sufficient consideration is given to which approach best suits the objective of the analysis.

This chapter provides a high-level overview of static and dynamic microsimulation modelling and the differences between them, and generally what factors should be considered when determining which methodology to adopt.

4.2 Static analysis

A "static" model is typically a spreadsheet model based on mathematical formulations of first principles, e.g. Fruin Level of Service. The model is usually deterministic, meaning an identical set of inputs will generally lead to an identical set of outputs. Pedestrian flow and density are analysed in aggregate, rather than for individual pedestrians. Only infrastructure elements are included, and they are typically represented by their expected pedestrian flow capacity (e.g. 100 pedestrians per minute for an escalator), other characteristics such as walk speeds are usually fixed and the route chosen (if modelled) is fixed.

As the name implies, a "static" analysis is typically limited to numerical performance metrics for a specific moment in time or aggregated over a period of time (e.g. average density over the peak 15 minutes or 1-hour). Whilst timetabled services can be reflected in the model (see 4.2.1), the aggregate nature of spreadsheet models may make them less suitable for complex environments where there are multiple route choices or where more compelling output (such as animation) is required.

Generally, a static modelling approach is sufficient for:

- Initial space proofing and infrastructure sizing (often to be subsequently verified by microsimulation modelling);
- High-level comparison of concept design options;
- Analysing situations with:
  - Low to medium pedestrian demand in complex environments or high demands in simple environments
  - Environments where conflicting movement is unlikely to be an issue
  - Geometrically simple spaces, e.g. minimal direction/level changes, minimal route choice variation
  - Low geometric detail, e.g. minimal spatial constraints allowing for high flexibility in dimensioning and placement of pedestrian infrastructure
  - Minimal interaction with external environmental factors, e.g. vehicles, management measures, operational perturbations
  - Minimal temporal variation in pedestrian demand and a simple demand matrix

4.2.1 Semi-Dynamic spreadsheet modelling

Semi-dynamic spreadsheet models represent a more complex form of spreadsheet modelling and produce results based around how demand changes over time at certain locations within the model. This type of model reflects the influence of profiles and process rates and captures the relative movement of people around a station and so take into account influences such as the platform/door interface and the relative distances between various station elements. This modelling of platoons of demand and the modelled walk times are a refinement over more basic models although they require more data as distances between walk points are required and usually involve complex macros. The 'semi dynamic' modelling of platoons may reveal that more capacity is required (because platoons overlap) or less if the demand streams do not coincide. Semi-dynamic models are broken down into relatively fine elements of time, e.g. every 15 seconds for 30 minutes. The demand passing through the model is influenced by the environment, queues, and process rates, but the routing is still wholly user defined.

4.2.2 Time-Space Modelling

This method goes beyond a simple flow per metre analysis and considers the impact of occupancy (rather than flow) to determine a Level of Service (LoS). This approach is useful where non uniform flows are anticipated and can therefore consider the impact of queues or other delays on a space. The time space method assumes the LoS is a product of the available space over time (supply) divided by the occupancy over time (demand).

EXAMPLE

Consider the example where we have a 100m long Metro corridor which is 2.5m wide. The demand is 100 people per minute. Simple flow calculations would suggest a LoS C (40 people per metre per minute), but in this example 50% of the demand are delayed for a further 120 seconds due to queuing. The time space method considers this additional occupancy:

Supply = Width * Length * evaluation period (60 seconds) = 15,000 metre seconds

At an average walk speed of 1.3ms^{-1} the walk time for the 50 people is 77 seconds (7,692 metre seconds)

50% are delayed by a further 120 seconds (6,000 metre seconds)

Average area per person = Supply / demand

= 15,000 / (7,692 + 6,000)

= 1.1m^2 per person

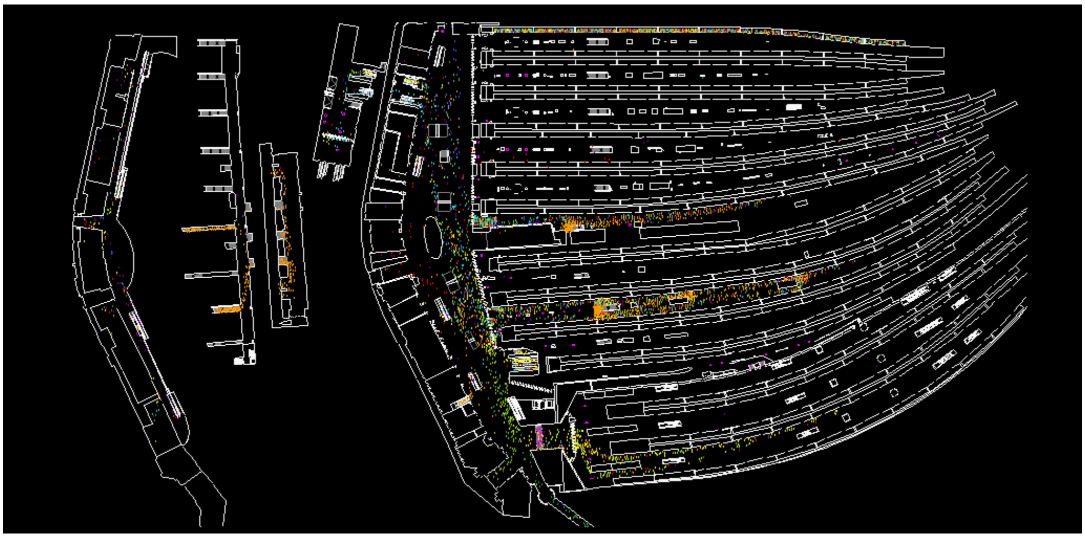
= LoS D

This approach can therefore identify potential capacity issues which may be missed from simple flow calculations.

4.3 Dynamic microsimulation analysis

A "dynamic microsimulation" model is built using specialist pedestrian modelling software, of which there are various commercially available packages. Although features and functionality vary by package, they all have the same core functionality, which is to model the movements and behaviours of individual pedestrians (often referred to as "entities" or "agents") over a specified simulation period, calculated for each time step. The model itself is a virtual representation of the pedestrian space, which can be either 2D or 3D as shown in Figure 4.

Dynamic microsimulation pedestrian model – Example 2D model view



Dynamic microsimulation pedestrian model – Example 3D model view

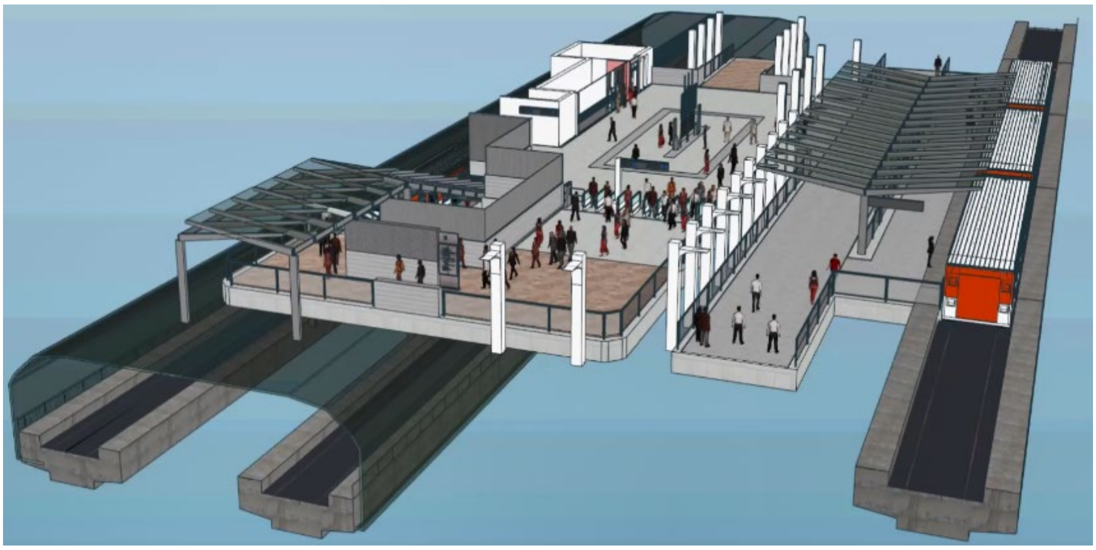


Figure 4 Dynamic microsimulation pedestrian model - Example 2D and 3D model views

Unlike a simple static model, a dynamic microsimulation model does aim to simulate the movements and behaviours of individual pedestrians responding to and moving through:

- Complex geometries
- Operational processes,
- Operational/management interventions,

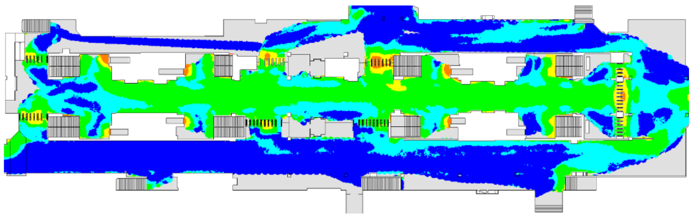
- Congestion influencing route choice

Dynamic microsimulation model can account for the interrelationships between these complex factors in a way that static analysis cannot, providing a much more detailed and holistic view of pedestrian flow. Typically, a dynamic microsimulation model is stochastic, meaning an identical set of inputs will not necessarily lead to an identical set of outputs, hence there is an inherent level of randomness built into the simulations.

A dynamic microsimulation model should be able to model 'emergent' pedestrian flow patterns such as the tendency to keep left in two-way flow environments, the 'self-organisation' phenomenon where pedestrians naturally form dynamic lanes. The simulation output capability varies by software package, but the dynamic and agent-based nature of the model allows for advanced processing of performance metrics that static analysis is unlikely to accomplish, including but not limited to those shown in Table 2.

Table 2 Common dynamic model outputs

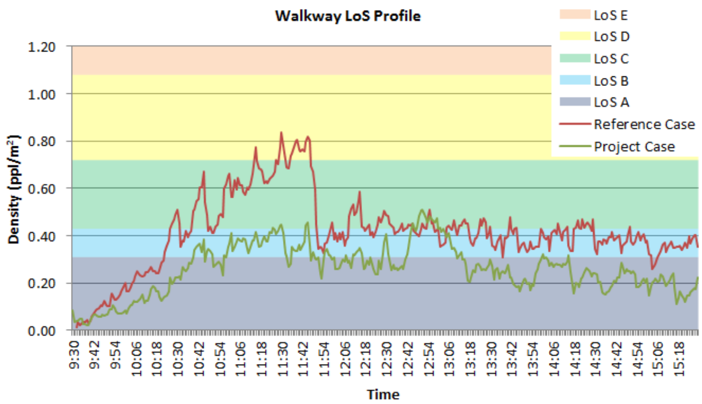
<table>
<tr>
<td>Detailed heat maps, which can be used to identify specific areas where pinch points, and flow conflicts occur. An example of a density heat map is shown to the right, areas are colour-coded based on Fruin LoS.</td>
<td>



Fruin LoS Criteria for Walkways

	A	B	C	D	E	F	
Density	0	0.31	0.43	0.72	1.08	2.15	pax/m²
Space	∞	3.25	2.32	1.39	0.93	0.46	m²/pax

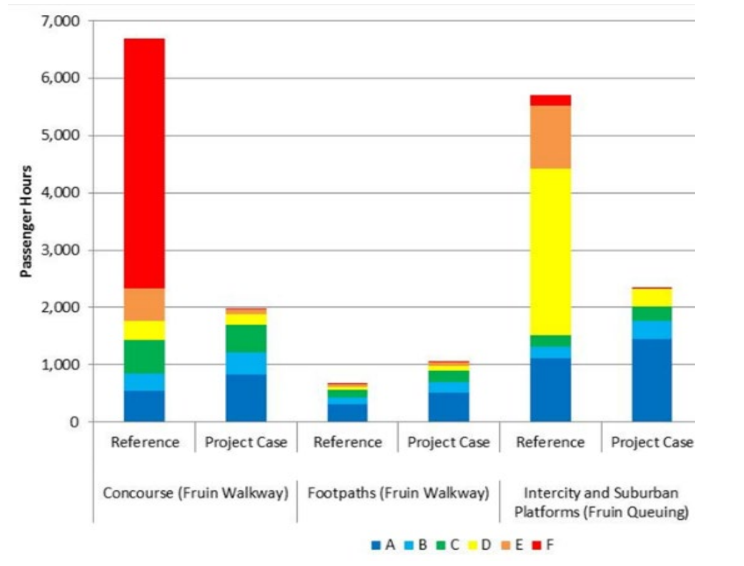
</td>
</tr>
<tr>
<td>Time profiles, to see how performance varies over the simulation period. An example of a time profile graph is shown to the right, this shows how LoS of a space varies over the course of a simulation.</td>
<td>



</td>
</tr>
</table>

'Big data' processing, where the experience of individual pedestrians in the model can be extracted and analysed. For example, the graph to the right shows a graphical output of cumulative time spent in different LoS bands experienced by all pedestrians in the model.

Detailed journey time and user experience analysis, including for specific activity types (walking, queueing, interchanging, stair use, etc.)



In addition to detailed outputs analysis, a dynamic microsimulation model also provides much enhanced visualisation capability over a static model, in the form of simulation snapshots and animations. This can be an overhead 2D view (Figure 5) with pedestrians represented as dots, or a full 3D view with animated people (Figure 6). Although simulation visualisation in itself does not provide better modelling analysis, it can be effective in communicating the modelling results to stakeholders, particularly to those with a non-technical background.

As discussed in section 0 these impressive animations do not necessarily translate into credible results, especially if a microsimulation model has been built without a validation / calibration phase (see section 0) or based on a weak data set.

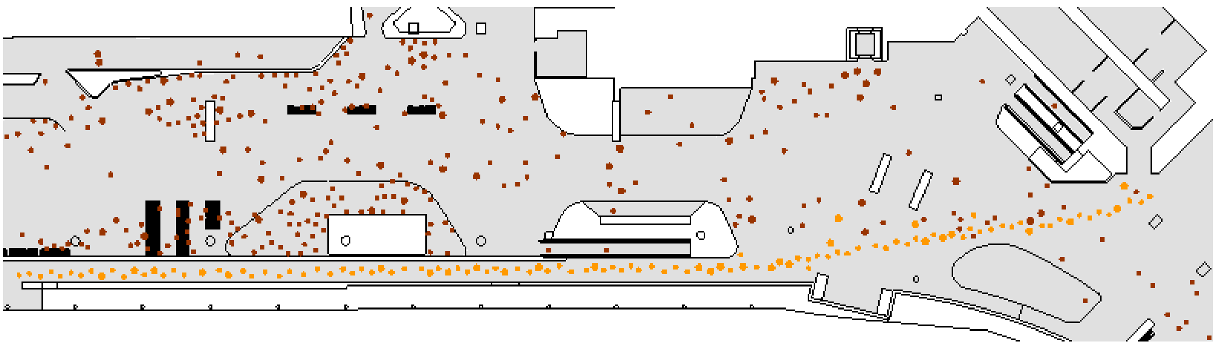


Figure 5 Example 2D Simulation Snapshot

Figure 6 Example 3D Simulation Snapshot

In general, dynamic microsimulation modelling is better suited for:

- Design verification for both space and infrastructure elements
- Comparison and assessment of developed design iterations and operational scenarios
- Operational concept development and management
- Communicating pedestrian environments and conditions to stakeholders
- Analysing situations with:
    - Medium to high pedestrian demands in complex environments
    - Environments where congestion may influence route choice or where pedestrian conflicts may be an issue
    - Geometrically complex spaces, e.g. high number of direction/level changes, multiple route choices
    - High geometric detail, e.g. high spatial constraints leading to low flexibility in dimensioning and placement of pedestrian infrastructure
    - Significant interaction with external environmental factors, e.g. vehicles, management measures, operational perturbations
    - Significant temporal variation in pedestrian demand, e.g. 'peak' or 'surge' demands from train arrivals, other modes or road crossings

4.4 Summary

Static and dynamic microsimulation modelling are distinct types of methodology, neither of which are universally appropriate for all situations. A high-level comparison summary of static and dynamic microsimulation methodologies is provided in Table 3.

Table 3 Static vs dynamic simulation comparison

Parameter	Static modelling	Dynamic microsimulation modelling
Technical capability		
Simulation methodology	• Deterministic • First principle formulations • Spreadsheet-based • Aggregated pedestrian flow • Aggregated time • Space and infrastructure represented by capacity	• Stochastic • Empirically derived movement algorithms • Specialist modelling software • Individual movements ('agent-based') • Individual time steps • Space and infrastructure represented by capacity and geometry
Outputs	• Numerical performance metrics for aggregated pedestrian flow for a specific moment in time or aggregated over a period of time • Results tend to take the form of graphs or very simplified LoS heatmaps.	• Numerical performance metrics for specific pedestrians, over a specified period of time • Performance time profiles • Graphical heat maps • 2D or 3D simulation snapshots and animations
Area of application		
Purpose of the analysis	Sufficient for: • Initial space proofing and infrastructure sizing • Modelling relatively simple environments (eg small stations) although almost any layout can be modelled to some extent. • Concept level design where detailed matrices may be unavailable	More effective than static modelling for: • Design optimisation for both space and infrastructure elements • Design verification for both space and infrastructure elements • Operational concept development and management • Communicating results to stakeholders
Complexity of model outputs	Suitable for analysing situations with: • Low to medium pedestrian demand • High demands in simple environments • Geometrically simple spaces, e.g. minimal direction/level changes, minimal route choice variation • Low geometric detail, e.g. minimal spatial constraints allowing for high flexibility in dimensions and placement of pedestrian infrastructure • Minimal interaction with external environmental factors, e.g. vehicles, management measures, operational perturbations • Minimal temporal variation in pedestrian demand, although more complex	Suitable for analysing situations with: • Medium to high pedestrian demand • Complex pedestrian flow, e.g. flow in multiple directions, multiple origins and destinations • Geometrically complex spaces, e.g. high number of direction/level changes, multiple route choices • High geometric detail combined with credible demand patronage forecasts • Significant interaction with external environmental factors, e.g. vehicles, management measures, operational perturbations • Significant temporal variation in pedestrian demand, e.g. 'peak' or 'surge' demands from train arrivals,

Parameter	Static modelling	Dynamic microsimulation modelling
	spreadsheets can be used to discrete time slices	other models or signalised pedestrian crossings
Speed and cost-effectiveness	• Quicker and more cost-effective for: • Low complexity situations • High-level comparison of multiple concept design options	• Quicker and more cost-effective for: • High complexity situations • Detailed comparison of developed design iterations and operational scenarios

5 Assessment criteria

Pedestrian modelling criteria are measures that attempt to classify the pedestrian conditions and are frequently used to demonstrate if a modelled design meets performance requirements. Criteria should be confirmed before the project commences and should be well-defined and objective to ensure practitioners and clients are aligned on the modelling outcomes. Criteria should be quantitative and specific to minimise the potential for misunderstanding and for the results to be misrepresented.

Some common pedestrian modelling criteria are explained in the following sections, as well as discussion on the appropriate use of certain criteria. Further detail explaining various criteria and how these are provided in Section 7.

5.1 Level of Service

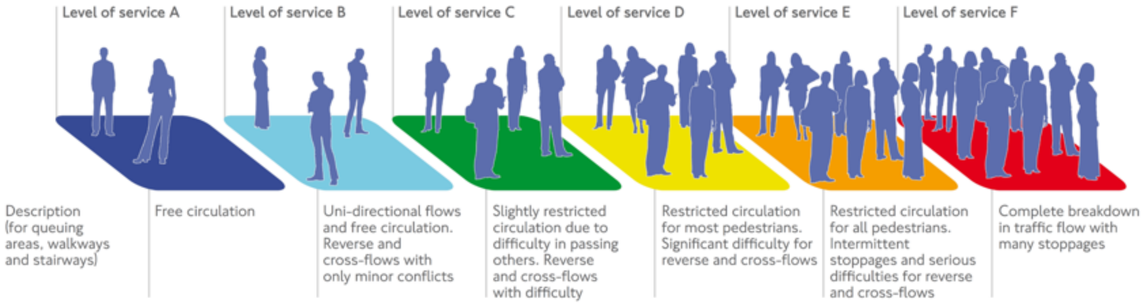
The Level of Service (LoS) is a common quantitative criterion for pedestrian models and is a categorical measure intended to broadly represent safety and amenity. The LoS is a category based on the pedestrian density, defined as the number of pedestrians per square metre (pp/m^2) or expressed as flow rates in terms if people per metre per minute (ppm), depending on the application. Similarly, to traffic models, the LoS is a category ranging from LoS A (most safe and comfortable) to LoS F (least safe and comfortable).

Level of Service is also a reflection of what is deemed acceptable and therefore comfortable in different environments, a poor LoS does not automatically represent an unacceptable situation. Hence, quite poor LoS conditions can be observed in locations such as busy transit stations in the peak hour or in stadia at completion of the event. In these cases, users can experience densities without discomfort or concern which would be totally unacceptable in other more benign environments such as a shopping precinct.

The most widely used measure of the LoS is the Fruin Interchange LoS, initially developed by John Fruin in the 60s as research for a PhD and published in 1971. A different set of LoS criteria were developed in the late 1980s to reflect more general footpath environments, where expectations and hence acceptable densities are different. The Fruin LoS categories were based on fundamental principles of pedestrian flow and relationships between flow rate, mean speed and density. The measure is based on the concept that increasing densities (and therefore decreasing space per person) leads to increased congestion and decreased flow rates, potentially resulting in unsafe and uncomfortable pedestrian spaces.

Pedestrian spaces are generally planned and designed to achieve a minimum LoS to provide users with a safe and appropriate amount of space for their particular requirements. However as discussed in 7.5, how the acceptable LoS is calculated and measured is sometimes poorly defined.

A visual representation of the LoS categories developed by Fruin is presented in Figure 7.



	LoS A	LoS B	LoS C	LoS D	LoS E	LoS F
Walkway - Street						
Average Flow (p/m/m)	13 or less	13 - 23	23-33	33 - 49	49 - 82	Variable
Average Area (m^2/p)	6 or more	3.7 - 6	2.2 - 3.7	1.4 - 2.2	0.6 - 1.4	0.6 or less
Average Speed (m/s)	1.32 or more	1.26 - 1.32	1.22 – 1.26	1.14 - 1.22	0.76 – 1.14	0.76 or less
Walkway - Interchange						
Average Flow (p/m/m)	23 or less	23 – 33	33 - 49	49 - 66	66 - 82	Variable
Average Area (m^2/p)	3.3 or more	2.3 – 3.3	1.4 – 2.3	0.9 – 1.4	0.5 – 0.9	0.5 or less
Average Speed (m/s)	1.32 or more	1.26 - 1.32	1.14 - 1.26	1.12 - 1.14	0.63 - 1.12	0.63 or less
Queueing						
Average Area (m^2/p)	1.2 or more	0.9 - 1.2	0.7 - 0.9	0.3 - 0.7	0.2 - 0.3	0.2 or less
Ave interpersonal space (m)	1.2	1.1 - 1.2	0.9 - 1.1	0.6 - 0.9	0.6 or less	Close contact
Stairs						
Average Flow (p/m/m)	16 or less	16 - 23	23 - 33	33 - 43	43 - 56	Flow variable
Average Area (m^2/p)	1.9 or more	1.4 – 1.9	0.9 – 1.4	0.7 – 0.9	0.4 – 0.7	0.4 or less

Adapted from: Fruin (1971); Bowman, Fruin and Zegeer (1989); London Underground: Station Planning Standards and Guidelines 2012 edition.

Figure 7 Fruin Level of Service categories

The four most commonly used Fruin LoS criteria are:

- Interchange Walkways LoS – applicable to pedestrians walking along corridors / tunnels etc in a transport interchange type of environment
- Street Walkways LoS – applicable to pedestrians walking along footpaths in more typical street type environments
- Stairways LoS – applicable to pedestrians walking up or down a stairway in a transit environment
- Queuing LoS – applicable to pedestrians waiting in a queue, such as at a signalised intersection or ticket gate array

These LoS criteria are based on the same principles but differ according to the thresholds of each category – for example, Queuing LoS C encompasses a higher density of pedestrians than Walkways LoS C. This is based on the concept that pedestrians are willing and able to accommodate higher densities when waiting in queues or using stairs than they would when generally walking. Pedestrians that move faster along walkways require more space to actively walk and feel comfortable than they do when shuffling in a queue or walking up stairs.

Typically, LoS C or better is considered acceptable for new designs, however this is project-specific and dependent upon a number of factors including the environment, project objectives and expectations of pedestrians. Different contexts may elicit different requirements for the acceptable LoS – for example, the LoS criteria for a metro station in Hong Kong would likely be different to the LoS criteria for an open plaza in Sydney.

The operational mode will also generally influence the LoS criterion. For example, a degraded mode (such as a missed headway in a railway station environment) would typically have a wider acceptable LoS threshold than standard normal operations. This is based on the operational mode occurring less frequently and pedestrians having a higher tolerance for discomfort under these infrequently occurring scenarios. Accounting for degraded modes could be done by reducing the required density within a LoS category (e.g. shifting the criteria from mid-range LoS C to the lower bound of LoS C/D) or by reducing the required LoS category, say from C to D. It would be a very rare occurrence that LoS E/F would be deemed acceptable, but a poor LoS is not automatically a fail, for instance, a crowd leaving the seating bowl of a stadium would regularly experience a LoS F with little discomfort – so the LoS criteria should never be the sole criteria used to identify design success. Issues with comfort and amenity generally occur when user expectations are *not* met.

5.1.1 Cumulative Mean Density (CMD)

Level of Service plots are a common output from microsimulation models and can be an excellent visual indicator of the pedestrian environment. CMD plots display the mean levels of density for areas occupied in the model within a specified time period. Areas which are not occupied are not included as part of the density plot calculation. For example, if there are periods of high activity followed by inactivity the CMD will only show the average LoS for periods of activity. This is an important factor in avoiding some of the pitfalls from averages under reporting congestion discussed in section 7.5.

> Always specify the appropriate LoS definition (walkway/queue/Transit Interchange / stair) and ask for microsimulation models to output LoS as Cumulative Mean Density plots.

5.1.2 Cumulative High Density (CHD)

CHD plots display how long various areas have registered densities greater than a specified limit. The range of colours represent time rather than density with darker colours representing areas with longer periods of excess density. CHD plots are useful in identifying key areas of congestion and provide details on the time spent at each LOS Criteria. This allows further understanding of the components of density contributing to the CMD output - it may be that whilst the CMD appears to acceptable, there are time periods of extreme congestion which are not.

5.2 Other Level of Service Criteria

5.2.1 Transport for NSW

Transport for NSW published The Walking Space Guide in 2020. It takes a more nuanced approach to assessing the Level of Service of footpaths in that it rates the spatial provision in addition to the capacity/demand calculation. Footpaths are categorised by type depending on their location and use. The type is in part dictated by demand so the LoS for many footpath types are simply dictated by available width. For footpaths with high demand the LoS is determined by assessing spatial and demand provision (people per metre per minute), with the worst result representing the final Level of Service. The Guide goes into detail in how to cater for street furniture and the implications of passing traffic on comfort levels.

The guide was based on a significant research and data collection exercise with over 475,000 observations and 5,500 subsequent interviews to ascertain perceptions of comfort.

For more details refer to: https://www.rms.nsw.gov.au/business-industry/partners-suppliers/document-types/guides-manuals/walking-space-guide.html

The practical application of the TfNSW criteria produces very different results for the same demand as illustrated in Figure 8 . For example, with a flow of 24 people per metre per minute, Fruin Walkway LoS would result in a LoS C, but the TfNSW criteria results in LoS F above 18 people per metre per minute.

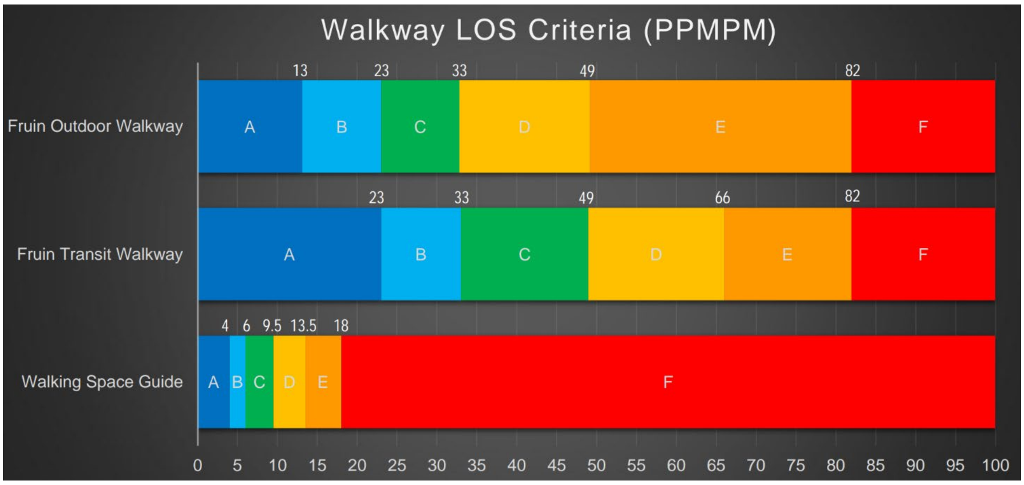


Figure 8 Comparison in Flow per metre per minute between Fruin and TfNSW criteria

This is not to say the TfNSW are somehow wrong – simply that they represent a more aspirational outcome which may be difficult to achieve in some environments.

5.2.2 Transport for London

Another process to determine the LoS measure is the Transport for London (TfL) *Pedestrian Comfort Guidance for London* (TfL PCG*)*. This is similar to the Fruin LoS but was developed more recently for the streets of London and has a greater focus on comfort rather than safety – therefore the LoS categories are more stringent and result in greater spatial requirements compared to the Fruin LoS.

For more details refer to: http://content.tfl.gov.uk/pedestrian-comfort-guidance-technical-guide.pdf

5.3 Travel time and delay

Travel time and delay are criteria that typically measure convenience for pedestrians and are similar to their traffic modelling counterparts. Travel time is defined as the time taken for a pedestrian to traverse from one point to another, and delay is defined as the time difference between a pedestrian's travel time under free-flow conditions (without any congestion) and their travel time under specified scenario conditions (with other pedestrians included). Delay can also be expressed as the time spent within a queue waiting at a control point, for example at a ticket gate array. In this case delay can be caused by the control point itself in the absence of congestion or other pedestrians.

Travel time and delay are commonly used to compare different design options (e.g. the location of a proposed interchange) to identify the travel time savings or impact of a preferred option, or the reduced delay due to the provision of additional infrastructure. Typically, designs with lower travel times and delays are preferred over alternative options.

Pedestrian spaces are generally designed to minimise travel time and delay for the convenience of pedestrians, or to reach an acceptable level of delay to reduce infrastructure requirements. This often results in a trade-off between the cost of providing infrastructure (financial as well as the opportunity cost of the space) and the inconvenience caused to pedestrians. For example, the number of ticket gates to be provided at a railway station will dictate how long pedestrians will have to wait to pass through the ticket gate array, but higher numbers of ticket gates require greater spatial requirements, capital outlays and operating expenditure. In some cases, travel times may be intentionally extended as a trade-off for other criteria (e.g. extending a concourse to provide additional area for queuing between a bank of escalators and a ticket gate array).

Although travel time and delay typically measure convenience, high travel times and/or extensive delays may also indicate potential safety issues. For example, long wait times at an intersection may increase the likelihood that a pedestrian decides to cross informally before the crossing activates. Long queuing times at an escalator from a metro station platform may also mean limited space is available for other passengers to alight from a train arrival. Careful judgment must be applied to evaluate potential safety issues arising from high travel times and delays.

5.4 Other criteria

The LoS and delay criteria cover many cases for the planning and design of pedestrian spaces, however different projects may warrant the need for different criteria. Other common criteria include:

- Evacuation time – the time taken for pedestrians to egress from an area. This is relevant for many buildings under an emergency scenario (e.g. fire), particularly for stadiums and underground railway stations.
- Platform clearance time – the time taken for passengers to alight from a railway station platform after a train arrival. This is used to ensure sufficient space is available for subsequent passengers alighting. Generally, the criteria to be achieved is for all demand to be clear of the platform before arrival of subsequent services, or that any remaining demand does not influence the alighting environment of subsequent services.
- Location of Congestion - A major pedestrian risk in stadia egress is the risk of a crowd crush (too many people competing for limited space) or trips and falls on crowded stairways. Stadia therefore usually adopt the 'Guide to Safety at Sports Grounds' aka The Green Guide, which is aimed at limiting the location of congestion (which can be LoS F) to the seating bowl with <u>all</u> subsequent movement occurring in free flow conditions.

  Further details can be found here: https://sgsa.org.uk/greenguide

The criteria to be adopted should be considered and confirmed before the commencement of a project and should be relevant to the context and surrounding environment. Project-specific criteria should consider responses to questions such as:

- Who is the customer using this environment?
- What are the expectations of the customer?

- What are the risks and safety hazards in this environment?
- What are the operating modes of this environment (e.g. degraded or emergency operations)?

5.5 Appropriateness of different criteria

Different situations may warrant the use of different criteria – a 'one size fits all' approach is unlikely to be suitable for many projects. Some criteria may not be applicable in certain situations, while other criteria become key to ensure safe and efficient operations. Consideration must be given to the environmental context, users, and objectives of the project, as well as the original intention of the criterion. For example, the advantages and disadvantages of the application of the Fruin walkway LoS compared to the TfNSW approach need to be considered as demonstrated in Figure 8, as well as the use of the LoS in general. The Fruin Transit LoS criteria are not appropriate for use in general footpaths – but because of their popularity, this Fruin definition is sometimes used as the criteria for non transit environments.

Thresholds and targets within criteria also need to be considered. For example, application of the Fruin LoS may be appropriate for a certain project, but the specific LoS to be achieved may depend on the environment, operating mode, and social characteristics. A typical requirement for walkway LoS C may be appropriate for a footpath during peak commuter periods but may not be appropriate for a recreational footpath in a tourist area.

> Criteria to be adopted should be selected carefully and can significantly influence the interpretation of pedestrian modelling results. Project-specific factors should be considered such as the customer expectations, movement dynamics and complexity of the operating environment.

The advantages of criteria such as the Fruin LoS and delay measures are that they are widely used and are standard outputs of pedestrian modelling software packages. With some supporting information they can also be easily understood by non-technical audiences. Disadvantages can include different ways in which they can be defined and their wide adoption – even if the environment is not really appropriate.

Whilst there are no criteria specifically aimed at the mobility impaired, their needs are generally assumed to be met if the environment achieves a Fruin LoS density – the assumption being that a low density environment should facilitate the movement of people with special needs. Caution needs to be taken however to ensure the desire lines of lifts etc are not in conflict with high demand desire lines such as to or from escalators.

5.6 How to define criteria

The definition of criteria used for pedestrian modelling is crucial to ensure desired outcomes are achieved and the design functions as intended. Well-defined criteria will assist in interpreting the outputs of the model and avoiding potential manipulation of the results. There are typically numerous ways to define criteria. For example, the LoS is measured as the number of pedestrians over a specified area. This allows for various ways LoS criteria can be defined, including:

- The time period over which this is measured – the LoS can be applied to a single point in time or over a peak period such as 15 minutes. The choice can have a significant effect on results, particularly in environments with varying dynamics such as metro stations.

- The area over which this is measured – the LoS could be an average determined for a given area, or the worst case LoS experienced in a design. The specification of area, if used, should also consider potential dead spaces which may skew outputs, or periods of zero demand which tends to reduce the reported congestion.
- Which density measure to be used – measures could include 'person density' and 'space density'. Person density can exclude times when there are no pedestrians present, and therefore the LoS isn't truly experienced; as discussed in 5.1.1 it is probably best to specify Cumulative Mean Density plots to avoid under reporting if LoS.
- The type of LoS to be used – this could be the Fruin LoS, TfNSW, TfL PCL, or other.

The specification of a generic 'LoS C' requirement without further explanation would leave these aspects ambiguous and may result in issues such as a technically compliant design that overlook safety issues or that does not meet the client's or customer's expectations. If issues arise, multiple perspectives/interpretations of the results may be valid and there may be difficulty reaching agreement.

Criteria should be well-defined to minimise the adoption of dubious practices and ensure the modelling outputs are interpreted correctly. The definition of criteria should include consideration of environmental factors, project objectives and site-specific influences.

Simply specifying an average LoS 'C' result can result in a wide range of environments which can all be reported as being compliant (discussed further in section 7.5).

5.6.1 Queuing

Queuing is a pedestrian activity which is often poorly specified by clients and poorly modelled in microsimulation output. In simple terms, a queue forms when demand for a process or resource exceeds the capacity of that process or resource. But reporting on queueing requires that the state of queuing is clearly understood. Perhaps surprisingly there is little clear definition of what constitutes a queue:

- when stationary?
- when shuffling forwards in a line – on which case what is the speed which constitutes a queue?
- when forward movement is limited by sheer weight of numbers?

Most station and pedestrian users would probably consider themselves to be a in queue when their progress rate falls below a certain speed threshold.

Queueing is a difficult concept for many microsimulation models – as they introduce a new behaviour – that of politeness and awaiting ones turn. Humans readily recognise where a queue is appropriate (see Figure 9), but without user intervention most models would allow a scrum to form around the process point rather than a well-defined queue.

Beware of queueing results from models which do not realistically model queue behaviour.

Queuing occurs in a range of environments so what represents an acceptable queue environment should be specific to that environment. Many specifications require a queue LoS 'C' or better – but this is a meaningless definition when considering the queuing behaviour associated with gatelines or at the base of escalators where linear queues tend to form. For example, Figure 9 shows typical queue formation at a busy CBD station gateline during the AM peak. The queue length is 5 to 6 people per gate with a delay which would be measured in a few seconds – but the spatial occupancy of this area is 25 people in 14.4m^2 which represents Fruin queue LoS 'D'. Clearly, LoS D in this environment is not an issue – what is more critical is the queue length and individual delays. Queue length can be critical – especially if there is the potential for queues to inhibit egress from escalators.

Queuing times may need to consider the definition of a queue, noting that many queues are dynamic queues where people aren't fully stationary. The definition of a queue may influence how long pedestrians are delayed and therefore affect whether the criterion is achieved.

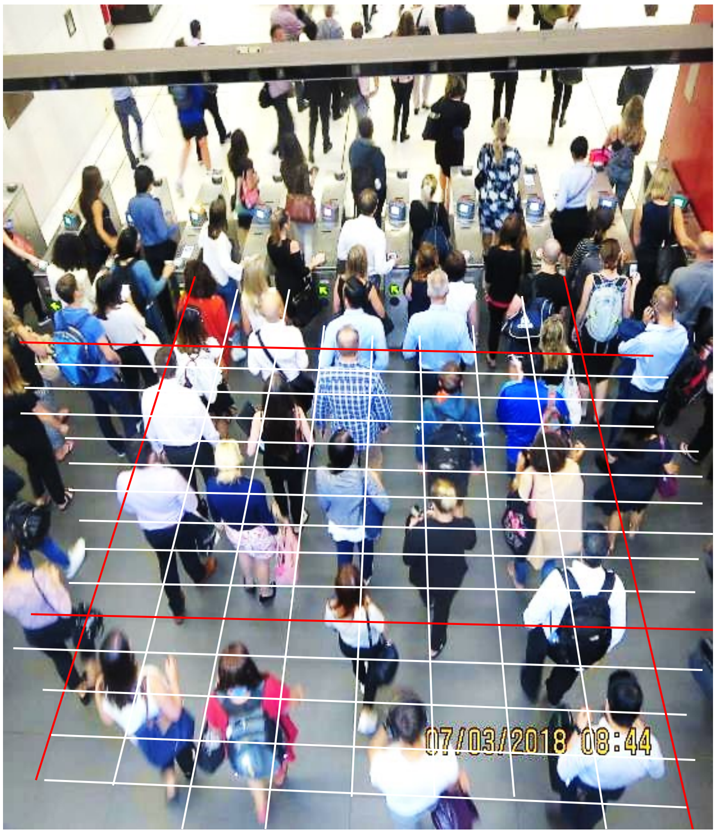


Figure 9 This queue at Martin Place in Sydney demonstrates why density is a poor measure of queuing at gatelines

For further discussion relating to the interpretation of results, refer to Section 7.

When specifying a microsimulation model, be sure to request that realistic queueing behaviours are modelled and the modelled queue behaviours are calibrated / validated. User intervention to force modelling behaviour should also be noted and explained.

For processes such as gatelines and escalators a more appropriate measure of queuing is queue length and individual delay rather than a Fruin LoS. When assessing platform conditions, consider requesting that both the Fruin Queue *and* Walkway LoS criteria are output as most platforms have both these forms of activity occurring in different platform areas.

6 Data requirements and model calibration / validation

6.1 Data inputs

In the field of pedestrian modelling - as in any other discipline using computer simulations - the quality and detail of input data contributes significantly to the definition of reliable and solid modelling outputs. A frequently encountered difficulty in the field of pedestrian modelling and crowd dynamics is the scarcity of systematic empirical quantitative and qualitative data on pedestrian movements providing guidance to the modelling.

The basic information needed to run a pedestrian model is a demand matrix and some form of spatial representation. Agent based microsimulation models are meant to reflect the behaviour of pedestrians and so a credible model requires a significant quantity of supplemental information which usually means some form of survey.

Site surveys of the actual area or environments representative of the area to be modelled can be undertaken to understand aspects of pedestrian movement such as:

- distribution patterns
- typical walking speeds
- walking time from one origin to destination
- train load distribution
- platform congestion
- service regularity and reliability, etc.
- Population characteristics – especially the mobility impaired (aged, encumbered with luggage, wheelchair users etc).

How this data is collected can be classified in two categories – manual and automatic surveys – and there are a number of methods that can provide meaningful information to use for parameters, model calibration as well as validation of simulation results for base and future scenarios.

6.1.1 Manual counts

Manual counts are commonly recorded by using data collection sheets or clickers in the field. Video technology allows for more careful and deliberate observation since the video can be slowed down or replayed as necessary. Whereas analysing video may be the most comprehensive manual count method, it may be more costly than using clickers or data sheets because it requires specific equipment and subsequent manual coding for each hour of video.

Manual count methods tend to be more accurate than automated count methods (although the automated processes are evolving). However, human error can lead to inaccuracies. Count accuracy depends on the level of motivation and alertness of the observer. Reducing the number of characteristics being recorded by the observer may improve count accuracy. In addition, because most data collectors are subject to fatigue, continuous counts over lengthy periods of time are not feasible. In terms of requirements, a summary of is illustrated as follow:

- Training: A training session with the team and data collectors to ensure what exactly needs to be counted and help ensure accurate data collection. The observers need to be instructed on where to stand, who to count, and how to use the data collection sheet.

- Data collectors: The number of data collectors needs to be carefully planned, as not all the information can be collected. An analysis of most relevant location for data point is essential.
- Daily supervision: Regular supervision of data sheets to verify proper data collection and resolve any problems.

When specifying the need to collect data for a model, always carefully consider the feasibility of the count – and have a detailed conversation with the crowd survey company to ensure the count can provide accurate results. Accurate counts can rarely be achieved in high demand conditions unless placed in an overhead position – a side view in low light conditions of a large crowd is unlikely to yield meaningful data.

6.1.2 Automatic counts

Choosing an appropriate automated counter requires understanding the specific type or types of pedestrian movements that need to be counted. Other key considerations include accuracy, equipment costs, installation costs, maintenance costs, size and location of pedestrian detection zones, data storage, and legal restrictions. A variety of automated pedestrian count technologies are available: Options include:

- Laser scanners
- Piezoelectric pads
- Automated video
- Active Infrared
- Passive infrared counters, and
- Array counters.

The accuracy of automated pedestrian counter rates vary widely and can depend on environmental conditions and pedestrian density. Most counters do not distinguish between a person walking, walking a bicycle, or riding a bicycle. Therefore, the use of automated counter data needs to be considered carefully. Table 4 describes the attributes of some of these count systems.

Figure 9 - Melbourne's pedestrian counting using overhead infrared sensors. Source: http://www.pedestrian.melbourne.vic.gov.au/

Figure 10 – Automatic counts of exiting and entering pedestrians at one Oxford Circus Station stairway.

Table 3 Comparison of common pedestrian counting methods

Characteristic	Passive infrared	Active infrared	Radio Beam (high/low frequency)	Automated video	Manual counts
Different user types				Yes	Yes
Direction of travel	Yes	Yes	Yes	Yes	Yes
User characteristics				Yes	Yes
User volume	++	+++	++	+++	++
Detection of zone width	++	+++		+++	+++
Count duration	+++	+++	+++	+++	+
Equipment costs	$$	$$$		$$$	$
Preparation costs	$$	$$	$$	$$	$
Hourly costs	$	$	$	$	$$$$

6.2 Typical data requirements for modelling non pedestrian modes

To effectively include the other modes, or their influence, the data listed in Table 4 may be required. In the event some data is unavailable, assumptions based on previous experience, literature and site observations can be used. However, which data can be replaced by assumptions is dependent on the intent and required level of detail the assessment and should be determined on a project-by-project basis.

Table 4 Typical data requirements for modelling other modes

TRANSPORT MODE	TYPICAL DATA REQUIREMENTS
General Traffic	— Traffic volumes — Intersection and crossing types — Signal phasing — Locations for property access In the absence of the above, in a simplified CBD environment with only signalised intersections, assessment can be undertaken with signal phase times only (i.e. proportion of time available for pedestrian crossing).
Active and micro-mobility: including bicycles, scooters etc.	— Volumes — Proportion of cyclists using the pedestrian or road corridor — Location and sizing of dedicated and shared infrastructure — On-street storage locations (if applicable)
Private transport: Taxi and rideshare	— Stop location — Pedestrian demand — Queueing characteristics of waiting pedestrians and waiting vehicles
Bus	— Timetable (frequency and dwell time) — Stop location — Boarding and alighting demand (by route) — Interchange to other routes, or other modes (if applicable) — Queueing characteristics — Service capacity
Rail (light, metro and suburban)	As per bus, with the following: — Rolling-stock configuration (length, number of doors, door width) — Distribution of pedestrians along service length (internal and along platform)

6.3 Modelling calibration and validation

To date, there is no widely accepted calibration standard available for assisting the microsimulation of pedestrian movement. This absence has led to models with no accompanying validation or calibration details – the client is invited to trust the model despite there being no link to reality. This is an undesirable situation given the critical nature of some of the decisions which are based on microsimulation output. For stations a poor model may result in congestion becoming an issue many years sooner than anticipated. For a stadium model, the peak demand is likely to be experienced at the *first* event and the impact may be on the safety of the crowd, so relying on an unvalidated model to demonstrate crowd safety is likely to incur significant liability issues should there be an incident.

Clients should request details of any validation or calibration processes to demonstrate the reliability of the model, for transit stations this may be little more than a visual comparison of modelled and simulation conditions. For stadia however the safety aspect is paramount and models should not be accepted without an extensive calibration and validation process to prove they are capable of reflecting realistic behaviours observed in stadia conditions.

It follows that modelling be commissioned well in advance of the design process so that the model is a tool to improve the design. If left too late, or there is insufficient budget, then the model may not undergo a rigorous development process and pressure to demonstrate compliance becomes the overriding objective – even though there is no evidence provided to demonstrate the output is realistic.

Figure 11 represents a simplified calibration / validation process:

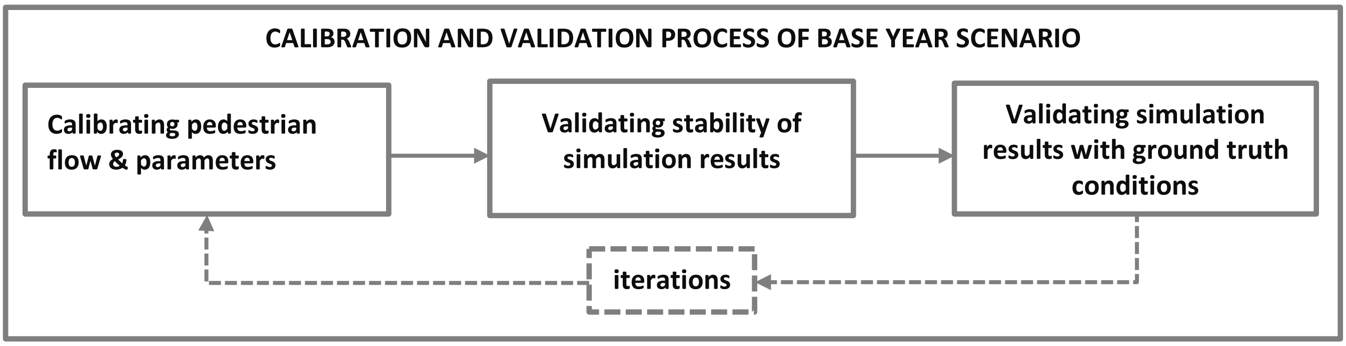


Figure 11 High-level calibration and validation process for microsimulation of pedestrian models

6.3.1 Calibration

Calibration is the process of making adjustments to the model with the intention of reducing the difference between modelled and observed data.

The calibration process for pedestrian models is generally achieved as a result of iterations between the simulation results (or performing a calculation) and the comparison of the output to empirical data (fitting) and modellers knowledge to further refine the calibration until a realistic behaviour of movements reaches a satisfactory level. In general, a similar approach used to calibrate pedestrian microsimulation models is adopted for two different modelling purposes:

- Model calibration for normal and delayed operations (bidirectional). And,
- Model calibration for egress scenarios (unidirectional).

An example is provided in Figure 15.

Very often the calibration of normal and delayed operations results in a more complex process, as this type of scenario assumes the circulation of pedestrian is bidirectional, normally using all available vertical transport systems and devices (e.g. ticket gates). Conversely, the calibration of egress models tends to be unidirectional and normally involves additional or reduced routes to safety areas, including a limited option for vertical transportation (usually evacuation stairs that are not meant to be used by pedestrians during normal and delayed operations).

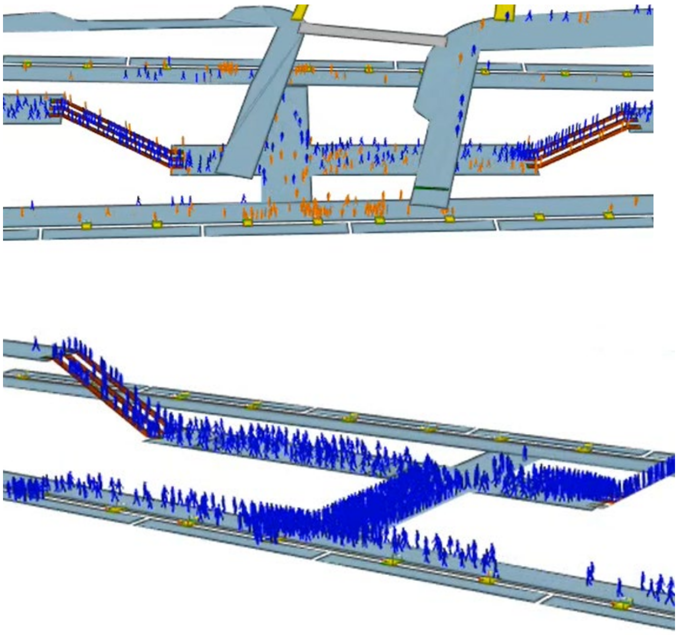


Figure 12 An example of a bidirectional pedestrian model (left) and unidirectional pedestrian model (right). Model results need to be carefully analysed in order to correct potential calibration flaws.

Another key factor that contributes to model calibration is the definition of the parameters to be used in the modelling. For instance, the capacity of ticket gates, escalators and other processes should be based on direct observations rather than specified capacities. In the absence of any locally sourced information (see Figure 13 as an example), commonly used parameters – normally available built-in to simulation packages - may be used.

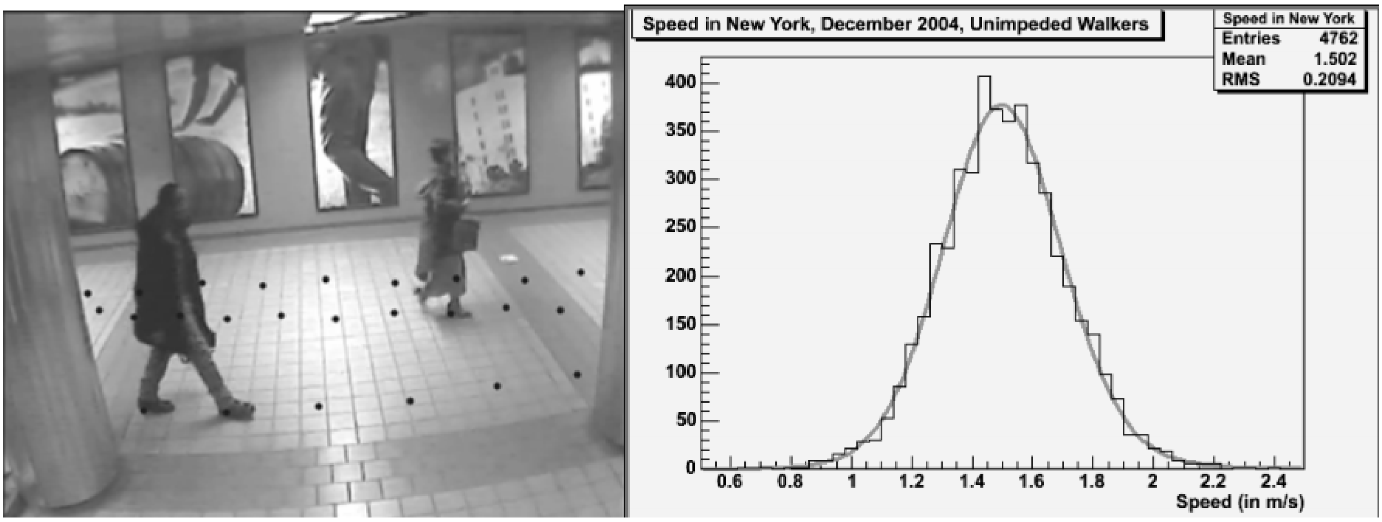


Figure 13 Walking speed measurements in Grand Central Station, New York. Source: Calibration and validation of the Legion simulation model using empirical data, MAIA Institute.

Further details on good calibration practice are provided in Chapter 4 of the following guide: *Pedestrian Microsimulation Guide – UK good practice guide*, Mott McDonald 2023: https://www.mottmac.com/article/78959/pedestrian-microsimulation-modelling

6.3.2 Validation

Validation is the process of comparing modelled and observed data that is independent from that used in calibration and is usually regarded as the final step of the model building process. The London Underground microsimulation modelling guidelines suggest that travel times and screenline flows are all potential validation mechanisms. Quantitative validation should always occur, and a rigorous validation can only be achieved if simulated output is compared to quantifiable observations.

A major factor affecting validation is whether the modelled environment is observable (e.g. an existing train station) or non-observable (e.g. a new sports stadium). For observable environments it is possible to collect data on the use of the space and pedestrian behaviours and therefore it should be possible to obtain a high degree of confidence in the model results

For non-observable environments (see 6.3.3) and should budgets be limited- a less rigorous qualitative validation can be undertaken if the required data is not available or too expensive to obtain, in these circumstances the validation process consists of a careful observation of modelled pedestrian animation and a comparison with direct observations as demonstrated in Figure 14 and Figure 15 (although calibration of key processes should still occur).

Potential calibration and validation approaches can include:

- **Origin–destination (O-D) matrix validation** – Surveyed counts and input demand matrices are compared against the output origin-destination matrix. This can be used to confirm that the passenger volumes have been accurately simulated in the model.
- **Flow-rate comparison –** Simulated flow-rates on vertical transportation, through ticket gates, and along passageways can be compared with the on-site observations. This can be used to demonstrate confidence in simulated walk speeds and passenger behaviour. For non-observable environments, surveys could be undertaken at environments which have similar characteristics (e.g. a similar rail station patronage in the same city and urban setting).
- **Journey time comparison** – Simulated journey times on key routes can be compared against observed journey times in free-flow and crowded conditions. This can be used for observable environments to demonstrate confidence in the simulated passenger behaviour in the model.
- **Visual validity** – The majority of pedestrian simulation software packages provide 2D or 3D visualisations. These visualisations can be used to verify whether the simulation can produce behaviours similar to those in reality. In the data collection phase, videos of pedestrian movement in the observable environment (or similar environment for non-observable models) can be collected and used for calibration and validation.
- **Sensitivity analysis** – Evaluates the response of the simulation model to changes in input parameters. A robust model should respond sensibly to changes as expected in reality. Increases in demand along a singular route should increase the journey time along that route.
- **Internal validity –** Running simulation models multiple times using different random seeds can be a useful validation approach. A robust model should show minimal variation between runs whereas, random seeds resulting in significant differences in model outputs suggests a lack of validity.

Figure 14 An example of a calibration and validation process (concourse level) – verify that at a specific time there is a correspondence between the footage and the microsimulation model.

Figure 15 An example of a calibration and validation process (platform level) – verify that at a specific time there is a correspondence between the footage and the microsimulation model.

Clients should consider having an independent third party review all stages of the modelling process and results - especially if the model has a major safety or design influence.

Further details on good validation practice are provided in Chapter 5 of the following guide: *Pedestrian Microsimulation Guide – UK good practice guide*, Mott McDonald 2023: https://www.mottmac.com/article/78959/pedestrian-microsimulation-modelling

6.3.3 What if the Environment does not yet exist?

The absence of an 'existing environment' is a commonly cited reason why the calibration / validation phase is skipped. However, this means that it is nearly impossible to judge whether the resultant modelled output is likely to occur or not and the absence of any link between reality and the modelled output needs to be understood by all parties. The animated output may look great, but what how credible is the output if not validated?

There is always an opportunity for a calibration / validation stage. A similar environment almost always exists somewhere, even if it is just stairs or escalators in a similar environment (perhaps in another city) - and the modelling team working on your project should be able to demonstrate their ability and that of the software to reflect some form of reality. The software may have been used successfully on other project, but the validation stage is also a test of the ability of the modeller as much as the software.

7 Interpreting results

Pedestrian modelling results often require interpretation. Based on the modelled situation and circumstance, interpretation of density maps, delays, crossflows and dwell times are necessary to understand the environment under review. This chapter will discuss how to understand and interpret results, and to know when environmental or scenario constraints are required in interpreting the results.

7.1 Output types

Different types of pedestrian assessment will produce distinctive result outputs. Chapter 4 outlines two key forms of pedestrian assessment: static assessment and dynamic modelling assessment.

Table 5 summarises some of the key outputs that can be provided by static assessment and dynamic modelling assessment. The dynamic modelling assessment provides enhanced simulation and analysis capabilities, for a more detailed understanding of the pedestrian environment. Each of the static outputs are explained in more detail in Table 6 and the dynamic outputs in

Table 7.

Table 5 Output types

Static Assessment	Dynamic Modelling Assessment
1. Infrastructure design requirements. 2. Priority movement flow and directionality. 3. Level of Service (LoS) at one point in time. 4. Approximate queuing at a specific location. 5. Approximate time spent in queue, per individual. 6. Approximate journey time travel.	1. Assessment of infrastructure in more detail, noting build-up of queuing and congestion. 2. Assessment of multi-directional passenger movement in the available infrastructure space. 3. Provide Level of Service density maps. 4. Provide Space Utilisation maps. 5. Provide dwell time maps. 6. Provide passenger demand clearance maps, not just for Fire Egress evaluation. 7. Provide an understanding of queue and congestion build-up over time, and why the queuing and congestion occurs. 8. Output individual and average travel time and congestion cost. 9. Ability to help inform fire and emergency evacuation movement and behaviour.

7.2 Static spreadsheet analysis

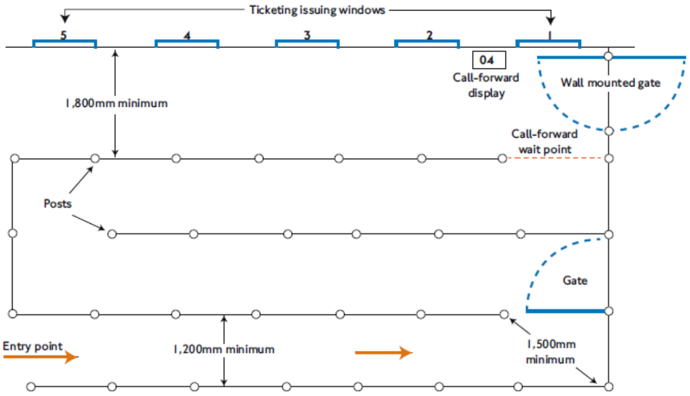
Interpretation of static assessment outputs are discussed in Table 6.

Table 6 Static assessment output examples

Item	Example Description	Comment
1	<u>Ticket Gates</u> The number of required entry gates is assessed against the peak 5-minute boarding demand, as follows: **Number of entry gates =** $Roundup\ (\frac{Hourly\ entry\ passenger \times peaking\ factors}{Gate\ capacity \times 5})$ Apply peak factors to obtain peak 5-minute entry passenger flow. **Number of exit gates =** $Roundup\ (\frac{Alighting\ demand}{Gate\ capacity \times 2})$ With train service contributing the highest number of alighting passengers increased by 25% to allow for contingency in a gap in service. **Total number of gates =** $Number\ of\ entry\ gates + Number\ of\ exit\ gates + Contingency$ Contingency of 1 additional ticket gate to be provided for every 10 calculated gates.	This approach is based on the gateline infrastructure requirement, from the Transport for London Station Planning Standard (2019). This is a formula on the number of gate infrastructure required. Using this formula will provide you with an approximate number of gates required, but you will also need to consider Wide Access Gates which are typically provided at the rate of two per gateline.
2	<u>Escalators</u>	The number of escalators is calculated by direction, on or off the platform, with the capacity of the escalators in the alighting

Item	Example Description	Comment
	Number of escalators off platform = $\frac{(Alighting\ demand\ per\ headway \div (Headway - 30\ seconds))}{100}$ **Number of escalators to platform** = $$Roundup\ (\frac{Boarding\ demand\ per\ minute}{100})$$ The number of 'to platform' escalators is rounded up and the number of 'from platform' escalators is rounded up where the calculated number of escalators is greater than 0.2 of the next integer. In general, it is good practice to add an additional escalator (or stair) to the calculated number to provide contingency for when an escalator is out of service. The details of this provision (one per level or one per entrance) is influenced by the station layout and may be subject to spatial availability.	direction sized to meet specified platform clearance times. In this example the platform clearance time is headway minus 30 seconds. For lower frequency service the clearance time is defined by customer service expectations. The calculation assumes that one train in each direction enter the station simultaneously. The requirement for contingency capacity is site specific, a station with multiple entrances may adopt a diversion approach in the event of escalator failure.
3	Priority movement flow and directionality $$\text{The average flow per minute over the peak 15 minutes} = \frac{\text{the peak 15 minute flow}}{15}$$	The formula shown on the left is the passenger flow data, also from London Underground SPSG, 2012. Movement flow and directionality can be worked out using this formula, whether over a 15-minute period or a 1 minute period. This will assist in understanding the key pedestrian movements. It is important to understand that the priority movement should be the focus during the design stage, in order to facilitate a smooth movement of travel for the majority of the pedestrian demand.
4	Level of Service (LoS) at one point in time <table><tr><th>Walkway</th><th>Effective width (m)</th><th>Ped flow (pax/ min) peak</th><th>Ped flow (pax/min/m)</th><th>LoS</th></tr><tr><td>X</td><td>4.1</td><td>200.00</td><td>48.66</td><td>C</td></tr><tr><td>Y</td><td>3.8</td><td>100.00</td><td>26.60</td><td>B</td></tr><tr><td>Z</td><td>2.2</td><td>150.00</td><td>68.18</td><td>E</td></tr></table>	An example of a LoS for a walkway, based on various pedestrian volumes is shown on the left. The effective width represents the space actually used by pedestrians; it is the physical space minus an allowance for the 'edge effect'. This shows the expected LoS during a certain time, but not the fluctuation of the walkway location. At the very worst, Walkway Z will show LoS E, but we need to understand that the pedestrian volume may not be a constant 150 people during the day.

<table>
<tr><th>Item</th><th>Example Description</th><th>Comment</th></tr>
<tr><td>5</td><td>Approximate queuing at a specific location



The maximum average Queue population (QP) for demand (d), previous queue size (Q) and capacity (c) is given by:

$QP = d + Q - c$

Only when d + Q > c

If d + Q < c then no queue forms.</td><td>The image on the left is from London Underground SPSG, 2012. This shows the potential queue at a ticket window, dependant on the number of servers and the ticket transaction time.

An approximate queue line length can be determined based on fixed assumptions. However, this static analysis does not take into account the variability of ticket transaction times, or the sudden reduction of ticket staff (although this can be represented in more sophisticated spreadsheet models).</td></tr>
<tr><td>6</td><td>Approximate time spent in queue, per individual

The approximate time spent in queue can be calculated based on the above example. If a queue (Q) exists with a process of capacity (c) the maximum delay is :

Q / c</td><td>It should be noted that this queue time will be a static interpretation and cannot account for variability or randomness. If the queue assumptions are used, the time spent in queue will reflect a best-case or worst-case scenario.

As discussed in 5.6.1 the queue length requires a distance per person calculation.</td></tr>
<tr><td>7</td><td>Approximate journey time travel

<table>
<tr><th>Segment</th><th>Horizontal Length (m)</th><th>Adj. Length (m)</th><th>Time to Traverse (mm:ss.s)</th></tr>
<tr><td>1</td><td>12.40 m</td><td>12.40 m</td><td>00:09.2</td></tr>
<tr><td>2</td><td>2.40 m</td><td>2.40 m</td><td>00:01.8</td></tr>
<tr><td>3</td><td>3.00 m</td><td>3.00 m</td><td>00:02.2</td></tr>
<tr><td>4</td><td>1.29 m</td><td>1.29 m</td><td>00:02.0</td></tr>
<tr><td>5</td><td>14.37 m</td><td>14.37 m</td><td>00:22.1</td></tr>
</table></td><td>An example journey time calculation is shown on the left. This assumes a walking speed of 1.35m/s.

In assessing static journey times, the impact of congestion and time spent in congestion through the journey, or the time delay of queuing, are usually not considered.</td></tr>
</table>

7.3 Dynamic modelling

In addition to numeric outputs, dynamic modelling can produce visual examples, such as those shown in Figure 16, which can be better understood by non-technical pedestrian specialists. A 3D view of the pedestrian movement and behaviour can assist in providing a highly visual interpretation and understanding of movement impacts.

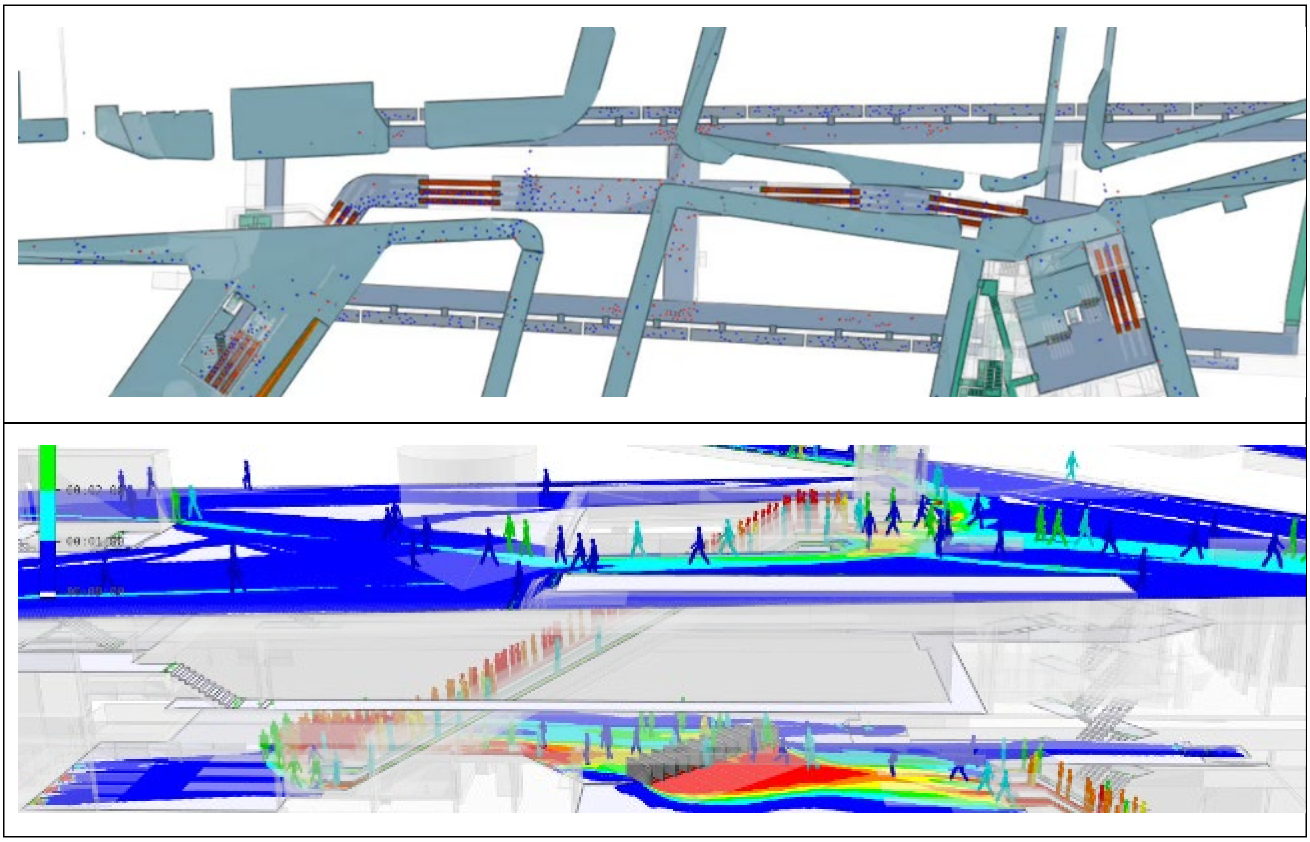


Figure 16 3D pedestrian modelling example

Dynamic modelling provides further robustness that cannot be achieved using static analysis. Dynamic modelling can extrapolate the combined impact of queuing and congestion, and include randomness in pedestrian behaviour and choice, which can provide realistic impacts and outcomes for the assessed infrastructure or precinct.

Table 7 summarises further consideration notes for key dynamic modelling output assessments.

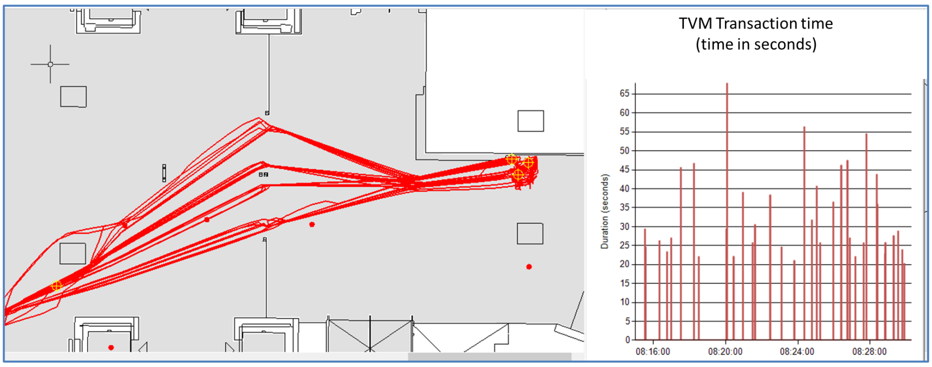
Table 7 Dynamic modelling output assessment

<table>
<tr><th>Item</th><th>Description</th></tr>
<tr><td>1</td><td>
Dynamic modelling can provide a better understanding of the impact of queue and congestion build-up.

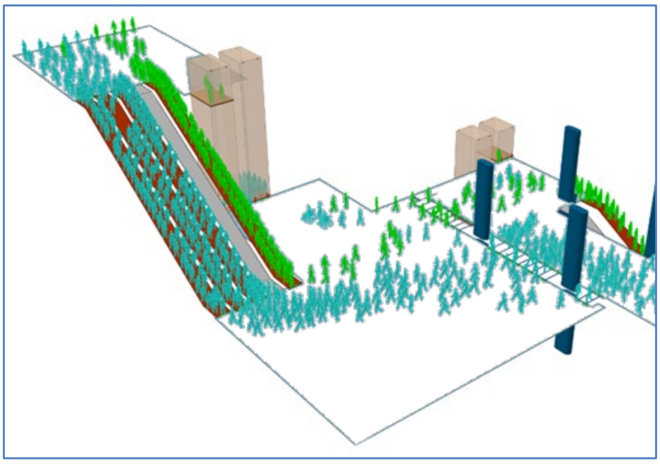
When inputting queueing metrics within the model, it is good practice to use a range of assumptions, as this will replicate a range of realistic behaviour. For example, for ticket queuing, it is good to use a range for ticket server transaction times, to replicate people paying with credit card, people paying with cash, and some people requiring more time to make a choice on payment.

The images below provide examples of station dynamic modelling including passengers purchasing tickets from a Ticket Vending Machine and passengers exiting through a gateline.

Example: assessment of ticket purchasing patterns and gateline throuputs in station concourses.

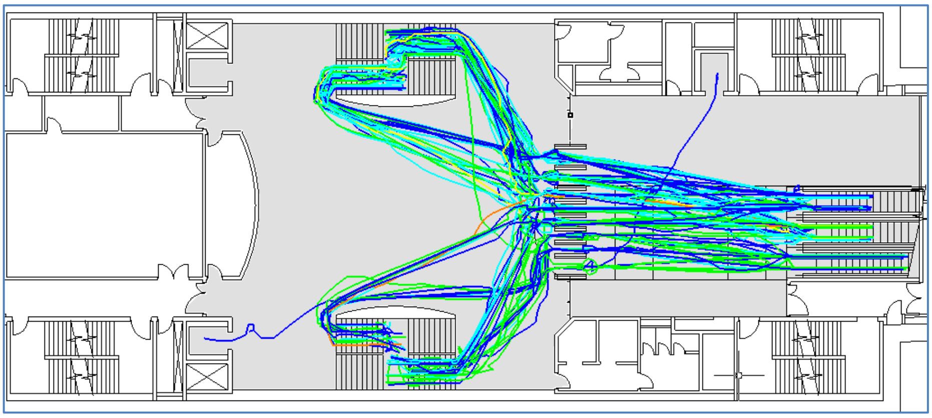
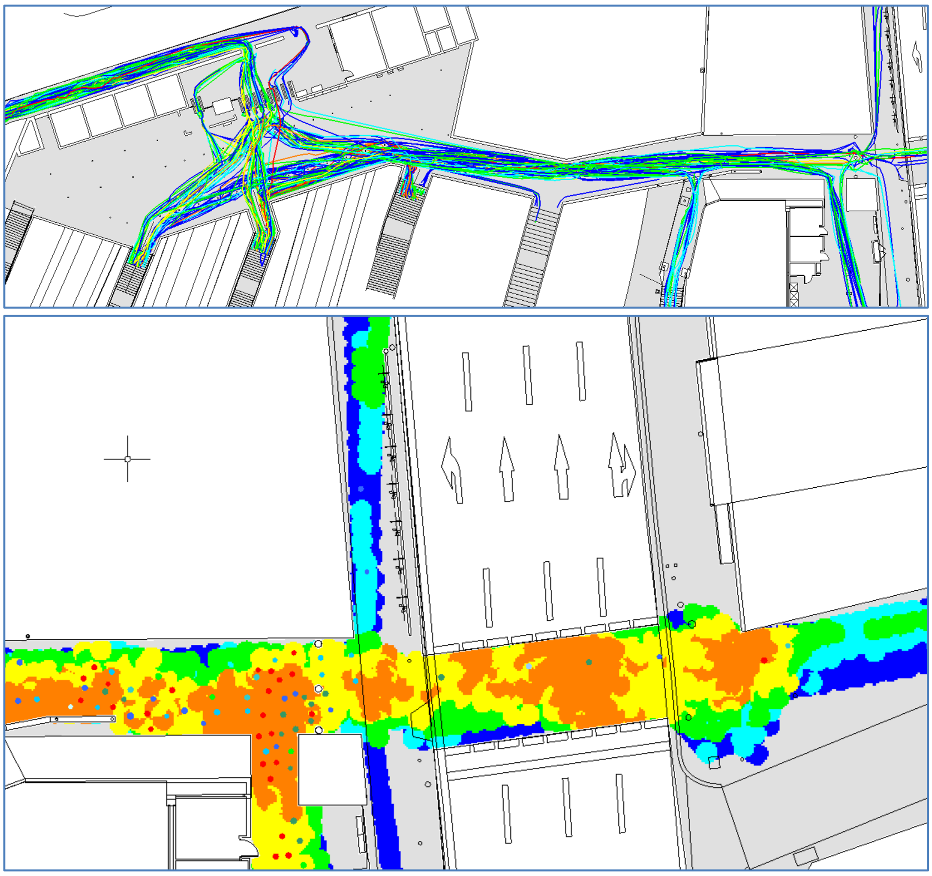


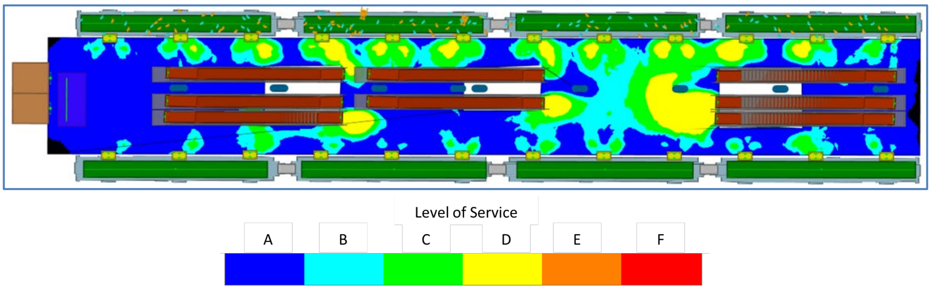
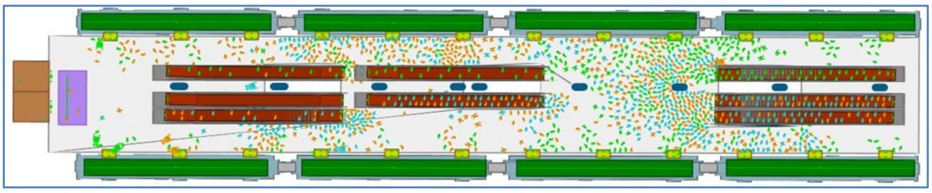
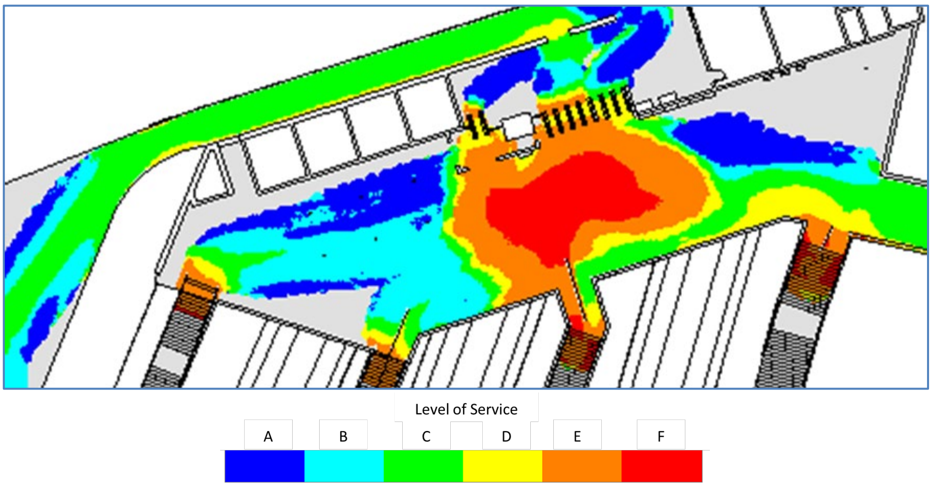
Example: assessment of passengers exiting a station through a gateline and VT with one escalator out of service.

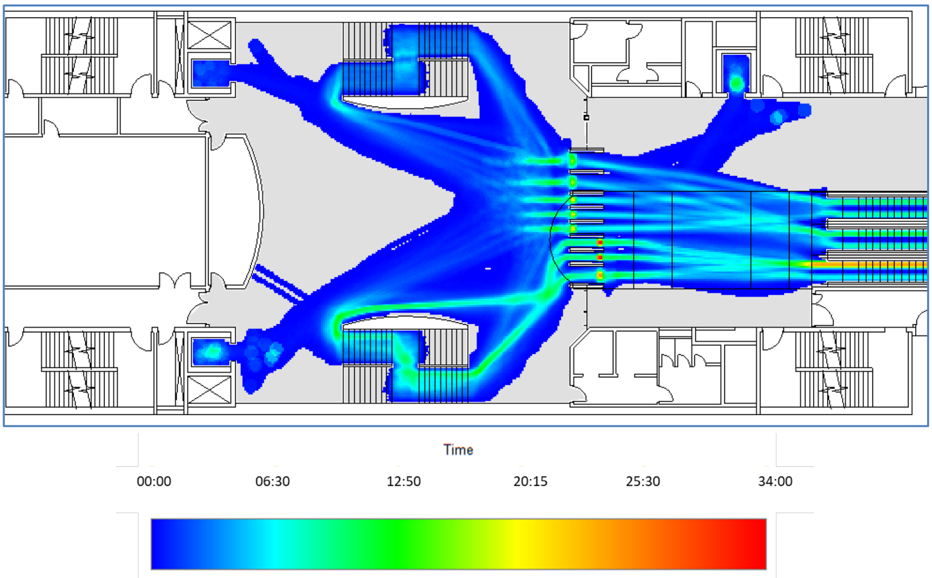
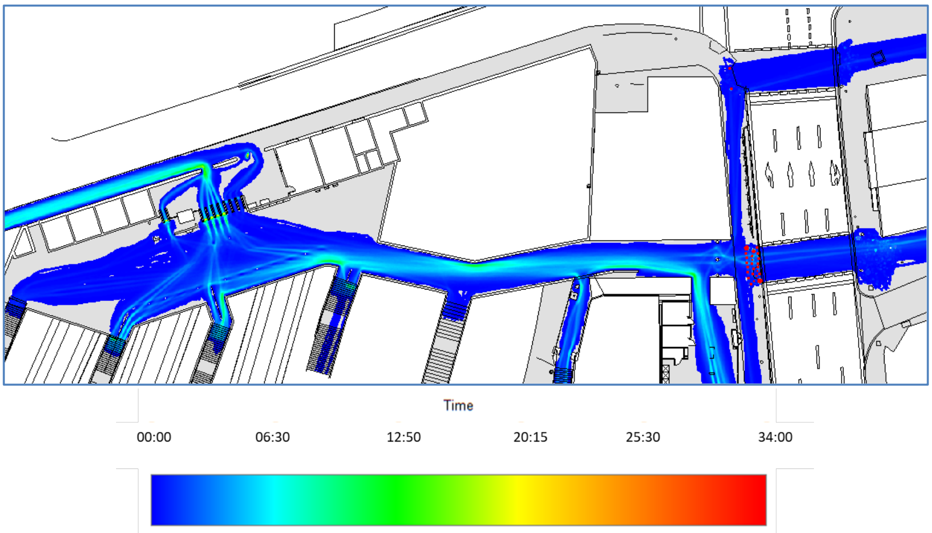

</td></tr>
</table>

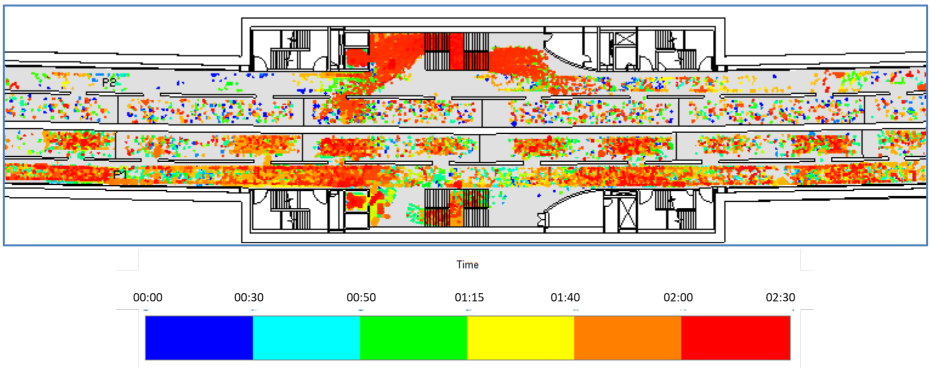
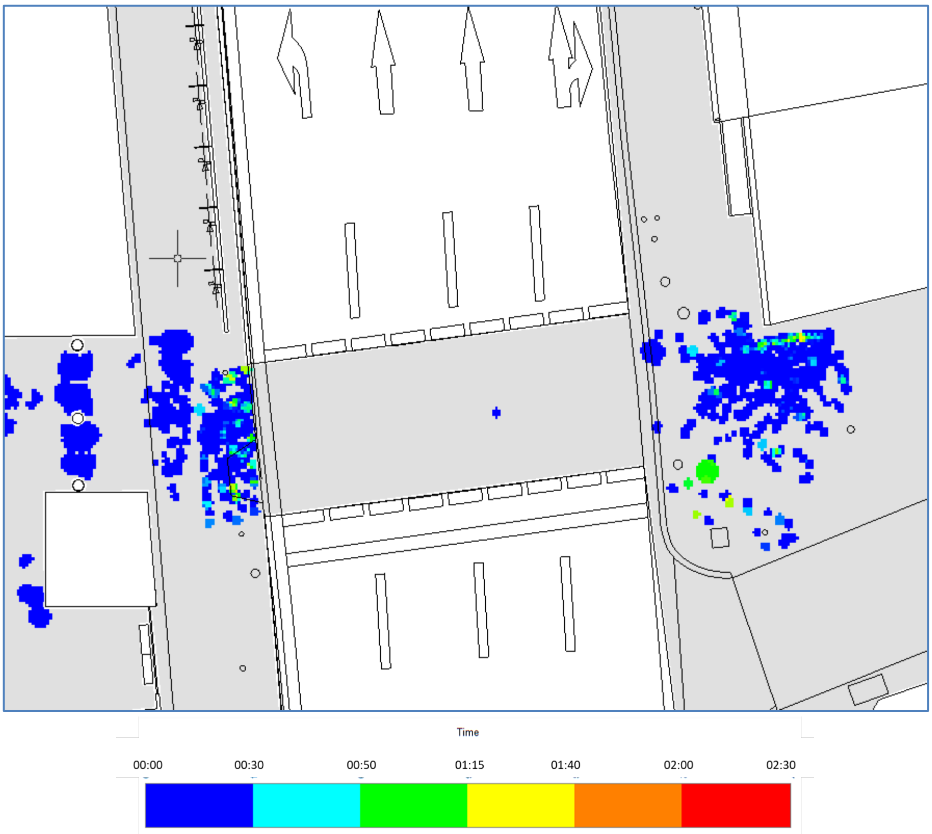
<table>
<tr><th>Item</th><th>Description</th></tr>
<tr><td>2</td><td>Dynamic modelling considers the infrastructure environment as a whole and can provide key cause and effect patterns.

For example, tracing the desire lines within a concourse can help identify conflict points and potential layout improvements.

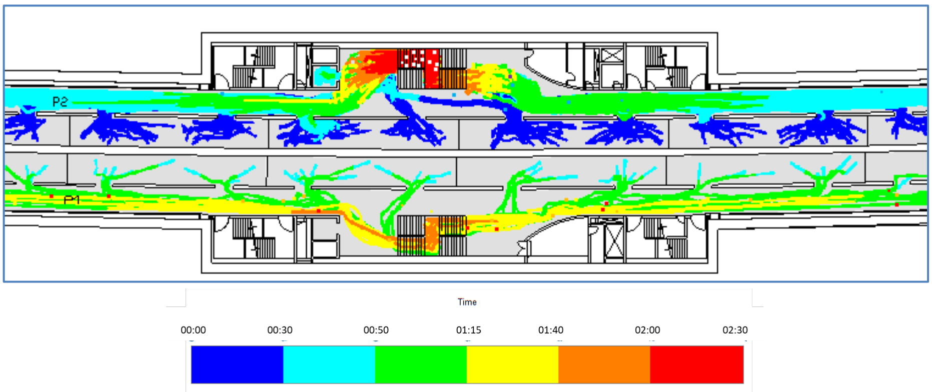
Example: assessment of multi-directional passenger movement in the available concourse space (desire lines plot).

When platform to concourse distance is short, train alighters may exit onto the footpath within a short time, causing to congestion on the footpaths adjacent to the station.
Example: assessment of multi-directional passenger movement in the available infrastructure space (desire lines plot, top) and impact on pavement congestion (Max Density Map, bottom).
</td></tr>
<tr><td>3</td><td>Density maps in dynamic modelling show the performance of the entire infrastructure, highlighting which section of the infrastructure is higher utilised, and where is this available capacity.</td></tr>
</table>

Item	Description
	For example, an island platform may become extremely busy due to the effect of two simultaneous trains arriving. Dynamic modelling can help identifying the best combination VT capacity and platform width. **Example: Experienced Level of Service map (top) displaying crowding on a station platform following simultaneous train arrivals, accompanied by a snapshot from the simulation (bottom).**   Dynamic modelling can highlight capacity constraints in station areas such as concourse and gatelines in certain conditions, such as construction or events scenarios. **Example: Cumulative Mean Density map displaying LoS in a pre-upgrade station concourse during the peak 15-minute period, highlighting potential congestion during construction phase.** 

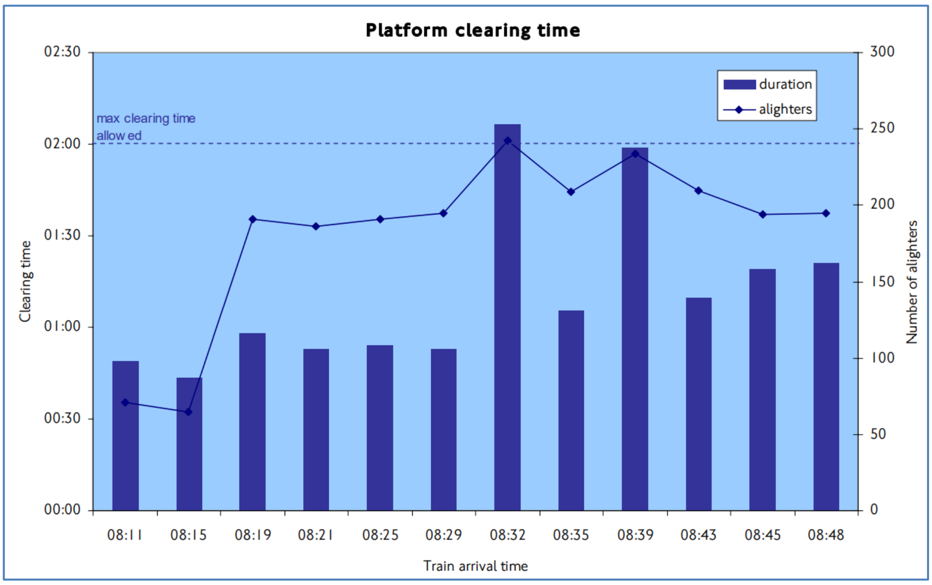
Item	Description
4	Space utilisation maps show key movement corridors and volume of movement, against all movement within the infrastructure. These maps assist in highlighting primary origin-destination paths and can show where the design does not align with direct line of sight. This map is recommended to be used to assist in the design process. The colours in Space Utilisation maps represent how often the space is used: blue being lightly used, red being heavily used, background colour not used at all. These maps can be used, for example, to demonstrate existing space usage in a ticket hall area, to decide where a ticket machine could be placed. **Example: Space Utilisation map showing the amount of time during which each area of a station concourse is occupied.**  Space utilisation maps can also help decide whether closing part of a passageway would impact the majority of passenger flows. **Example: Space Utilisation map showing the amount of time during which each area of a model is occupied in preparation for upgrade works.** 
5	Dwell time maps provide minimum, average and maximum dwell times. This is generally taken for the whole journey and shows where along the journey, most time is spent.

Item	Description
	The average dwell time is recommended to be used, as a minimum dwell time may not account for the majority of the pedestrian volume, and a maximum dwell time may be too conservative for use in the design process. **Example: Dwell time map showing the amount of time spent at each location during platform egress.**  **Example: Dwell time map showing the amount of time spent at each location during street-level approach to a station (including signalised pedestrian crossing).** 
6	Clearance time maps are especially useful for platform analysis and fire egress evaluation. Clearance time maps should show the minimum, average and maximum time, to provide a holistic understanding. For some circumstances, an 85th percentile is taken to assess the clearance time.

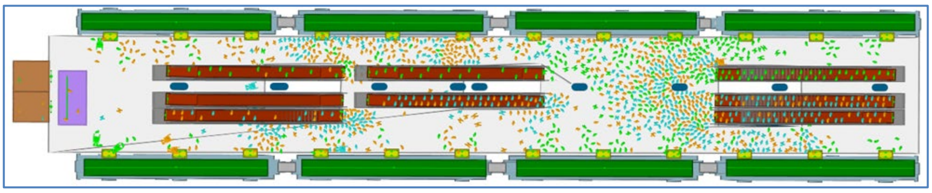
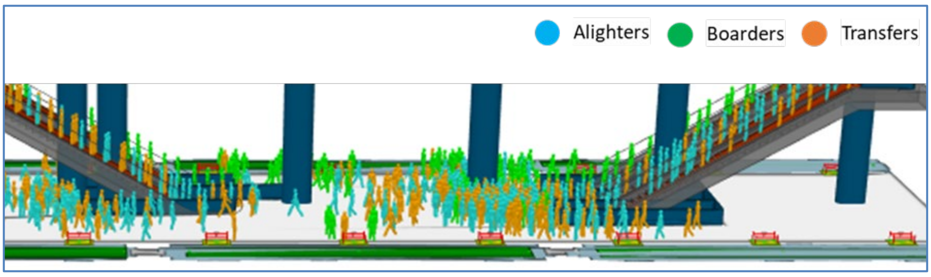
<table>
<tr><th>Item</th><th>Description</th></tr>
<tr><td></td><td>
Example: Egress time map showing the amount of time taken to clear a platform from each alighting point following a train arrival



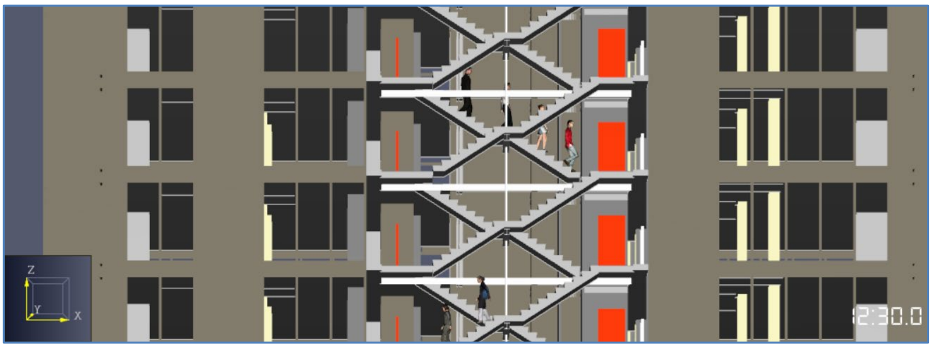
Example: Egress time graph showing the platform clearing time and alighting loads following each train arrival



</td></tr>
</table>

<table>
<tr><th>Item</th><th>Description</th></tr>
<tr><td>7</td><td>
The visual understanding and evaluation of how and why congestion or queueing builds up can help resolve such issues.
Typical findings relate to insufficient VT capacity, lack of platform space, gateline width or temporary surges in pedestrian flows in degraded operations or event scenarios.
Example: Snapshots from a 3D dynamic simulation showing passengers on a busy platform following simultaneous train arrivals



</td></tr>
<tr><td>8</td><td>
Under some project circumstances, the congestion cost experienced along an individual's journey is important to note.
This metric should also be accompanied by an average congestion cost, due to the randomness and range of behaviour assumptions inbuilt into the dynamic model. It is possible to estimate the annualised cost (and cost variations across different design options) associated with time, distance, activities and congestion experienced by passengers.
Example: Generalised Journey Time summary showing the cost (in GBP assuming a 7.59GBP/hour Value of Time)
<table>
<tr><td>VOT (£/hour)</td><td>£7.59</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Days per year</td><td>250</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>BY ACTIVITY</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th></th><th>Weighting</th><th></th><th>JT</th><th>GJT</th><th>CF</th><th>Cost Journey</th><th>Cost Congestion</th><th>Total Cost</th><th>Annualised</th></tr>
<tr><td>Global: On Stairs</td><td>1.0</td><td></td><td>0:00:00:00.00</td><td>0:00:00:00.00</td><td>0:00:00:00.00</td><td>£0.00</td><td>£0.00</td><td>£0.00</td><td>£0.00</td></tr>
<tr><td>Global: On Escalator</td><td>1.0</td><td></td><td>0:00:00:00.00</td><td>0:00:00:00.00</td><td>0:00:00:00.00</td><td>£0.00</td><td>£0.00</td><td>£0.00</td><td>£0.00</td></tr>
<tr><td>Global: Walking</td><td>2.000 + 0.500 CF</td><td></td><td>4:19:34:17.10</td><td>9:15:08:34.40</td><td>0:14:57:26.28</td><td>£1754.37</td><td>£113.53</td><td>£1867.90</td><td>£466975.11</td></tr>
<tr><td>Global: Waiting</td><td>2.500 + 1.000 CF</td><td></td><td>2:04:52:40.44</td><td>5:12:11:40.47</td><td>0:02:31:41.69</td><td>£1003.36</td><td>£19.19</td><td>£1022.55</td><td>£255636.56</td></tr>
<tr><td>Global: Queuing</td><td>3.4</td><td></td><td>0:00:00:00.00</td><td>0:00:00:00.00</td><td>0:00:00:00.00</td><td>£0.00</td><td>£0.00</td><td>£0.00</td><td>£0.00</td></tr>
<tr><td>Global: Delayed</td><td>2.5</td><td></td><td>0:15:52:04.82</td><td>1:15:40:12.00</td><td>0:00:00:00.00</td><td>£301.10</td><td>£0.00</td><td>£301.10</td><td>£75273.82</td></tr>
<tr><td>Global: On Stairs Up</td><td>4.0</td><td></td><td>0:15:07:15.62</td><td>2:12:29:02.47</td><td>0:00:00:00.00</td><td>£459.07</td><td>£0.00</td><td>£459.07</td><td>£114768.43</td></tr>
<tr><td>Global: On Escalator Up</td><td>1.5</td><td></td><td>0:21:56:11.40</td><td>1:08:54:17.15</td><td>0:00:00:00.00</td><td>£249.75</td><td>£0.00</td><td>£249.75</td><td>£62436.79</td></tr>
<tr><td>Global: On Stairs Down</td><td>2.5</td><td></td><td>0:08:34:36.01</td><td>0:21:26:30.00</td><td>0:00:00:00.00</td><td>£162.74</td><td>£0.00</td><td>£162.74</td><td>£40685.56</td></tr>
<tr><td>Global: On Escalator Down</td><td>1.5</td><td></td><td>0:12:35:16.21</td><td>0:18:52:54.31</td><td>0:00:00:00.00</td><td>£143.31</td><td>£0.00</td><td>£143.31</td><td>£35828.12</td></tr>
<tr><td>TOTAL</td><td></td><td></td><td>10:02:32:21.59</td><td>22:08:43:10.80</td><td>0:17:29:07.97</td><td>£4073.70</td><td>£132.72</td><td>£4206.42</td><td>£1051604.40</td></tr>
</table>
</td></tr>
</table>

Item	Description
9	Ability to help inform fire and emergency evacuation movement and behaviour. This output is often assessed in tangent to the advice from the Fire Engineer. A fire or emergency egress dynamic model can pressure test movement along the appropriate fire evacuation routes, and evaluate the impact of congestion or queueing due to lack of fire evacuation infrastructure. **Example: Snapshots from a Fire Evacuation dynamic simulation (Pathfinder), showing occupants evacuating a high-rise building**  

7.4 Things to watch out for

7.4.1 Perceived Accuracy

One of the greatest benefits of microsimulation is the ability to produce realistic animations of pedestrian movement around complex environments which can highlight issues and demonstrate how the infrastructure may be used under a range of demand scenarios. This paradoxically is also its greatest weakness as it can also output this compelling animation on models which are based on flawed data and little more than the opinion of the modeller. The compelling nature and apparent sophistication of the process can often result in '***perceived accuracy***' – i.e. a much higher level of confidence and credibility is assigned to the results of the model simply because the output looks impressive.

Perceived accuracy is likely to occur in microsimulation models which are not accompanied by a fully documented calibration / validation phase, are unable to directly link output results to reality and have not been subject to a third-party review. The animation may look fantastic – but it may be just that an animation rather than the output of a credible model.

7.5 Average Level of Service

Specifying the LoS requirement is important, as there is currently an absence of widely adopted acceptance criteria for dynamic modelling. For example, it is common to specify that a pedestrian environment must operate at LoS C. The specification may or may not include a reference time frame, the use of edge effects and whether periods of zero flow should be included in the assessment – and so should be agreed from the outset.

For some projects (especially if a developer is promoting a design) meeting the specification is the objective. As demonstrated in 7.5.2, there is a wide range of responses which can all meet the same specification, so it is important that the specification does not oversimplify the LoS requirement.

7.5.1 What is meant by average?

Most modelling requirements specify an average condition over a time period (the most commonly used is 15 minutes), but even in a high frequency environment this can include significant periods of low or zero flow. The inclusion of 'emptiness' significantly improves the reported average level of service.

Figure 17 is a simplified example but demonstrates the issue. The demand profile represents 1,410 people arriving on an island platform over a 15-minute period from five simultaneous train arrivals, they are linked to an upper level concourse by two 'up' escalators and one 'down' escalator. In simple average flow terms this equates to 94 people per minute. However, excluding the periods of zero flow results in an average flow of 125 people per minute.

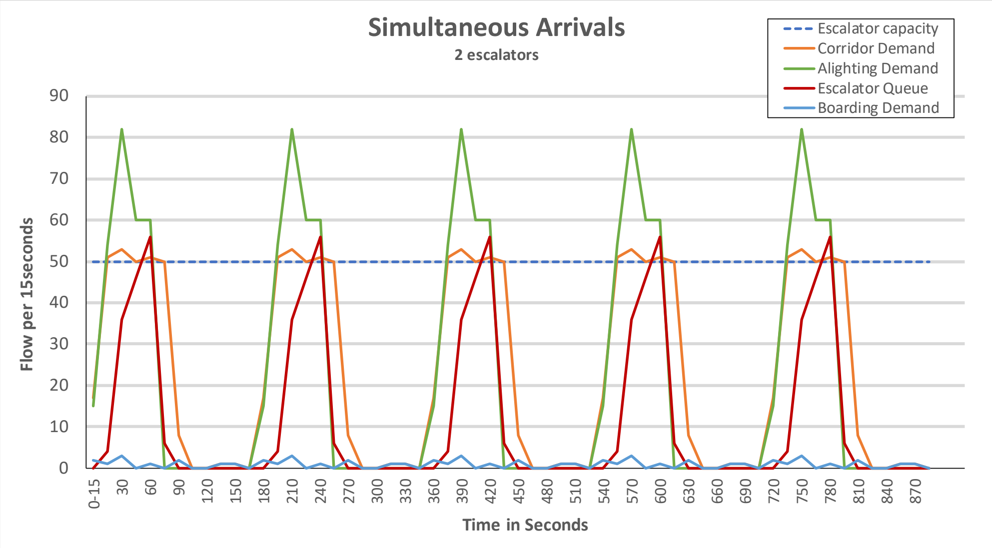


Figure 17 Example flow profile arising from 1410 alighting passengers from simultaneous train arrivals on an island platform

So using the same demand profile can yield two different average results for a 15 minute period. Furthermore, how the range of experience of the same 1,410 people varies according to how the 'average' condition is calculated is extensive. Some clients may be surprised how many people can experience a very poor LoS but still achieve an average LoS C.

Different software packages present their interpretation of average results in various ways, the results should always be accompanied by a clear statement of how the average results are calculated. This applies to both static and microsimulation results.

7.5.2 A Range of Results for the Same Demand

In Figure 17 the alighting demand is very peaked but is filtered by two up escalators onto a connecting corridor. It follows that in this example, whenever there is a queue at the base of the escalators the escalators are operating at a capacity of 50 people per 15 seconds. The demand profile could also be represented by an offset train arrangement as per Figure 18 or a more random pattern as indicated in Figure 19.

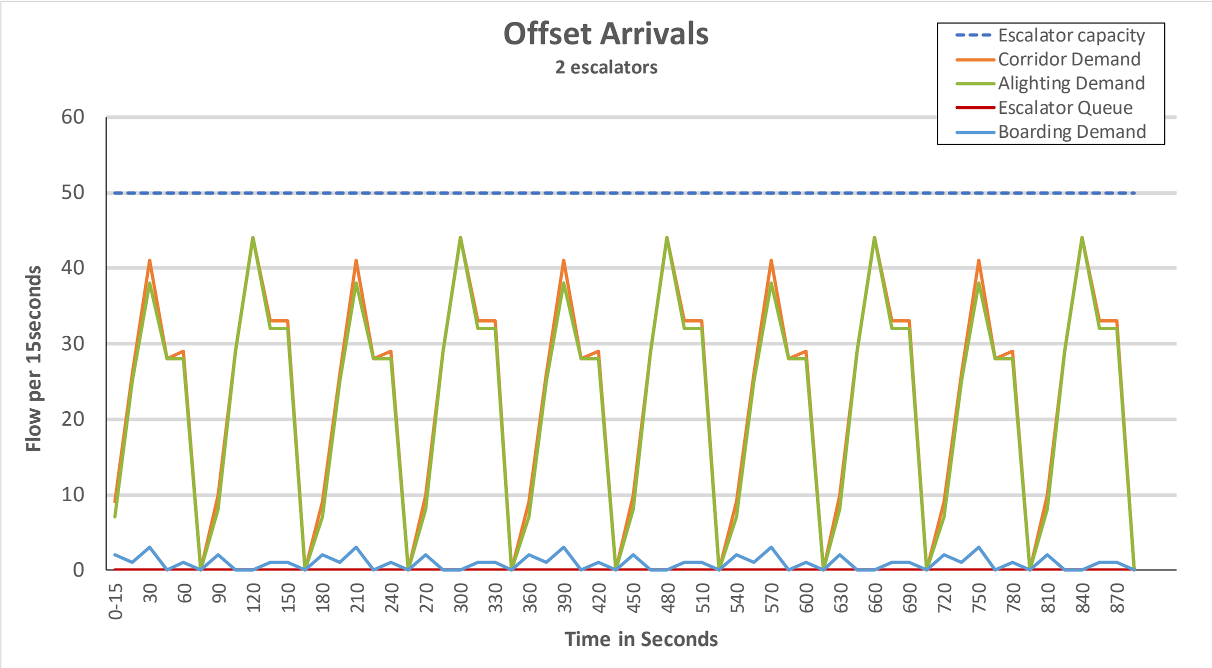


Figure 18 Example flow profile arising from 1410 alighting passengers from offset train arrivals on an island platform

Clearly, if all trains are modelled to arrive at the platform offset from each other, then the escalator capacity is not exceeded and the animation of this situation would show people alighting from trains and moving onto the escalators without delay.

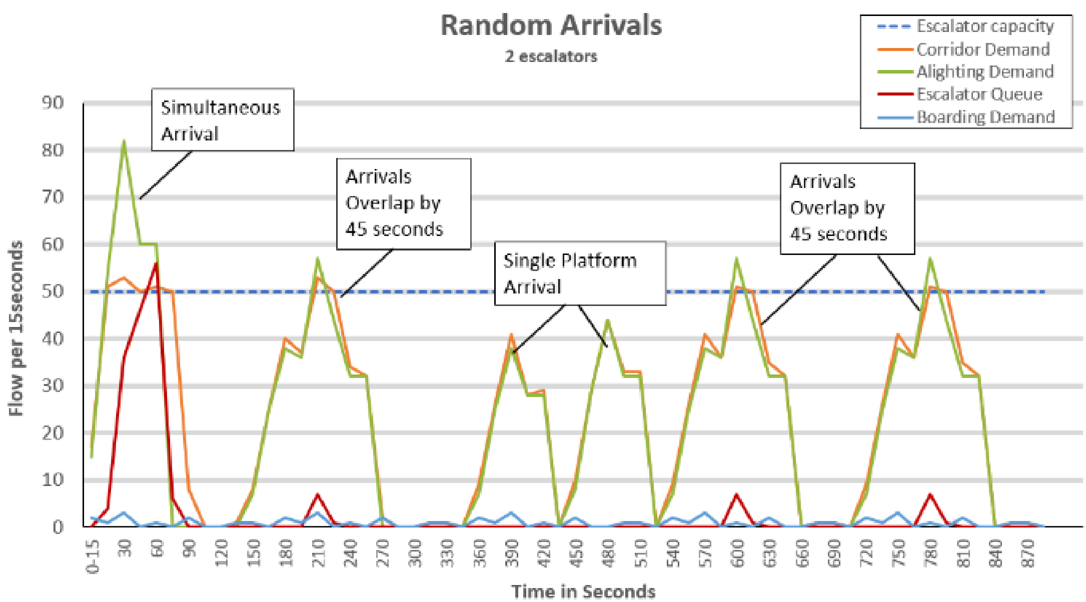


Figure 19 Example flow profile arising from 1410 alighting passengers from random train arrivals on an island platform

Using a more random train arrival pattern, the first train would result in some escalator queues but minimal queueing thereafter. The key point is that the overall demand is identical over the 15-minute period but the arrival pattern has an impact on the reported level of service.

These options for the demand profile result in considerable variation in how the corridor could be described as operating depending on how the meaning and duration of average is interpreted and whether an allowance is made for edge effects or not. This range of results is provided in Figure 20.

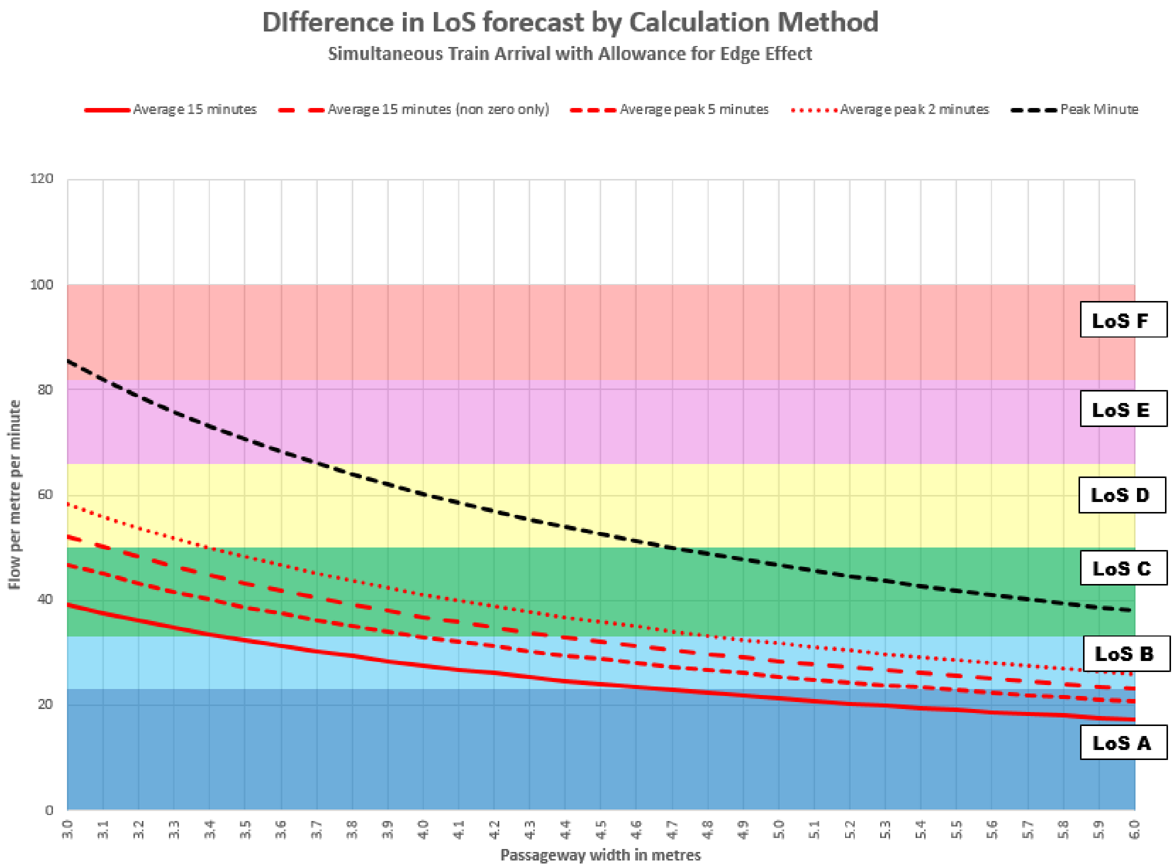


Figure 20 The range of results for the same corridor width

These results demonstrate that even within the same train operating pattern, the results can vary significantly depending on how the average condition is specified. As shown in Figure 20 a 3-metre-wide corridor is calculated to operate at LoS C if the 15-minute average demand is assumed, but the equivalent peak minute yields a LoS F for the same demand, edge effect and train arrival pattern. These are spatial results which indicates how the corridor operates at various widths. In Figure 21 we contrast these results with what proportion of the demand would experience a particular level of service.

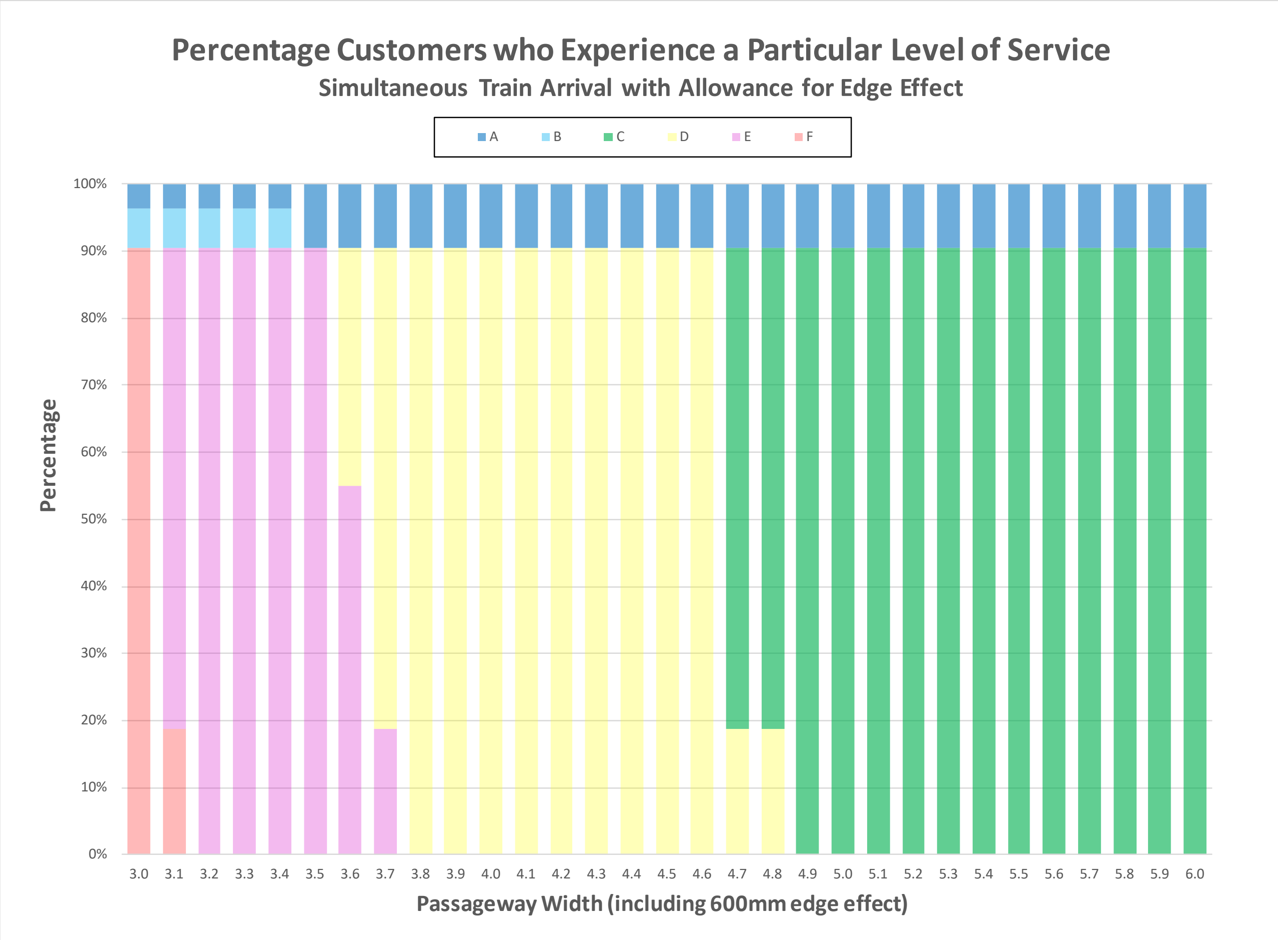


Figure 21 The proportion of demand who experience a particular Level of Service

The results in Figure 21 indicate that 90% of the people would experience LoS F in a 3-metre-wide corridor whilst the average LoS over 15 minutes from Figure 20 would suggest LoS C. Even if we took the peak 2-minute demand as our source of data it would suggest 3.5 metre of corridor would still yield an average of LoS C, whereas according to Figure 21 around 90% of the demand would experience LoS E.

> This range of results for the same demand illustrates why the model specification is so important – a contractor trying to save costs could make a reasonable case that a 3m corridor does achieve a LoS 'C' criteria if all that was requested was "achieve LoS C".

7.6 Measures to Improve the Specification

The key in procuring an effective dynamic model is to prepare an effective specification. The following measures will help procure a model which better reflects the probable actual experience of the users and to aid the design review process.

7.6.1 Approach

- Understand the purpose of the model and the reliance placed upon the output. Design development will require a more robust model (and specification) than a scoping study. Anything associated with stadia has far greater influence on the safety aspect of movement – so stadia models should be credible, robust, and demonstrably able to replicate reality.

- Set a clear objective for the model. If there may be conflicting requirements for spatial provision (i.e. between retail and dynamic space) then ensure the dynamic requirements are clearly stated and how the impact of the retail areas on this activity should be assessed.

- Microsimulation is data hungry. There is little value modelling broad assumptions at a fine level of detail. Beware of perceived accuracy. Over-specifying a model may yield little real value if not supported by the same level of robust data.

Resilience is the ability of the system to cater for and recover from unexpected events. Sensitivity analysis can help identify a range of potential outcomes and can be an important component of demonstrating the resilience of the system. There needs to a clear definition of what constitutes a successful demonstration of resilience, this demonstration may be more nuanced than simply setting a target LoS.

7.6.2 Model Specification

- Clearly express the demand profiles to be analysed, if there is the potential for multiple / simultaneous train arrivals then request that this is reflected in the modelling.
- Most models report average conditions, consider requiring the reporting to include a quantification of actual experience of pedestrians. Consider setting an upper limit (e.g. 10%) on the number of pedestrians who experience a LoS worse than 'C' under normal conditions (for resilience testing this percentage may increase). The causes of exceptions should be provided, e.g. compression turns may arise irrespective of the spatial provision – but this needs to be clearly identified.
- In many cases there would benefit in reporting average conditions over a timescale shorter than 15 minutes. Average results over 5 minutes or 2 minutes would provide a closer correlation to average and actual conditions – but should always be accompanied by some quantitative assessment of customer experience.
- Specify whether edge effects should be included in the analysis and the allowance to be adopted. It is acknowledged that edge effect is probably irrelevant at very poor levels of service and not every environment would result in a 300 mm gap (a glass balustrade for instance).

Specify what validation activity should be undertaken, even if the infrastructure does not exist there is value in obtaining some evidence that the model (and modeller) can reflect reality.

7.6.3 Technical review requirement

An independent third-party review is a very powerful method of establishing the credibility of the static and dynamic model, especially the assumptions used in the assessment. The involvement of this third party should be stated from the outset – and their input throughout the process would generally result in a more robust model and analysis output.

8 Further reference material

Many local transit authorities will have their own requirement documents which should be referred to in the first instance.

Other sources include:

- TfNSW Walking Space Guide, July 2020.
- TfNSW Functional Spaces, Part 2: Station, TFNSW (TS 04951.2:1.0, ESB 003 , August 2022)
- Pedestrian Comfort Guidance for London, Transport for London, 2010.
- Legion Spaceworks: Best Practice Guide (London Underground, V3.2 January 2016).
- Station Planning Standard (2019), Transport for London :
    - S1371 A7 Station Capacity Planning
    - S1372 Station Staff
    - S1375 Planning for Ticket Issuing Facilities
- Transit Capacity and Quality of Service Manual, Transportation Research Board, 2013
- Station Capacity Planning Design Manual, Network Rail
- Guide to Safety at Sports Grounds, Sports Grounds Safety Authority:
- Pedestrian Microsimulation Guide – UK good practice guide, Mott McDonald: https://www.mottmac.com/article/78959/pedestrian-microsimulation-modelling