Fire Protection and Evacuation Procedures of Stadia Venues in New Zealand

by

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Key words

Stadia, stadium, evacuation, New Zealand, egress, pedestrian flow rates, crowd movement, entertainment venues, crowd management.

Abstract

This study investigates the vulnerability to fire and preparedness of New Zealand's stadia for effective evacuations. The study covers aspects of crowd behaviour, observational findings and issues that must be considered when accommodating crowds. It provides an overview of the features stadia use to protect stadium patrons from fire, and a brief history of some famous stadium incidents and their contribution to the profile of the modern stadium.

In 2001 there were two major mass casualty fire disasters in highly populated buildings in the USA. Subsequently there has been increased attention placed on the vulnerability of high profile sites and gathering places to large-scale mass casualty events. Effective mitigation in such variable populations is two-part: evacuation and protection of the populous.

New Zealand (NZ) does not have work-place buildings of the scale of those in other developed countries such as the USA. The largest capacity structures in New Zealand are entertainment venues, namely stadia. In 2002 New Zealand had ten operational large stadia with the capacity to accommodate in excess of 20,000 patrons. The NZ Fire Service has attended 28 call outs to these stadia over the last 3.5 years. Three of these call-outs were to attend actual fires. By identifying issues particular to stadia evacuations (structural and management practice) it is hoped gain insight as to how to prevent New Zealand stadia from entering the international list of major mass casualty case studies.

Experiments performed in this study included;

- Analysis of the observed flow movements of egressing crowds at stadia
- Simulation of stadium egress using modelling software
- Estimated crowd flow potential based on previous pedestrian movement studies and standard calculations.

> The results obtained by these methods were then compared in order to establish their relative consistency and credibility when applied to the New Zealand stadium crowd environment.

In the course of this study it was found that there is a lack of consistency across New Zealand stadia in both fire protection and crowd management practices. In several instances, overseas regulations and codes have been adapted for use in the different New Zealand stadia. International practice with regards to stadium design and egress requirements for such varies; hence a review of different international codes and standards was incorporated into the study because of their applicability to New Zealand practice.

Experimental analysis showed marked variation in the results obtained for egress when applying different methods of estimation. This relates to the underlying assumptions made in applying the various methods and their appropriateness to the particular dynamics of a "stadium crowd".

1 Introduction

Stadia have facilitated large crowds since their inception. With modern design techniques, the size and facilities of these venues have evolved and changed dramatically. In contrast to many other structures designed to hold large populations, stadia are subject to ever changing occupants and uses. Whereas a shopping malls and high-rises house the same occupancies for months to years, a modern stadium transforms itself weekly. It may facilitate a sporting event one weekend and then host an exposition through the week. With a stadium, not only do events and event management teams change frequently but so do retail concessions around the grounds. This rapid turnover of occupants and uses has greatly changed the considerations in stadium design since their early beginnings.

In the last decade most of New Zealand's stadia have undergone major renovations and modifications to allow them to accommodate more diverse activities than their original designs allowed for. Corporate suites are increasingly being used by owners as offices and or function rooms increasing non-event occupancy numbers and events are becoming more frequent. In order to attract high profile events and cater to corporate ownership, the modern stadium must be well furnished and provide a wide array of conveniences for both performers and patrons. As the quality of the stadium and the demand to see a performance or game increases, so does the acceptability of higher prices and hence potential profit to the owners. New Zealand's stadia capacities range from less than 10,000 to 50,000, with larger stadia being in the areas of the country with higher population densities. New Zealand stadia are relatively small by international standards so a greater number of events must be held to achieve an acceptable level of profitability; hence there is much pressure for stadia to attract more diverse events than for their larger counterparts overseas.

Large population densities occur in stadia, creating the potential for significant numbers of casualties and deaths should an untoward incident occur. Thankfully untoward incidents such as fires are uncommon[1]. Even so; it might be expected that as building technology has developed there would be a drop in the frequency of fires in this type of structure. This has not been the case. In fact, stadia disasters in general, including fires, have steadily increased in number and severity over the last few decades (Table 1). This may be partially attributable to increased usage and capacities.

Stadium disasters are rare; however they have resulted in approximately 3000 physical casualties over the last decade worldwide. Individual incidents involve large numbers of casualties and hence have a greater impact on the community than less sensational incidents that occur more frequently such as car crashes[2]. The disasters that have occurred have largely been a result of egress problems. The vast majority of disasters have occurred at soccer stadia; however there is no reason to assume that New Zealand is invulnerable to this sort of tragedy based simply on sporting codes. Indeed, fire call-out statistics indicate that New Zealand's stadia have been subject to a number of minor fires in the past and it may simply be a matter of time before a more serious incident occurs.

Although only a fraction of stadia disasters occur as a direct result of fires, egress and evacuation procedures are crucial in preventing tragedy should a fire occur. Psychologists have found that crowds do not tend to behave as individuals do. As there are many individual behaviour patterns there are also many crowd behaviour patterns. Flight behaviour and subsequent crushing has been illustrated in a variety of structures fires involving crowds. In the majority of the events in Table 1, insufficient egress and/or poor crowd management contributed to the resulting injuries and fatalities.

At this point New Zealand has only experienced a handful of stadium fires, of which no casualties have resulted (Appendix D). In line with international trends, many New Zealand stadia have been upgraded in the last decade, but against international trends there has not been an increase in disasters or potential disaster incidents. This study hopes to determine whether or not this is due to a fortunate lack of the occurrence of low probability incidents.

Year	Location	Country	Incident	Contributing factors	Injuries	Fatalities
1902	Ibrox	UK	Structural Failure		517	26
1946	Bolton	UK	Structural failure	Stampede	500	33
1964	Maryland, Baltimore	USA	Crushed, lacerated children	Escalator gate closed, Human error	60	1
1964	Lima	Peru	Stampede - Crushing	Riot following referee decision	500	318
1967	Kayseri	Turkey	Stampede	Fighting weapons and resulting riot	600	40
1968	*Buenos Aires*	*Argentina*	*Stampede - Crushing*	*Hooliganism/Fire – burning paper thrown on crowd at egress bottle-neck*	*200+*	*74 or 73*
1971	Salvador	Brazil	Stampede	Fighting led to flight	1500	4
1971	Ibrox	UK	Structural failure - Crushing	Crowd behaviour egress reverse flow	140	66
1974	Cairo	Egypt	Stampede - Trampling	Riot following referee decision		49 or 48
1979		Nigeria	Stampede - Trampling	Lighting failure led to flight	27	24
1981	Athens	Greece	Stampede - Trampling	Locked gate, no front to back communication	?	24
1981	Hillsborough	UK	Crushing	Crowd surge	38	
1982	Lenin, Moscow	USSR	Crushing	Reverse flow in egress		61 or 340
1982	Cali	Columbia	Stampede - Trampling	Intoxicated patrons inciting flight	250	24
1985	*Bradford*	*UK*	*Fire*	*Rubbish ignited poor housekeeping*	*100+*	*56*
1985	Mexico City	Mexico	Crushing	No front to back communication at locked gates	30	10
1985	Heysel	Brussels	Structural failure - Crushing	Crowd behaviour	437	39
1988	Kathmandu	Nepal	Stampede - Crushing	Hail storm led to flight, locked exits no front to back communications	700	10 or 93

1989	Hillsborough, Sheffield	UK	Crushing	Inappropriate police behaviour and overcrowding	400+	95 or 96
1991	Orkney	South Africa	Crushing	Fighting led to flight against fences	1900	40
1992	Bastia	Corsica	Structural failure	Temporary stands collapse, poor construction	?	10
1992	Maracana, Rio de Janeiro	Brazil	Structural failure - Crushing	Crowd behaviour	50	0
1996	Guatemala City	Guatemala	Stampede	Individuals falling down, blocking stairwell	180	83
2000	Harare National Sports	South Africa	Stampede - Crushing	Inappropriate police behaviour	scores	12
2000	Sao Januário	Brazil	Stampede - Crushing	Fighting and oversold event	200	
2001	Ellis Park	South Africa	Crushing	Crowd behaviour and oversold event	hundreds	47
2001	Accra	Ghana	Stampede - Crushing	Inappropriate police behaviour	277	126
2001	Akashi	Japan	Crushing	Insufficient egress due to poor organisation and planning	120	10

Table 1: Stadium Disasters over the last century adapted from Dickie[3] and Fruin[4]

Table 1 shows mostly non-fire related disasters. Amongst these incidents there is a prevalence of crushings as crowds attempted to flee undesirable events. In most stadia disasters that have occurred over the last 30 years crowd behaviour has been the main contributor to the casualties. In some instances conflicting or non-specific numbers were available.

1.1 Profile of New Zealand Stadia

Stadia, for the purpose of this thesis, should not be confused with indoor arenas. Indoor arenas are permanently fully enclosed. Indoor arenas are single structures. In contrast, stadia have an outdoor arena surrounded by stand and embankment structures. Some stadia may have sliding roofs that can cover the arena when desired but the majority of the time the arena is not covered. No stadia in New Zealand have sliding roofs, all are permanently uncovered.

There are three schools of thought as to why New Zealand stadia have avoided major incident. The first is that it is because of the quality of their structures and management practice. The second is that it is primarily due to good fortune. The third is a combination of the other two. Regardless of the cause New Zealand stadia are less likely to experience a major incident or as severe an incident than in some other countries. This is purely because New Zealand's population base does not support the usage patterns enjoyed by the likes of say Australian stadia.

1.1.1 Event Times

A study on the probability of major fires occurring in Australian stadia gives some interesting results. Bennetts *et al*[5] estimated, using Australian and international data, that the probability of a significant fire in a modern stadium during a major event is once in 952 years if the stadium is not sprinklered and once in 47, 619 years if it is sprinklered (this assumes that 3% of fires have the potential to become large during occupied hours). Bennetts *et al*'s define a major event to be one with close to full capacity occupancy. Bennetts *et al*'s figures may therefore be misleading in that not all scheduled events are attended by capacity crowds. There figures are also biased in that their estimates are for fires occurring in furnished and storage areas of the stadium only.

1.1.2 Non Event Times

Outside of event times there can be as many as two hundred people in various parts of a stadium on a regular basis. These people are involved in catering, sporting practices, event management and various other activities. With such low occupant density the potential for a fire to develop unnoticed increases. This was illustrated in the Texas Stadium fire in the USA on October 13th, 1993[6].

The Texas Stadium fire occurred in the private suite area of the stadium on a non-event day. The suites concerned were accessible by corridors, internal stairwells and elevators. There was no open-air access to this part of the stadium. Cheerleaders practicing on the field detected the fire in the suite of fire origin and alerted the fire service. By the time fire fighters reached the fire, some three minutes later, it had had spread to twelve suites on two levels and to the plastic seating in the nearby bowl area.

Before the fire was extinguished it had spread to several suites. Smoke had penetrated the adjoining corridor and entered the air-handling duct, resulting in smoke damage to a quarter of the suites in this part of the stadium. Heat melted vision panels in the suites affected by fire and through these openings smoke had vented into the playing field area.

If Texas Stadium had had a greater occupancy at the time, such as that of an event day, one of two scenarios might have occurred. Firstly the fire might have been detected earlier and extinguished before it became established. Secondly the fire might not have been detected early enough to prevent its development, resulting in casualties in the surrounding rooms, hallway and main bowl area.

What special considerations with respect to fire protection and evacuation are required for managing and designing a stadium as opposed to any other structure? It is widely accepted that management has as great a role to play in effective fire protection and evacuation as the design of the structure[7]. Currently New Zealand, unlike the UK[8] and USA[9], does not make any special provisions for such places. This study investigates whether it needs to, or whether current regulations and management practice are sufficient.

Historically New Zealand legislature and regulations - with respect to safety - have for the most part developed responsively to major incidents and disasters in New Zealand ("stable door" legislation) or have mimicked changes in British legislature. An exception to this was when the UK passed the Safety at Sports Ground Act 1975 in response to incidents at sporting events and stadia. Although the potential loss associated with a stadium disaster appears insignificant when compared to the collective loss from house fires annually, it would be a tragedy for such an event to occur simply because New Zealand did not adapt its regulations in response to the experience of other nations.

The purpose of this thesis is to assess whether New Zealand stadia offer effective fire protection and evacuation procedures, to ensure the safety of all stadium occupants.

2 Objectives –

The objectives of this thesis are to:

- Examine the stadium occupant profile and determine how stadium occupants differ from occupants of other large capacity structures. The occupant profile has been limited to rugby and Australian football league game patrons so as to provide comparable demographics across multiple stadia

- Examine past stadium fires and incidents resulting from egress issues.

- Determine whether New Zealand stadia with the capacity to hold greater than 20,000 patrons fit the profile of those stadia that have experienced disasters in the past.

- Examine the coordination of stadium events in New Zealand to determine how effective evacuation of New Zealand stadia might be.

- Compare evacuation calculations, simulations and observations to determine how accurately crowd movement has and is being anticipated in the stadium environment.

- To identify current international trends in stadia with respect to fire protection and evacuation.

- To determine whether New Zealand is inline with international practice.

3 Literature Review

3.1 The Development of Stadia

As with most types of structure, stadia have changed as construction trends and consumer demands have dictated. Because of this there is great disparity between the construction and layout of a modern stadium, a partially upgraded stadium and an older style stadium. Stadia are large complexes and may consist of one or more structures. Due to cost and seasonal considerations the complexes may be constructed or modified in parts over a number of decades. This may mean reduced seating for a long period if the structures are being modified continuously or that larger discrete sections are modified at given intervals with construction occurring over a number of “off seasons”. Hence different parts of a stadium may be built to different specifications as what was common practice when the alterations were started is obsolete by the time the final stages are commenced. To understand some of the issues for egress planning and fire engineering at a stadium an overview of stadium constructions found in New Zealand has been included.

3.1.1 Construction of older stadia

Older style stadia are generally of timber or brick construction with lather and plaster finish. Seats consist of wooden benches or bleachers in single tier stands. Large sections provided no seating. Turnstile entries to the grounds were narrow and often set into concrete outer walls close to ticketing booths, as were the similarly narrow exits.

Tiered grass or concrete embankments and terraces were often included around large parts of the arena as festival seating. These were traditionally the rowdiest sections of the stadium[10]. Tickets for these sections were cheaper than for seated sections as they provided less comfortable viewing and could accommodate more people per area than seated viewing areas. The stands may or may not have been roofed. Facilities under and around the stand consisted of changing rooms, public toilets, an office, ticketing booths, turnstiles, supporters’ club with a bar, score board, commentators box, storage space and a caretaker’s area. Vomitories and these other facilities were typically small and of brick or concrete block construction, designed to take up as little potential viewing space as possible. This has led to some stadia having somewhat complex egress paths.

This somewhat Spartan style of stadium remained typical for the first half of the 1900s possibly due to the influence of two world wars and the depression.

3.1.1.1 Advantages

Older stadia were low cost, low maintenance constructions requiring no more than a fresh coat of paint and someone to sweep up the rubbish after the games. The venues were designed to take the maximum number of people in the smallest possible space. When this type of stadia was in vogue people were used to queuing for war rations and other commodities. Queuing to get in and out of a stadium was no different to the queuing required for many other activities and the tolerance for delays was much higher than it is today. With only the radio as an alternative, those who wished to view an event had little alternative to patronising the stadium.

3.1.1.2 Limitations

- No or little provision for comfort was included. Generally events were restricted to daylight hours as lighting was only provided to those facilities under the stand that needed it.
- Most stands were single tier so in order to accommodate larger crowds more land and deeper stands were required.
- Patrons were often vulnerable to the weather.
- Access in and out of the grounds was often limited by turnstiles. Vomitories and turnstiles were one person wide. Stairs were often steep and poorly lit.
- No or very little provision was made for mobility-impaired patrons.
- Police were responsible for crowd control
- Fire engineering and pedestrian movement were not appropriately incorporated into designing the structure

3.1.1.3 Existing examples in New Zealand

Parts of Carisbrook, and Eden Park are still of this type of construction. Jade Stadium retains only the Stevens Street Memorial Gates as a remnant of its earlier days.

Figure 1 Stevens St Memorial Gate, Jade Stadium

3.1.2 Construction 1970s – 1990s

With the increase in air travel, improved roading, urbanisation, and television coverage of sporting events stadia, became more accessible and visible to the public. Consequently, many stadia were altered and new stadia built in an effort to attract international sporting events and the subsequent capacity crowds. In order to attract people to the stadium, the stadium had to be more appealing than competing alternatives. Stadia had to move away from the image of offering little more than just a cold pie and a spot to stand with your mates in the rain. Corporate sponsorship started to develop and the level of facilities began to exceed those of basic amenities. Christchurch has two early examples of this type of construction; the eastern stands at Jade Stadium and the stadium at QEII (then able to seat 34,000) both of which were constructed for the 1974 Commonwealth Games. Due to the incident at the 1972 Olympic Games where nine Olympic athletes were taken hostage, safety of patrons and competitors became a major focus of stadium management. Security features such as large gates allowing for emergency egress began to be incorporated into the designs.

Multi-tier stadia were developed to accommodate more patrons, provide more space and improve viewing without increasing the distance from the field. This was especially important for existing stadia, as greater patronage could be accommodated without the need to purchase more land. For patrons this provided a viewing benefit by keeping all patrons close to the arena. It also introduced the additional benefit of providing shelter to the lower tiers without extensive roofing. The contrast between older and 1970s-90s styles is illustrated below by the two main Melbourne stadiums; Colonial Stadium and the Melbourne Cricket Ground (MCG).

Figure 2 Colonial Stadium with its retractable roof open. Each level sits above the previous one providing a compact stadium with proximal views for all patrons.

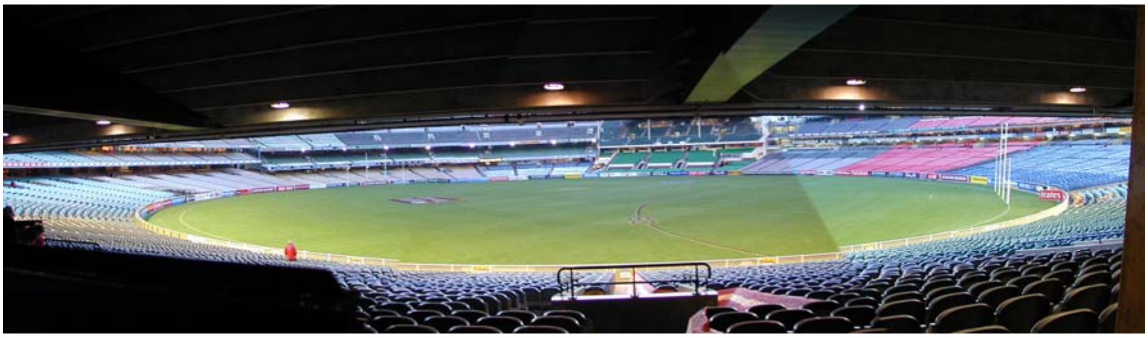


Figure 3 View of the MCG from the Great Southern Stand looking towards the Members Pavilion. Patrons in the back rows at the MCG are a great distance from the arena.

Over time the comfort and quality of general patrons' seating has improved, as has the quality of members' lounges and corporate suites. This has led to an increase in the quantity of furnishings, kitchen facilities and car parking; hence a greater fire load is present in some areas of the stadium than was ever envisaged for older style stadia. Some stadia, such as Aussie Stadium go so far as to include facilities such as television studios and nightclubs within their corporate and lounge structures. This alters the usage pattern of the stadium and may impact on the fire spread scenarios for the stadium in ways not anticipated in the design of pre-existing nearby structures within the stadium.

Changing usage patterns, fire loads, proximity of patrons and capacity of stadia may vary considerably from the type of structure that was envisaged in determining the building code requirements for stadia. This was illustrated in two American stadium fires in 1993[11].

The potential for fires in refurbished areas was realised in the USA in 1993 when two stadia; one in Texas and one in Georgia; experienced fires in their suite areas. Both stadia had been built in the 1960s and refurbished in the subsequent decades. Whilst no one was hurt in either event, both fires caused extensive localised damage. Both fires started by accident, one from a food warmer and one from electrical wiring. Both fires spread to other suites with one spreading to the plastic seating in the main arena. Both fires resulted in thick black smoke in corridors surrounding the fire. Smoke also entered the main arena through windows that fractured and melted as a result of the fires.[12]

3.1.2.1 Advantages

The increase in fire loading at stadia has not gone completely unnoticed. Stadia, just like any other type of structure, have for the large part continued to make improvements in fire safety. This has occurred in line with law changes and as technology and knowledge of fires and fire suppression has improved[13]. However because a stadium is large and is often made up of a number of structures some parts of the stadium may have escaped improvement as surrounding structures have been upgraded.

Changes to stadium structures that have been introduced since the 1970s and enhance fire protection and evacuation of structures and patrons include:

- streamlining egress paths
- increasing exit numbers and widths
- greater sign posting with fire procedures
- installation of manual call points and sprinklers in covered areas

- no smoking policies
- separate fire service access points
- video surveillance
- Dedicated power supplies for lighting
- Intumescing pathway indicators
- Greater uniformity of stairways
- Installation of smoke alarms
- Fold up seating (allows for less accumulation of rubbish)
- Lower density of seated population on individual levels
- Introduction of EWIS (emergency warning intercommunication systems) into the communication system.
- The availability of television screens to relay information

3.1.2.2 Failings

As alluded to previously, stadia are not generally refurbished in one operation. The redevelopments tend to occur in stages over several years or even decades. This is so as to keep the stadium operational, maintaining near capacity crowds during the sporting season, and to spread the costs incurred over a longer period. In doing this, not all of the fire safety system is necessarily brought up to the current standards in a single phase. This increases the likelihood of a series of different contractors continuing upon previous work and the likelihood of disparity between the designed structure and the built structure. Examples of this were related during interviews at stadium visits around New Zealand.

As with earlier stadium designs, many of this style of stadia have large quantities of fixed wooden seating. Most stadia in New Zealand that still have wooden seating are in the process of converting to folding plastic seating. The disadvantages of wooden seating are that it is easy for rubbish to accumulate under the seats and the seats take up more walk space than folding seats. Folding seats increase the available walk space once a person stands up. This makes removal of rubbish easier through improved access to the underside of seats by cleaners. Plastic seating also offers the stadium the advantages of low maintenance and comfortable seating.

3.1.3 Present Day Construction

The modern stadium is now expected to be a multifunctional event centre. As such, fire engineering and evacuation planning are becoming increasingly important to designing stadia in order to provide safe venues under a wide range of circumstances[14].

Key characteristics of current stadium construction practice are:

- Prestressed concrete and steel construction are now the construction materials of choice. Outdoor seating is predominantly plastic on metal frames.
- Versatile, multi functional facilities within the structure.
- High level of furnishings within corporate, function and administration sections of the structure.

Stadia now provide facilities for corporate viewing, dining, special functions, vehicle access, under cover car parking, multimedia production areas, museums, catering, offices, indoor training areas, retail outlets, lounges, and security; as well as all the basic facilities found in a older style stadium.

As stadia have become more complex, their construction materials have tended towards less combustible materials with increasing levels of fire resistance throughout. Unfortunately this does not necessarily translate to greater property protection. The potential for smoke, fire and water damage to the contents of suites, lounges and other facilities as a consequence of fire has increased as the level of furnishings and electrical equipment has increased.

Bennetts et al[15] identify the potential for smoke logging in narrow corridors to the rear of corporate suites as a potential hazard. This situation could develop before occupants in suites adjacent to the fire are aware of the need to evacuate. Consequently it may be necessary to provide shorter egress routes than those required by the building code[16].

The size of stadium corridors is such that they could accommodate rapid smoke filling. If the entertainment event in progress is particularly exciting crowd noise may obscure initial sounders and/or patrons in surrounding suites may be engrossed to the point where they delay leaving and subsequently become trapped[17].

3.1.4 Future construction

Superstadiums have been developed overseas, but at this point New Zealand does not have the population to justify such structures[18]. It has therefore been hypothesised that there will be no major changes from current stadium design in the near future.[19]

The most likely change is in the proportion of suite and lounge facilities. The potential for a greater proportion of the stadium to comprise of suite facilities has increased with the introduction of corporate sponsorship. This means that the level of comfort and aesthetics of the stadium venue is likely to incorporate greater quantities of furnishings and catering facilities. This is likely to improve the fire safety of older stadia as modifying or replacing existing structures will mean that the fire protection afforded those structures will have to be upgraded. This does not however mean that the level of protection required under the existing building code or in overseas codes is sufficiently relevant to the ever changing usage and contents of these structures.

3.2 International Practice

There are three main issues that were addressed in researching this paper:

- Identifying risk posed by fire in stadia
- Identifying variables that affect evacuation of a stadium
- Comparing regulations and guidelines used to manage these variables and risks

It was noted that different countries have addressed these issues in different ways.

Many variables play a part in fire prevention and effective evacuation of stadia. The diversity of stadia that have been involved in fires and evacuation problems make it difficult to generalise as to which variables play a greater role than others.

Some of the variables that affect evacuation concern human behaviour of the occupants, such as:

- Sobriety of patrons
- Anonymity within the crowd
- Euphoria of the crowd
- Familiarity with the grounds
- Age and mobility demographics of the patrons

- Interest in the event
- Fear
- Anger
- Surging and other unsafe behaviour

Others relate specifically to the stadium, its location and its management:

- Fire protection built into the stadium
- Design and labelling of egress routes
- Visibility
- Tolerance of management and police to disruptive and destructive behaviour
- Competency of staff with regards to the evacuation procedures
- Availability of information to evacuees
- Legal obligations/requirements
- Weather
- Smoking policy of stadium
- The robustness of the evacuation procedures
- Fire loading of suites and indoor areas
- Occupancy of the stadia
- Familiarity of the fire service with their local stadium
- Ability of the fire service to reach the stadium quickly
- Surrounding properties and associated hazards
- Maintenance and housekeeping of the stadium

3.2.1 USA

To date the USA has had remarkably few stadium incidents of note. Those that stand out include a Texan stadium fire (on a non-event day), a Georgian stadium fire (prior to a game)[20] and a fire that occurred during the 1934 reconstruction of Fenway Park[21].

The Texan stadium fire, at Texas Stadium, Irving, rapidly spread to affect two levels of corporate suites and seating in the main bowl.

The Georgian fire occurred in the press suites at Atlanta Fulton County Stadium on July 20th, 1993 in Atlanta. This fire was started by an unattended open flame food-warming device. Investigators concluded that the device ignited some nearby combustible materials within the room. Interestingly the fire was not detected by stadium occupants. An off duty fire fighter watching the pre-game coverage on his television at home was the first to report the fire.

The room of fire origin flashed over shortly after the fire service arrived. The entire press suite area and several private suites were affected. The fire was extinguished after an hour and the scheduled game went ahead only slightly delayed. The stadium was not hosting a capacity crowd and so potentially affected patrons were accommodated in other parts of the stadium. Although the disruption to the game was minimal repair costs and the potential injuries and disruption had the fire occurred during the game were still significant.

The Fenway Park fire in Boston occurred on January 5th, 1934. Every appliance in Boston at the time attended this fire. The fire was caused by an overturned salamander. A canvas covering was accidentally ignited as workmen tried to dry fresh concrete with the salamander. The fire quickly spread to the bleachers and ended up destroying most of the stadium, which was then rebuilt. Although this fire effectively occurred in a construction site rather than a stadium it did demonstrate the potential for fire spread within the stadium. As many stadia are renovated in parts over several seasons the potential for fire spread from a construction zone remains a relevant consideration for stadium fire engineering design and egress management today.

In none of these incidents was anyone other than fire fighters injured. The NFPA standards and code and other compliance documents played a part in the lack of injuries, the major contributing factor was that none of these events occurred during peak occupancy times. The Texan and Georgian fires occurred in parts of the stadium that were completely unoccupied, the fires being observed from other parts of the stadium. The Fenway Park fire occurred in the presence of workmen. The fire occurred outdoors. All onsite workmen were present at the ignition of the fire and were easily able to escape the fire off site. The impact of any of these fires, had more occupants been present, could have been much greater.

Although injuries were avoided, the damage that occurred as a result of these three fires was considerable. NFPA investigations into the Texan and Georgian fires concluded that the stadia would have suffered significantly less damage had their fire protection been brought up to the latest NFPA code requirements.

As mentioned, none of these three fires occurred during peak occupancy. In New Zealand most stadia have the facilities to accommodate cricket, soccer, rugby, rugby league and in some cases hockey and athletics. Because stadia in the USA are largely designed to suit a specific sporting code, e.g. grid iron football, baseball, or athletics, without the same pressure to perform multiple functions, the frequency of use has differed considerably from some other countries. One of the largest stadia in the USA, Beaver Stadium held only six sporting events in 2002. This low usage rate greatly reduces the opportunity for a fire to occur during a peak occupancy period when compared to a New Zealand stadium which might accommodate twenty or more major sporting events per year as well as various other functions. Usage of Australian and British stadia is greater again.

There are three NFPA publications in US building regulations that are concerned with stadia construction and safety. NFPA 101®: Life Safety Code®[22], NFPA 102®: Standard for Grandstands, Folding and Telescopic Seating, Tents, and Membrane Structures[23], and NFPA 5000™: Building Construction and Safety Code™[24]. None of these are used throughout the USA but they are the most commonly accepted across the country.

NFPA 5000 covers design requirements of “Grandstands and Bleachers” in chapter 32.7, identifying the allowable types of construction for these types of structure. It also lists the frequency of inspection and load bearing capacities but does not provide a great deal of *detail* specific to stadia. NFPA 102 does relate specifically to stadia, as opposed to the other documents, rather than considering many types of structure. NFPA 101 again is concerned with a wide variety of structures and has specific sections and clauses that relate to stadia, bleachers and grandstands.

NFPA 102 is intended to provide life safety for occupants of assembly seating in relation to fire, storm, collapse and crowd behaviour. This standard provides general minimum requirements for stadium components but does not differentiate between different occupant loads or cover specific methods of achieving these requirements.

NFPA101 applies a similar methodology to the Acceptable Solutions in the Approved Document for the New Zealand Building Code[25]. NFPA 101 provides the greatest amount of information and detail on the requirements of stadia construction and management to ensure life safety and fire protection. NFPA 101 details minimum acceptable requirements of structures for given occupancies and provides an appendix of explanatory materials and diagrams to assist in interpretation of the Life Safety Code.

The Life Safety Code, as with the Approved Document for the New Zealand Building Code is only one method of achieving life safety and there is allowance for alternative solutions to be used so long as they are approved by the "authority having jurisdiction" and provide either equivalent or greater life safety than that required in the Life Safety Code. There are however two main differences; occupancies are divided into a greater number of types and life safety evaluations are required for certain structures, stadia included. The Life Safety Code provides more detailed guidelines than those of the other two NFPA documents, the Life Safety Code's purpose being to address fire and safety issues particular to specific structures. For each structure type general and egress requirements as well as protection, special provisions, building services and operating features are described. Stadia and stadium components are covered in chapters 11-13[26] overlapping three of the 32 types of structure addressed in this Code. These chapters deal with special purpose, old and new assembly occupancies.

The Life Safety Code has specific requirements for various components that comprise a stadium such as grandstands, telescopic seating, festival seating and bleachers. The Code specifies parameters for a range of occupancy numbers varying from 50 - >25,000. The parameters covered are very similar to those covered in C1 – Outbreak of Fire, C2 – Means of Escape, C3 – Spread of Fire, C4 – Structural Stability During Fire, F1 – Hazardous Agents on Site and F6 – Lighting for Emergency of the Approved Document for the New Zealand Building Code but are specific to assembly occupancies.

3.2.2 United Kingdom

The UK - in contrast to the USA - has been subject to a significant number of stadium disasters as indicated in Table 1. Only one of the UK incidents listed in the table involved fire but they all identified failures within either the structure and/or management that led to problems in evacuation from the incident. A number of Acts of Parliament have subsequently been passed that pertain specifically to sports grounds including the Fire Safety and Places of Sport Act 1987[27]. These Acts were brought about largely as a way to minimise the effects of football hooliganism but have much greater effect by addressing the issues of crowd management, evacuation, prevention of crowd crushes, and many other crowd safety issues that sporting and stadium events may produce. Local authorities issue annual certificates allowing stadia to operate but can also issue prohibition notices preventing stadia from operating if they develop safety concerns prior to the expiry of the current certificate.

It should be noted that in Approved Document B for the UK Building Regulations 2000[28] a stadium falls into the category of "Assembly and Recreation Type 5 purpose group". As such it is not distinguished from other places of assembly – in this way it is the same as the Approved Document for the New Zealand Building Code. Where the UK requirements for stadia do differ is in that they have special compliance requirements above those of the building code that must be met in order for a stadium to pass its annual safety inspection. These documents cover such additional structural features as turnstiles, crush barrier placement of, and ramp slopes along with requirements of risk assessment and management practice. The compliance documents that address assembly areas such as stadia include BS 5588: Part 6: 1991 Code of Practice for Places of Assembly[29], Guide to fire precautions in existing places of entertainment and like premises[30], Safety of Sports Grounds Act 1975[31], Fire Precautions (Workplace) Regulations 1997[32], the Fire Precautions Act 1971[33] and the main one; the UK Guide to Safety at Sports Grounds 1998[34].

One of the most significant UK incidents was the Bradford Stadium disaster on 11th May 1985[35]. Although this had fewer casualties than the Hillsborough disaster in 1989[36] it is by far the most dramatic stadium disaster in British history and had legislative repercussions[37]. The incident was dramatic for two reasons, firstly the entire incident was televised and secondly the rapidity with which the fire developed and spread. The size of the fire and the images of people emerging from the stand with their clothing alight were broadcast around the UK and the world. This resulted in intense interest in the subsequent investigation and much public outcry, demanding that government ensure this sort of tragedy could not reoccur[38]. The result of the investigation was to introduce the Fire Safety and Safety of Places of Sport Act 1987 and the review of the Home Office Guide to Safety at Sports Grounds. This was republished as the UK Guide to Safety at Sports Grounds[39] (1989) - commonly referred to as the Green Guide because of the colour of its cover.

Sporting spectator tragedies were not unknown in the UK. Ibrox, for example had two deaths due to crushing in 1961 and a further 66 in 1971, the second of which led the Wheatley Report[40] and subsequently the first edition of the Green Guide[41]. It was not until after the 1971 tragedy that stadia began to change their policies with regards to safety of patrons.

The Green Guide was further developed in 1990 in response to the Hillsborough disaster[42]. This guide covers all aspects of event management at an event as well as design requirements for architects and engineers. It has been revised three times since its inception. The document itself has no power and is only a guide. The use of this guide is however a determining factor in the issuance of annual certificates of safety that are required for all football fields with a capacity to accommodate 5000 spectators or more and all other stadia and sporting facilities able to accommodate upwards of 10,000 spectators[43]. It divides stadia into categories based on a range of criteria. Depending on the level of fire protection afforded a stand, acceptable evacuation time recommendations for individual stands range from 180 seconds through to 8 minutes[44]. The acceptable period is able to be increased if additional safety measures are added to the stadium operating manual.

As mentioned previously, sports grounds including stadia in the UK require a current safety certificate. The Green Guide provides recommendations and instructions on how the structure should be designed and maintained, as well as how the grounds and events should be managed. Evacuation procedures fall under the umbrella of management and detailed guidance on acceptable practice is provided. Some of the information is common sense, some historic practice, some occupational safety and health, and some based on research in such fields as pedestrian movement, crowd control, crowd psychology, structural engineering and fire engineering. Strict adherence to the Green Guide and an increase in police powers to deal with hooliganism over the past few years has markedly reduced the UK's stadium incidents[45].

3.2.3 Australia

The Australian Building Code (BCA)[46] classes stadia as "open spectator stands" in clause C1.7 and as such they may be constructed as Type C construction (for simple stands with one tier of seating) or Type A construction (for more complex structures) subject to concessions outlined in Table 3 of Specification C1.1[47]. BCA96 does not make special considerations for special purpose buildings such as stadia. In the case of the Olympic Stadium, fire modelling illustrated that the deemed to satisfy egress requirements were insufficient and hence larger egress areas were designed[48]. In the case of at least four of the newest Australian stadia the UK Green Guide has been considered in the design of the structures[49].

In 1998 Bennetts et al[50] of the Centre for Environmental Safety and Risk Engineering at Victoria University of Technology published a report exploring the implications of the "deemed to satisfy" requirements of the BCA for Type A construction stadia. The report provides guidance on considerations that should be made based on issues that have arisen historically in stadia and have the potential to impact on the performance of fire safety aspects of fire engineering for this type of construction. It highlights a number of issues that are peculiar to stadia and grandstands. These include the size of the evacuating crowd and potential impedance on fire-fighters ability to set up expeditiously. It does not, however, provide an opinion or assessment as to whether the BCA adequately addresses these concerns within the requirements for Type A construction.

The most memorable Australian stadium fire in recent history occurred in August 1999 when the MCG scoreboard caught fire[51]. The fire occurred on the 27th of August just as the players were entering the field for an AFL match between the Carlton Tigers and Richmond. One of the major hazards during this fire was when flaming pieces of scoreboard fell away and carried by the wind, drifted onto the top deck of the nearby the

Ponsford Stand. This had the potential to become a significant source of fire spread and injury but was quickly brought under control by prompt and effective response efforts of staff and fire service. The city end of the grounds where that scoreboard was located was immediately evacuated, the fire extinguished and twenty five minutes later the game commenced. Nobody was injured during the fire but the video scoreboard was severely damaged making the cost of the fire in the order of $10,000,000 including the cost of replacement screen and installation.

Other than severely damaging the scoreboard no damage or injuries resulted from the fire. The incident did however raise concerns about evacuation and crowd management for an event especially in relation to ticketing areas[52]. Ticketing areas were a problem in that people exiting from the area were noticeably slowed. The MCG now has comprehensive emergency procedures and advises other stadia on how to prepare emergency plans[53].

3.2.4 New Zealand

Requirements with respect to egress and evacuations are laid out in the Fire Safety and Evacuation of Buildings Regulations 1992[54]. Stadia as facilities that accommodate greater than 100 people in a common gathering place require an evacuation scheme. Requirements with respect to fire protection and means of escape are laid out in the New Zealand Building Regulations 1992[55].

New Zealand has over the past 12 years had 909 fires at stadia, grandstands and sports fields that were responded to by the fire service (Appendix D). Of these incidents an unknown amount occurred at the major sports stadia (those with spectator capacities of ≥ 20,000) (Appendices C, D).

Remarkably few published studies are available on New Zealand stadia. Most of the information that was readily obtained through studies of overseas stadia had to be obtained through interviews and internal records of stadia and fire service communications for New Zealand stadia.

Many fires and false alarms have occurred at large stadia in New Zealand but none have resulted in injury or major damage (Appendices C, D). Of those fires and false alarms occurring during scheduled events, one of the most interesting of these was at North Harbour Stadium, on 29th of August 1998[56]. In this instance no fire occurred but a sprinkler above a deep fryer activated. This activation did not trigger the evacuation alarms to automatically sound. The alarms were manually activated some sixteen minutes later[57]. At this point evacuation of the entire complex was initiated. Shortly after that, the public address system was used by the attending fire service to advise patrons that there was no fire and they could remain in their seats. This caused a level of confusion amongst both patrons and staff, bringing to light issues that needed to be addressed in the evacuation procedures for that stadium[58]. Subsequently, North Harbour Stadium has placed a strong emphasis on evacuation procedures and was the first major stadium in New Zealand to achieve an approved fire safety evacuation plan. [59,60]

Other fire related incidents of note in New Zealand have occurred at Eden Park (scoreboard fire)[61] and Carisbrook (Figure 4) where numerous fires have been set over the years by spectators on the terraces[62]. The fires at Carisbrook were peculiar to that stadium in that spectators were for a time allowed to bring furniture, such as couches, into the terrace area to watch sporting events. Occasionally, particularly when it was cold, some of these items of furniture were deliberately set alight by the spectators. The record number of fires on the terraces occurred in 1998 with 30 being set in one day. Management at Carisbrook banned the practice of bringing furniture into the grounds in 1999 because of persistent fire lighters.[63] The Dunedin City Council liquor licensing co-ordinator has stated that the potential for lighting fires was one of the reasons that plastic and paper cups have not replaced cans for beer sales at Carisbrook[64]. Despite efforts to stop the practice through minimising fuel sources and through prosecutions, fire lighting continues to occur at Carisbrook on occasion.

Figure 4 "Atmosphere heats up...Smoke from one of several small fires lit on the terraces wafts across the crowd."[65]

The Approved Document for the New Zealand Building Code 2000 makes little mention of stadia. It lists an occupant density of 1.8 users/m^2 for stadia and grandstands[66], and 2.2 users per linear metre for bleachers and bench seating[67]. The Document addresses components of stadia but does not consider the stadium entity as a whole, in the same way that the BCA does in Australia. Grandstands are classed as CL (crowd occupancy with an occupant load exceeding 100) or CO (crowd occupancy space for viewing open air activities) purpose groups[68] with areas such as the concourse possibly falling into the CM purpose group[69]. The fire hazard categories (FHC) for these purpose groups is 1 or 2 depending on the fire load energy density (FLED)[70]. There are of course other purpose groups that apply to specific fire cells within the stadium such as basement car parks and kitchens; however the majority of the structure consists of the arena seating, the concourse and the suite and lounge areas. These firecells are limited in size to 5000 m^2 for unsprinklered fire cells of FHC 1 and 2500 m^2 for FHC 2[71]. In theory this should limit the fire load to 2,000,000MJ in unsprinklered fire cells. There is no floor area limit for sprinklered fire cells. Based on communications and stadium visits, most New Zealand stadia have sprinklered all of their internal areas and many of the unenclosed areas. However, some of the older stadia have not yet upgraded all of their facilities and some large, furnished, unsprinklered fire cells remain.

3.3 Human and Crowd Behaviour

Human behaviour is difficult to predict and many variables affect it. In developing evacuation procedures and planning structural design that facilitates effective evacuation for specific population types or sizes it is important to consider the variables that are most likely to influence that population. With stadia, crowd dynamics play a major role in effective evacuation so it is important to understand the basic profile characteristics of the crowds that will patronise the stadium under consideration.

The most obvious and stereotypical example of stadium crowd behaviour is British soccer fans. British soccer fans have an international reputation for drunken, disorderly behaviour and starting fights[72]. For this reason a soccer stadium may be designed with many segregated areas in order to limit the number of patrons that would be affected by a disorderly incident or preventing disruption to the pitch[73]. This has a flow on effect to egress layouts, safe egress times and response times for reaching and controlling an incident. These can be calculated using access tree diagrams[74] to determine the required safe egress time (RSET) but to quote Sime; - "The one component of RSET namely human behaviour is the one that poses the problem"[75]. It has long been recognised that even stadia hosting events of a common ilk may experience widely different crowd behaviour[76].

In the same way that stadia holding paraplegic games have specific features to facilitate the mobility profile of their patrons, all stadia must be designed considering the psychological profile and movement patterns of their typical patrons. One obvious difference in the crowd composition for a stadium crowd profile versus an office building crowd profile is the influence of alcohol. The proportion of the population that is to some degree under the influence of alcohol at a stadium event is significantly higher than might be expected for an office building. This is due to stadium events having a social context where alcohol consumption is often an accepted part of the associated social ritual, unlike a workplace, where it is not. As such, alcohol plays a larger role in defining the profile of the evacuating crowd and potential sources of fire. This was illustrated in the Carisbrook management decision to not introduce disposable cups or plastic bottles for alcohol sales[77].

Destructive behaviour whilst uncommon is in general, far more likely to occur with a stadium or entertainment type of crowd than it is amongst most other crowd populations[78]. An example of this was the June 23, 1968 incident in Buenos Aires where 73 people died from crushing injuries as pressure built up against a closed exit door (door 12)[79]. Patrons were leaving after a soccer match between River Plate and Boca Juniors when youths began throwing burning newspaper into the crowd from an overhead terrace. This resulted in a stampede as people attempted to escape the flaming missiles. Unfortunately a large part of the fleeing crowd headed towards a closed door and with no front to back communication, crushing injuries and deaths occurred. In addition to those people crushed against doors, patrons in the stairwell were also injured. Descending patrons increased their movement rate attempting to flee. This led to crushing injuries in the stairwells beneath the youths as well.

3.3.1 Flow Rates

Much work has been done in the study of sports spectator crowds, possibly because of the frequency with which soccer crowds have been involved in mass casualty incidents. One such study, by Poyner, et al[80] included flow rate measurements of the egressing crowd. In their study flow rates were measured for a period of twenty minutes, starting ten minutes before the final whistle and continuing for ten minutes after the final whistle. The study was conducted at eleven stadia but only three had sufficient lighting for egress to be filmed and accurately analysed (results from these three stadia are discussed below). Poyner et al state that the results obtained by head counting at the stadia were not as accurate as those obtained from reviewing film footage; hence only three of the data sets are reliable. It should be noted that this study was not looking at emergency egress but at normal flows.

All of Poyner et al's results were obtained by viewing patrons leaving at the end of football games. Due to poor lighting conditions and the technology of the time most of the videoed egresses were unsuitable for analysis. As a low yield of reliable data was produced, this information in isolation is of limited value. It does provide an interesting comparison to flow rates obtained by other researchers in other types of buildings, as well as rates obtained in the course of this research from video footage of patrons leaving rugby football games in New Zealand and Australia.

The results of Poyner's monitoring showed a maximum flow rate of 118 people per minute, achieved across exit ways within a minute of the final whistle[81]. This indicated an unimpeded flow rate of 1.9 people per metre per second. The flow rate rapidly declined to a specific steady state flow rate of 1.4 people per metre per second. This rate was maintained for 5 minutes, followed by a similar rapid drop off over the following two minutes and all flow ceased after 18 minutes. During the 18 minutes of egress some 1200 people passed through the 2 metre wide gates being monitored. As Poyner et al only studied the final exits they did not make any observations regarding bottle-necks or comparisons of flow rates on stairs, ramps or terraces. It is assumed (although not stated) that all of the exits studied were flat terrain on a straight path.

Other studies observing different types of crowds have produced different rates to those observed by Poyner et al. A comparison of some of these is shown in table 2 and figure 5 on the following pages.

Studies reviewed were conducted by a number of researchers looking at different crowd populations in different countries. Not all studies were concerned with flow rate and density relationships. A summary of flow rates from some of these studies is shown in Table 1 and Figures 2 and 3.

Study Author (year)	Crowd Type	Terrain	Study Type	Density at maximum flow rate (people/m^2)	Maximum flow rate (people/m/s)
Ando et al[82] (1988)	Rail Commuters	Flat	Speed-age relationship	-	-
Fruin (1971)	Walkways	Flat	Speed-density relationship	2.04	1.37
	Stairs	Stairs		2.78	0.93
Nelson & MacLennan[83]	Evacuation Trials		Safe egress times	-	-
Pauls	Evacuations	Stairs	Speed-density relationship	2.04	0.92
Poyner, et al (1972)	Football Crowd	Flat	Speed-density relationship	-	1.96
Predtechenskii (1969)	Stadia	Flat	Speed-density relationship	4.00	0.80
		Stairs		2.04	0.66
Proulx[84] (2001)	Video Footage		Human behaviour	-	-
Puskarev[85] (1975)	Shopping malls & Sidewalks	Flat	Collision Avoidance	1.0	0.98-
Simulex32	Simulation Calculations	Flat	Modelling	1.23	1.16
		Stairs		1.23	0.58
Tanaboriboon et al[86] (1989)	Market Places	Flat	Levels of Service	2.7	1.68

Table 2: Crowd Flow Studies

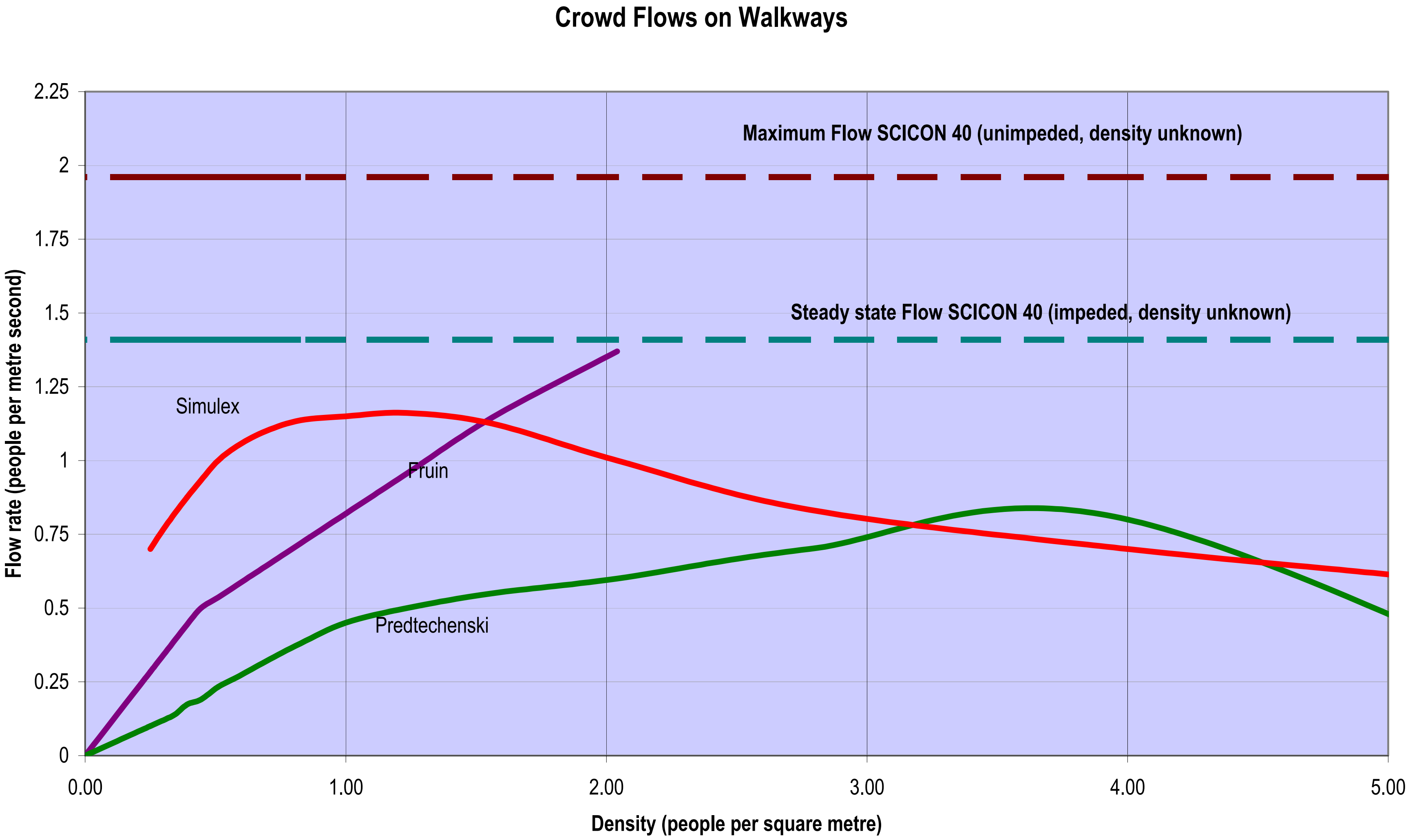


Figure 5: Flow Rates on walkways

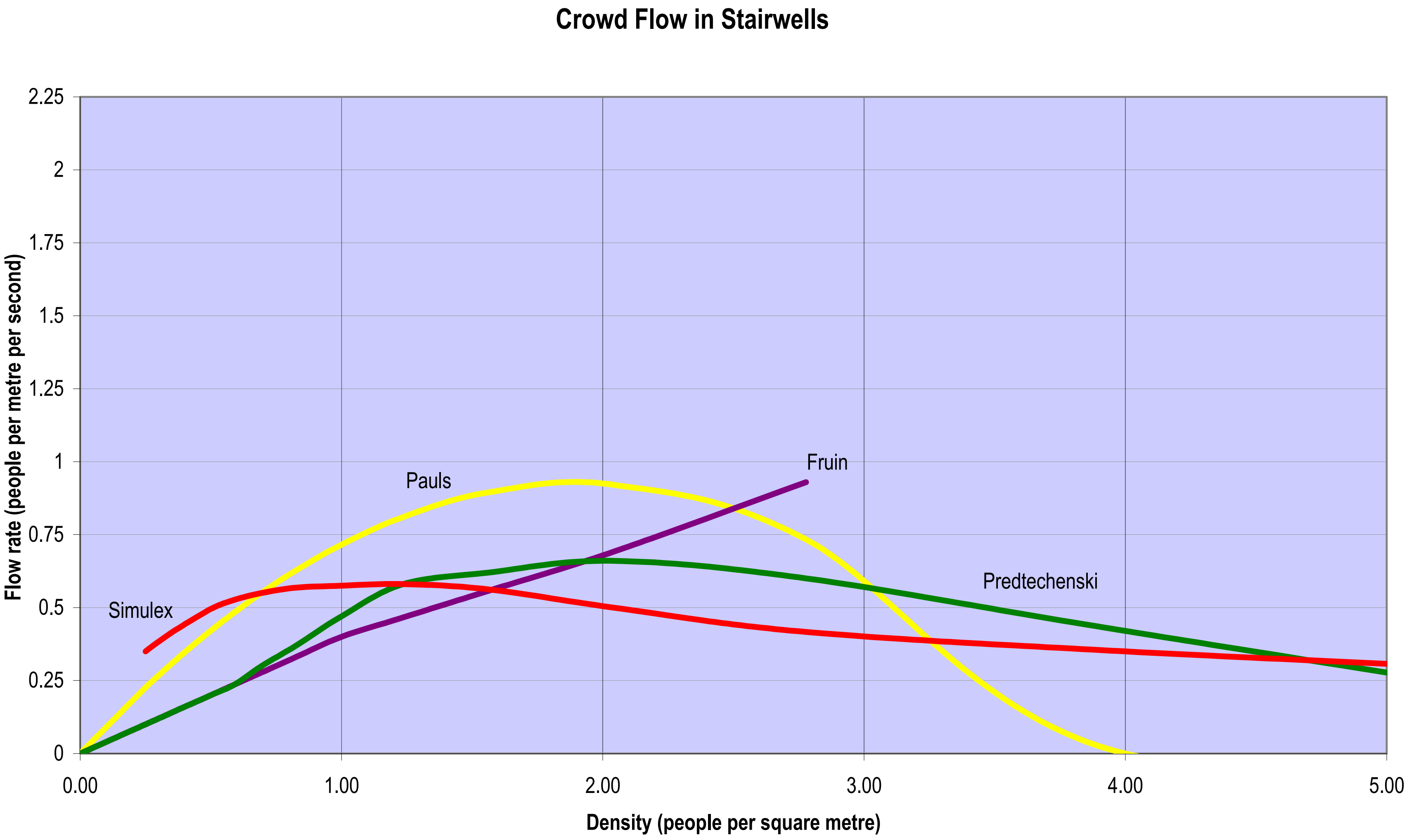


Figure 6: Flow Rates on stairwells

It is noticeable from the charts that there are distinct differences amongst the various calculation methods and observations. This is not unusual and is to be expected, as people do not always behave in the same way. The differences are possibly indicative of different crowds exhibiting different behaviour patterns. All are based on observational data and therefore valid. It is pure speculation as to the source of these behavioural differences as the studies do not make assertions as to psychological inputs that may have contributed to the flow rates.

Fruin describes six different "levels of service"[87]. Those displayed in the previous charts and table correspond to levels E and F, "congested stairs and walkways". These are recommended for determining egress paths for emergency movement and limited space situations. Fruin's flow rates increase and then flat-line once a critical density is reached. The density impedes speed above the critical density but not to the point where flow rates decline through stagnation of movement.

Fruin's research was published some months earlier than Poyner's and looked at crowd flow on a number of different terrains or "levels of service". Fruin quotes seven people per square metre as sufficient density for the crowd to act as a fluid, propagating shockwaves[88]. He describes this concentration of people as preventing any individual action. This density can result in people fainting from heat, anxiety and pressure. There is no way for individuals to help those who fall and their injuries can be severe[89].

Pauls and Predtechenskii, in contrast to Fruin, both observed optimum flow rates with flow rates decreasing above the critical density. Pauls' critical density for stairwells is similar to Predtechenskii's but the flow rate achieved is notably higher. Pauls flow rate at critical density is 0.94 people per metre width second whereas Predtechenskii's is 0.67. This equates to a flow rate 1.4 times that observed by Predtechenskii.

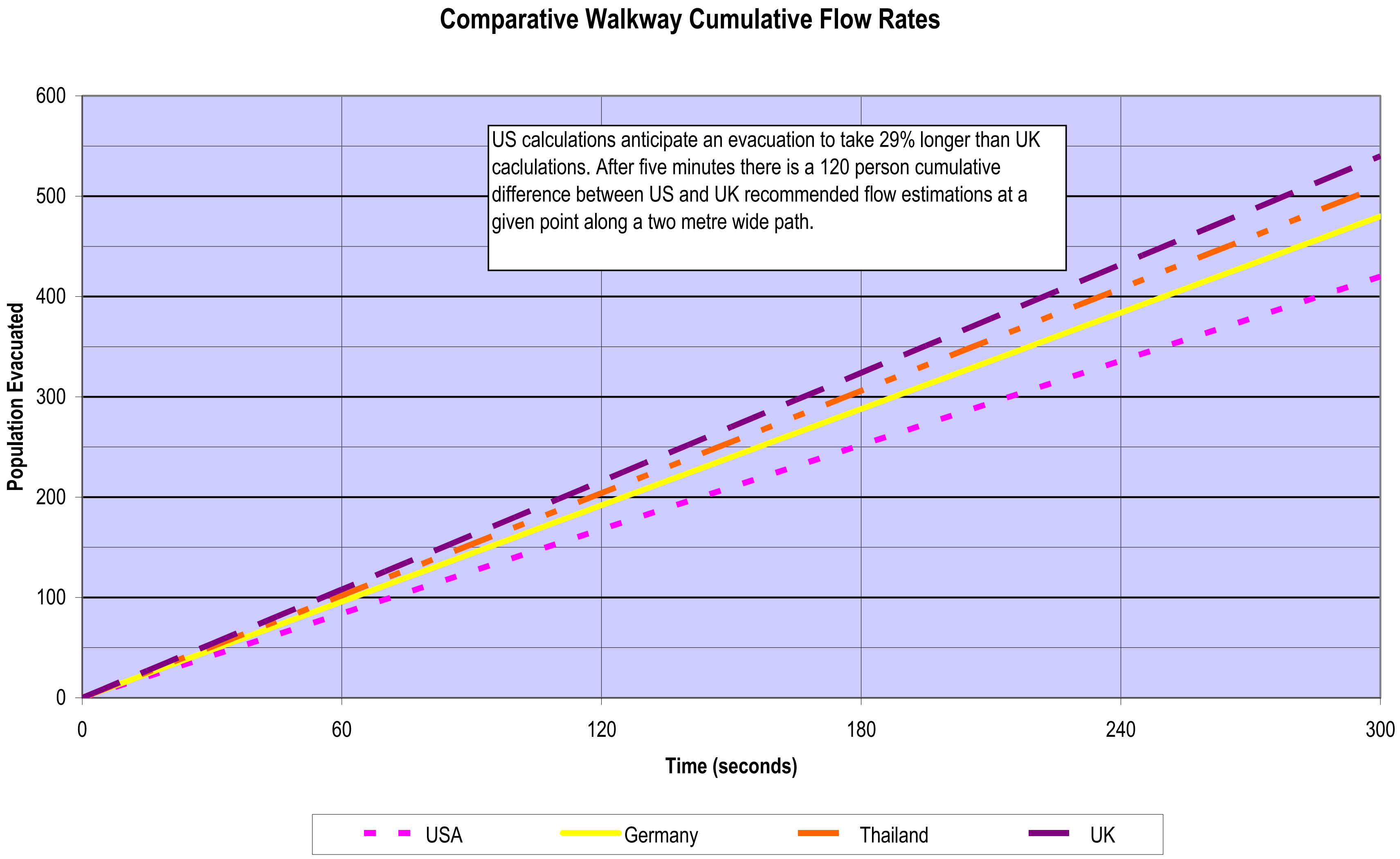
Nelson and MacLennan[90] list a maximum specific flow for corridors, aisles, ramps and doorways of 1.3 people per second per metre effective width. This is lower than that given by Fruin or that observed in SCICON[91]. It is of note that the maximum specific flow obtained using Simulex peaks at a lower density than that of the other authors with unimpeded walking speed range from 0.8-1.7m/s. Fruin by contrast recorded average walking speeds of 0.51-1.27m/s. This maximum speed is achieved in unimpeded flow that is, with a density less than 3.8 people/m^2 Nelson and MacLennan or 2.2 people/m^2 [92].

With all of these varying recommendations and results which ones have become standard practices for estimating flows at stadia? It appears that there is little conformity between nations. Different nations have adopted recommendations based on research performed on crowds in their countries. No literature could be found that identified how the different nations selected the rates they adopted with the exception of the UK, where the SCICON study was commissioned specifically for the purpose of establishing flow rates at stadia[93].

The following chart outlines maximum walking flow rates that have been adopted in various different countries:

Source	Country	Rate
Fruin	USA	1.4
Puskarev	USA	1.4
Brilon	Germany	1.6
Tanaboriboon & Guyano	Thailand	1.7
Green Guide	UK	1.8

Table 3: Internationally Recommended Flow Rates[94]



US calculations anticipate an evacuation to take 29% longer than UK caclulations. After five minutes there is a 120 person cumulative difference between US and UK recommended flow estimations at a given point along a two metre wide path.

Figure 7: Cumulative Flow Calculation Comparisons

3.3.2 Wayfinding

Occupants may desire to evacuate a structure quickly, but may have difficulty finding their way out[95]. This may be due to visual obscuration, physical barriers, disorientation or lack of familiarity with the building. Regardless of these factors there are two other obstacles the occupants must overcome. These are the influence of others and an innate desire to egress along their ingress route[96].

Using video footage from surveillance videos in public buildings, Proulx[97] observed that the most common response to an alarm is to ignore it as "just another false alarm." As some individuals ignore the alarm a passive, psychological pressure to conform to the group delays other individuals from evacuating or alerting others. They do this in order to avoid mistakenly causing a scene having adopted the assumption that if it was an actual alarm everyone else would not be ignoring it. Proulx also observed that people tend to exit via the door they entered, often ignoring fire exits along their egress route. Proulx further observed that there was a tendency to complete activities prior to leaving the building - even in the presence of smoke. Proulx is not alone in observing this type of behaviour. Although this study was conducted in real fire situations a number of studies of this behaviour under simulated conditions have also been conducted. Latane and Darley[98] observed this type of behaviour in experiments in the 1960s.

The repercussions of such behaviour can be significant. The delay in movement may make wayfinding more difficult as smoke and fire cut off routes and diminish the senses. As a fire develops the danger to people becomes greater and in extreme cases may be sufficient to prevent people from successfully egressing from an affected structure. The most notable example of such behaviour in stadium crowds occurred at Bradford Football Stadium in 1985 where people unnecessarily delayed moving away from the fire affected stand[99]. As a consequence many casualties resulted.

3.3.3 Crowd Density

Crowd density is well recognised as a major factor in determining the speed of an evacuation and hence egress routes are designed so as to accommodate the egressing population without the crowd density exceeding the predetermined limit. This is for the large part strictly a numbers game. The influence of the crowd dynamics is often ignored[100].

Psychologists describe human interaction within a crowd as a collection of "cells"[101]. Small groups of individuals make up a cell. These individuals have limited communication with each other regardless of whether they know each other or not. The cells overlap one another and a collection of these cells make up a crowd (figure 8). Individuals may be members of several cells at a given time but they are not able to communicate with cells they are not currently a part of. This is most obvious in situations where poor front to back communication leads to crushing injuries[102]. People on the outer edges of the crowd are less densely packed and are unaware of the conditions further in. Individuals on the outer edges can act independently of the crowd body however as crowd density around an individual increases individual actions decrease[103].

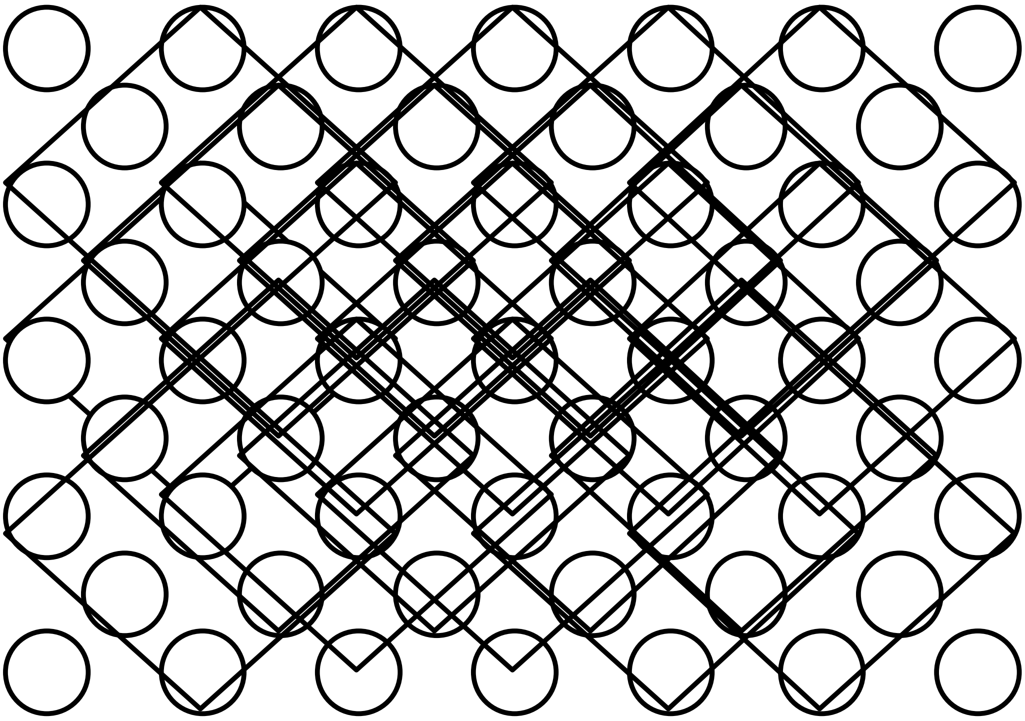


Figure 8 - Overlapping cells within a crowd

The crowd goes through phases as the density increases. Initially the crowd behaves like a gas where the molecules, or in this case cells are constantly changing. Cells can absorb shockwaves and can compress or expand as physical boundaries and obstacles are encountered. Then as the density increases further, groups of cells compress to the point where they condense and act as a fluid. Fruin[104] suggests seven people per square metre as the required density for this to occur. Fruin uses different densities to quantify the level of service available to individuals. Level of Service A is free motion uninhibited by other people. Level F is when only shuffling motion is possible because of the lack of space around a person. Fruin's levels of service and the size of a person within his model are illustrated in the following figure.

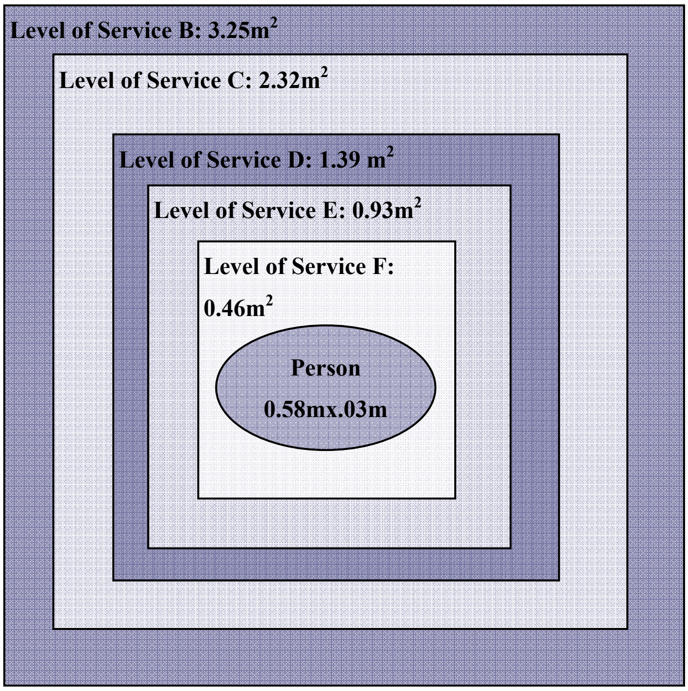


Figure 9 Fruin's Levels of Service

Analysis of video footage of the Hillsborough disaster illustrated how Fruin's model falls over when applied to stadia[105]. The footage showed movement of the order of 1.3m/s (4.7km/hr) at densities consistent with Level of Service E (0.78 m^2 per person). Fruin suggests that at this density only restricted motion is possible.

In the "fluid" phase the cells are fairly constant in their composition. Cells can no longer absorb shockwaves. Ripples can be sent through the crowd. As with any liquid it is virtually incompressible. People at the back of the crowd may perceive the compression of cells from “gas” to “fluid” as forward movement and hence push forward, further exasperating the situation. In this type of situation security often identifies the problem at the front and advises those people at the front not to push, when in fact they are incapable of independent motion and it is the gentle jostling at the back that is actually causing the problem[106].

The crowd densities that produce fluid type behaviour are best avoided, hence, they do not occur except under rare and extreme conditions. Fruin describes these in terms of force, information, space and time (FIST). There are five environments that result in this type of crowd density.

3.3.4 Flight

In a bid to escape from danger, a crowd may attempt to move faster than it is able to crushing those in front. This type of behaviour was exhibited in Buenos Aires in 1968 when hooligans threw wads of burning paper down into packed stairwells[107]. It has also been observed in stadia at the onset of hail storms and heavy rain[108].

3.3.5 Surging or Craze

The opposite of flight behaviour. The crowd rushes towards something causing the front of the crowd to surge forward, much as a wave builds as it approaches land. This predominantly occurs in festival seating arrangements[109]. This is unlikely to occur in a fire situation.

3.3.6 Interruption of flow

Where a walkway narrows producing a bottle-neck the crowd is unable to maintain speed crushing those near the front[110]. This occurred at a stadium’s ticket stiles prior to a game in New Zealand in 2002. Pressure was relieved by opening egress gates to allow unimpeded ingress.

3.3.7 Blockage of flow

An extreme version of interruption of flow where no flow is possible. This typically occurs when doors are blocked or they open into the crowd. Crash or crush doors are designed to avoid this situation, “crashing” open when a critical “crush” pressure is applied to the opening mechanism. Illegally locked gates were involved in a number of the crushing incidents mentioned in Table 1 and have been the cause of crushing injuries and deaths in many structure fires over the years[111].

3.3.8 Crossed flow

Unlike the other four situations this results in the people in the middle of the crowd being exposed to the greatest pressure. Crossed flow occurs when part of the crowd changes direction or multiple flows fail to merge successfully. Crossed flow has the potential for the greatest incidence of injury as pressure is applied from different directions making it more difficult to maintain balance or “ride the wave”. Moscow’s Lenin Stadium (1982), Hillsborough[112] (1989) and the Ibrox incident[113] (1971) all resulted from crowds changing direction. Areas where poor merging occurs are often identifiable during normal egress situations and can be addressed preventing major incidents from occurring.

3.4 Coordination/management

Coordination and management of a stadium crowd is different to that of an office building. As a place of entertainment the crowd is more social and potentially less compliant than that of an office building or a hotel might be. This can be due to a number of factors, the increased likelihood of members of the crowd to “egg on” an individual who is confronting authority[114], greater dissociation from self into a mass mentality, increased annoyance at having an enjoyable activity interrupted and the higher incidence of the influence of alcohol amongst crowd members.

In USA stadia, like many other countries, alcohol is provided for patrons to purchase. However the in the USA low alcohol beer is the norm at such venues, reducing the potential for drunken behaviour. College stadia, which make up a large proportion of the largest stadia in the USA may not provide any alcohol if they are part of a dry campus. The USA is also different in that due to low labour costs it is more viable for alcohol to be provided in cups. This limits the quantity that an individual is able to carry thereby reducing the level of consumption. This is not the case in other countries.

In the UK control of alcohol at stadia was only introduced after the Bradford disaster[115].For the most part alcohol consumption is not a problem for stadium management but in certain circumstances it has the potential to make crowd behaviour disruptive and or more difficult to manage or coordinate. Many studies of response time and reasoning impairment have shown that inebriated individuals are less responsive than sober individuals. Several incidents that have developed into disasters at stadia have been instigated by drunken individuals. For these reasons the potential for alcohol consumption to affect egress management and crowd movement in emergency situations has to be recognised.

4 Experimental Method

The experimental part of this study was designed to gather information about actual crowd movement and levels of fire protection in New Zealand stadia. From this it was anticipated that it could be determined whether crowd movement at New Zealand stadia is consistent with that of other researchers and that suggested by standard texts such as the SFPE Handbook of Fire Protection Engineering[116]. Information about the level of fire protection in New Zealand stadia and stadia in Australia was gathered so as to assess whether there were any major differences in the protection afforded stadium structures in New Zealand as compared with other countries.

- Observational experimental data was collected in two ways:
    - Interviews or survey sheets with stadium management and persons related to managing egress and/or fire service liaison at the various stadia
    - Video footage of egressing crowd movement at stadium events

- Egress simulation data was obtained using Simulex evacuation software and CAD drawings of stadia or sections of stadia.

- Hand calculations were performed using formulae from Section 3 Chapter 14 Emergency Movement of the SFPE Handbook 3rd ed.[117]

- Comparisons of emergency movement data from video footage, simulation output and hand calculations were then made.

4.1 Personal Correspondence

Interviews were conducted with stadium operations and security management, fire safety officers and fire service personnel associated with the various stadia. A copy of the interview questions and the individuals that were interviewed is included in Appendix B. Interviews were used to obtain information on how crowd egress was managed, the fire protection methods used at the venue and problems that had been encountered, anticipated or overcome.

4.2 Observing Stadium Egress

4.2.1 Crowd Movement

Of the stadia visited, an initial survey of the stadium was conducted and suitable locations to record egress were identified. These locations were chosen based on information from stadium staff about their experience with egress flow around the grounds. Those sites that had potential visibility problems, would interfere with egress flow or did not have obvious landmarks to measure against were dismissed. The remaining sites were measured across the width of the egress path. Where possible, distances between landmarks along the egress paths were also measured. These measurements were taken in order to allow video footage to be later analysed for:

- Speed of flow
- Density of flow
- Flow rate

In some cases additional areas were identified as unusual during the egress. Where these were videoed measurements were taken after the egress had ceased.

The majority of video footage was recorded at the end of “Super 12 Competition” rugby games. Recording started shortly before the end of games and a verbal cue was recorded upon hearing the final whistle that ended the game. Where the final whistle was not used as a cue the actual time as recorded by the video camera was used to provide starting and finishing times for sequences. Recording was stopped either when crowd density dropped to the point where other patrons did not impede movement or when no further patrons were using the egress path.

Video footage of vomitories and concourse areas around food vendors was obtained at half time or prior to the game only where crowd densities were sufficient to be of interest.

Due to the liquor licensing arrangements at stadia in New Zealand, it was not practical to collect observational data for comparison from corporate or lounge areas. These areas remained populated after the end of the game, and continued to be occupied until they were closed.

4.2.2 Individuals within the crowd

In some cases the time taken for an individual to traverse a known distance was recorded. In densely packed crowds this was only possible with individuals who stood out from others, primarily by wearing an unusual, large or brightly coloured article of clothing. Attempts were made to record similar footage of mobility impaired individuals however opportunities for this were limited. Where viewing access was suitable families or groups within the crowd were identified and their interaction with the greater crowd was noted. Verbal cues recorded on the video footage identified these individuals or groups for later analysis.

Video footage was obtained using a single digital video camera. Consequently it was not possible to obtain data from all areas of the various grounds. Total evacuation times were estimated from observations of the control room surveillance cameras or observations taken within the grounds.

4.2.3 Video Analysis

Video footage was analysed using the eyeball technique. Although this is not difficult it is arduous and must be repeated for each set of data that is collected in a given sequence. Footage was transferred to computer. Footage was edited to start at the time of the final whistle (or other cue). The time since the initial cue and the number of patrons to pass the preassigned landmarks were then recorded by hand while viewing the video footage. Where individuals or groups were identified as being of interest, the time taken for them to traverse a known distance was recorded and compared to that of other presumably unrelated members of the crowd. Playback was viewed using frame advance and counts were taken every 1 second of recording. Not all video footage collected was suitable for analysis.

Figure 10 illustrates the following examples of observational analysis.

4.2.3.1 Flow Rates

All of the individuals whose heads have been marked with a black dot passed arrow A within a 1 second increment. The width of the walkway was measured. This analysis technique provides data in terms of specific flow (people per time per effective width).

4.2.3.2 Speed

The man in the striped jersey and cap to the left of the diagram (oval) has just passed the mark in the join on the concrete (arrow A). The time taken from him reaching this mark until his head drops when he reaches arrow B indicates the time it takes for him to reach the top of the stairs. As the distance between arrows A and B is known his speed can be calculated.

4.2.3.3 Density

The crowd density can be established by counting the total number of heads between the dotted lines marking arrows A and B in a given frame.

Figure 10: Observational Method

4.3 Calculations

A selection of calculations found in Section 3 Chapter 14 of the SFPE Handbook 3rd ed.[118] were used to perform hand calculations on sections of egress paths at different stadia.

4.3.1 Premovement Time:

Assumptions were made in order to justify the use of egress footage at the end of a game as an approximation of emergency movement. The most significant assumption is that there is no premovement time at the end of a game.

Evacuation times are a way of gauging the speed with which occupancies empty. This information is gathered routinely during evacuation trials and data from actual emergency evacuations. From these studies it has been found that there are four main determinants in evacuation times; premovement activity, speed of evacuees, distance to safety and density of the crowd, all other variables affect one of these four determinants. For example, poor visibility affects speed and possibly premovement, obstacles and uneven terrain can affect speed, density and distance, obviously detectable danger such as visible smoke may affect premovement, speed and density. Speed, distance and density are not independent of each other either. If, as in the case of a high rise building there is significant distance to traverse to a point of safety people become tired and speed decreases. Similarly if the front of the crowd is moving more slowly than the back of the crowd the density will increase.

The information from crowd movement is then compared to the speed with which a danger, such as a fire spread, could develop in the occupancy to determine whether the occupant's could/should/did evacuate rapidly enough to avoid injury. This determines the "required safe egress time" to complete an evacuation (RSET) and the "available safe egress time" before conditions become untenable (ASET). RSET is the time required to evacuate the building based on occupancy levels and egress path distances. ASET is the time available to perform an evacuation before the egress path is likely to be compromised by untenable conditions. ASET can be increased by increasing the fire protection of an occupancy and should always be greater than RSET.

RSET is a sum of the various time increments required to perform evacuation tasks from the time of fire ignition until the evacuation is complete. This can be summarised as:

$$t_e = t_d + t_a + t_{pm} + t_m$$ **Equation 1**[119]

where t_e= time to evacuate, t_d= time from ignition to detection, t_a= time from detection to notification, t_{pm}= premovement time and t_m= movement time.

Observations of the end of rugby games were assumed to have t_d, t_a, t_{pm}=0, therefore $t_e = t_m$, with t_m commencing when the referee blows his whistle for full time. Simulations and calculations that are compared against observational data therefore have also assumed $t_e = t_m$.

This assumption is based on the following:

- the majority of occupants have no reason to stay after the game
- patrons are with their associates and have all their possessions in hand
- patrons are anticipating the referee's whistle
- many patrons attempt to "beat the rush" and leave as promptly as possible
- weather conditions during rugby season are often such that people are in a hurry to get somewhere warm
- queuing times absorb any delay to evacuate by slow to respond patrons

The assumption of no premovement time would be invalid during an actual fire evacuation. Premovement time has been ignored in this case only to simplify the acquisition and application of observational data.

In the event of a fire alarm sounding the premovement time would be greater. While weather conditions and having possessions in hand may be common to both situations, patrons are not anticipating a fire alarm and if the game is still in play they are not likely to be keen to leave. Similarly patrons may assume that a fire alarm is a false alarm and therefore only a temporary interruption. In this case there may be no initial motivation to evacuate unless obvious signs of fire can be observed. If the game continues despite the alarm, patrons may decide not to leave, obstructing others and slowing down the evacuation. Of even greater concern, should something sensational, happen during the evacuation some patrons may try to return to the arena against the flow of the crowd resulting in crush injuries to those evacuees in the middle of the crowd. This was typified by crowd movement at the 1971 Ibrox incident[120] when members of the crowd tried to rush back into the arena.

4.3.2 Effective width

It is commonly recognised that people do not use the full width of a pathway. They maintain a boundary layer between themselves and stationary obstacles.

$$\text{Effective width } (W_e) = \text{clear width} - \text{width of boundary layers} \qquad \textbf{Equation 2}$$

Boundary layer widths were selected from those recommended in the SFPE handbook page 3-369[121].

Element	Boundary Layer
Obstacle such as bollard, column or rubbish bin	10cm
Walls bordering concourses, passageways and vomitories	46cm
Walls bordering corridors, ramps sand stairs	15 cm

Table 4: Boundary Layers

4.3.3 Speed

Speed is determined to be a function of occupant density and speed factor, k, which is determined by the slope of the surface between densities of 0.54 and 3.8 people/ m^2. This can be expressed as:

$$S = k - akD \qquad \textbf{Equation 3}$$

where a= 0.266. k = constants reflective of the established maximum speed for studied terrains (for flat surfaces using Fruin's data k=1.40[122]). Density is assumed to be optimum when maximum specific flow is achieved, and is taken as 1.9 people per metre squared of exit route space. This is interpolated from the specific flow - density relationship outlined in the SFPE Handbook[123] and deriving the maximum density from the formula for specific flow as shown in the following equations, Equation 4, 5.

4.3.3 Specific Flow and Calculated Flow

Specific flow (F_s) is a measure of evacuating persons past a given point as a function of speed (S) and density (D).

$$F_s = SD \qquad \textbf{Equation 4}$$

Optimum density can be derived by:

$$\frac{dF_s}{dD} = k(1 - aD) = 0$$

Equation 5

$$\Rightarrow D = \frac{1}{2a} = \frac{1}{0.532} = 1.88$$

Optimum density is therefore dependant on *a*. As *a* is independent of the type of egress, e.g. stairs, concourse, etc specific flow should be maximised at this density for all types of egress.

Calculated flow (F_c) is the flow predicted for a given point as a function of specific flow and effective width.

$$F_c = F_s W_e \qquad \textbf{Equation 6}$$

Calculated flow predicts the maximum capacity that can be achieved through an egress path.

4.3.4 Varying k

Estimates of evacuation flows and densities using a combination of observational data and established research were also calculated for comparison with the observed data using equation 4 and its derivative equation, equation 3, relating speed in terms of densities and constants based on terrain.

As mentioned previously, k = constants reflective of the established maximum speed for studied terrains. A table of values reflective of Fruin's work can be found in Chapter14 of the 3rd edition of the SFPE Handbook[124]. A value of k=1.8 was used in order to establish values based on Poyner's work.

4.3.5 Estimated Egress Times (time for passage)

Assuming that the gate, stair or pathway that was monitored was representative of all egress from the stadium and that in an evacuation the maximum F_s were maintained once it was reached estimates of the potential minimum egress times through the monitored point could be extrapolated to provide values for the total stadium. It would be unlikely for the extrapolated values to be accurate as few stadia were laid out symmetrically and certain exits are used preferentially based on external incentives such as proximity to public transport. It must be stressed that these values only provide a best estimate based on the collected data and should not be used as a definitive method of calculating stadium egress potential.

The formulae used for estimating egress times for a population (P) are referred to as time for passage (t_p) in the SFPE Handbook[125]. Time for passage calculations were made once maximum F_s was reached.

$$t_p = \frac{P}{F_c} \qquad \textbf{Equation 7}$$

Using equations 3, 4, and 5, F_c can be expressed in terms of density and effective width:

$$t_p = \frac{P}{(1 - aD)kDW_e} \qquad \textbf{Equation 8}$$

A table of the spreadsheet calculations performed on observational data can be found in the results section. Actual results from the spreadsheet are located in Appendix E.

4.4 Computer simulations

A number of computer programs are available that facilitate the simulation of evacuations with inputs for premovement (or delayed evacuation), speed, density and distance. The problem with simulations is that despite the convenience, people and crowds do not always behave with the response that the model predicts. Many models are based on the flow of objects such as ball bearings or traffic. One of the main problems with these models is that movement occurs in one direction independent of other individuals. Conversely within even dense crowds small groups will fight against the crowd to maintain contact or protect weaker individuals within their group. Direction of motion available to humans (as opposed to simulations) is multidirectional within all but very dense crowds. Humans are able to reverse, sidestep, travel against the crowd, faster than the crowd or take unusual paths such as sliding down stair rails to bypass others. This is done through altering personal space, varying pace, pushing, communication with others and taking advantage of variations in the crowd movement around them. These movement patterns can in some instances affect the general crowd flow but they are difficult to model and are not considered by simulation software.

In predicting crowd movement it must be recognised that a crowd is not a mindless mass. Although it may act with one overriding personality, individuals within the crowd are constantly making decisions that affect that personality. Examples observed during this study included variations between different sporting crowds and based on the location and accessibility of the stadia. At some stadia it was observed that although people entered the stadium from all entrances, the majority of them attempted to leave through only one or two exits, rather than exiting the way they entered. The reason for this was people had gone from work to the stadium using a wide range of transport and were going from the stadium to town or to home via the local public transport depot. Similarly it was recognised by stadium staff and observation that there were often blockages to egress at the base of light poles or by feature objects such as inflatable advertisements where people had arranged to meet. During an evacuation it must be recognised that while people’s prime motivation should be to escape danger other considerations will also be affecting their movement.

4.4.1 Egress Simulation

One way of testing the efficacy of a structural design for evacuation purposes is to run computer simulations. There are several advantages to running a simulation as opposed to a trial evacuation:

- A simulation can be performed prior to or at any point during construction as the actual building is not required.
- There is no disruption to the venue or its occupants.
- Large numbers of people do not need to be sourced (as with a trial evacuation at a stadium).
- Alterations to egress routes can be made quickly and simulations rerun without the associated logistics of rerunning a trial evacuation.
- A simulation produces a permanent, viewable record of the evacuation plan for the entire structure that can be easily reviewed in sections or as a whole.

A number of software packages are available for this purpose. The one used in this study is Simulex32.

4.4.2 Egress modelling

Egress modelling has developed along two different lines. This is indicative of the background of the modellers[126]. One line of development has evolved from human behaviour research whereas the other has evolved from traffic modelling.

With the first type of modelling a wide range of characteristic inputs are available and the modelling takes into account the way individuals within a crowd interact and allows for the impact of different behaviours and stimuli. The software involved is complex and consequently involves considerable computing power. The second type of modelling treats individuals within the crowd as independent individuals that do not interact with others. This is particularly evident when a conflict occurs and the individuals do not act cooperatively to overcome the conflict. For example one individual stopping to let another pass. Limited characteristics are available. These relate to speed, size and response time. With this type of modelling two different approaches to movement have been taken, one treats the flow of people as discrete particles and can be described as "ball bearing" modelling[127]. Ball bearing modelling is also known as "cellular automata" modelling. The other treats the flow as a fluid or suspended solution. With this type of modelling individuals are swept along in the flow and eddies are created on the periphery. Simulex32 is one of the available models in the "ball bearing" category, sometimes referred to as optimisation modelling[128].

4.4.3 Software

The software used for the modelling part of this study was Simulex32 product version 2.7.0.1 produced by IES Ltd. Simulex32 is a coordinate-based model designed for calculating evacuation movement of individuals in a multi-storey building. Simulex32 was developed by Dr Peter Thompson of IES Ltd.

4.4.3.1 Simulex32

The Simulex32 model is quite simplistic with evacuation movement almost exclusively determined by the shortest route to an exit. It determines the rate of flow based on body size (of which four options are possible) and density of the crowd. Way finding and environmental conditions are not considered. Conflict Resolution within Simulex32 consists of two or more people banging into each other with some sideways shuffling in an attempt to get past each other. However if both individuals are trying to progress in the same general direction or if there is insufficient clear space for the individuals to shuffle past then an impasse is reached and neither person moves. This phenomenon results in opposing rather than merging flows. Models with greater behavioural properties apply rules and protocols to allow individuals to make decisions, resolving such conflicts.

To develop a Simulex32 model a CAD drawing must first be developed and this is used to define the boundaries and distances to exits. The CAD drawing is inserted into Simulex32 as a DXF file. DXF files are standard ASCII text documents used to store vector data. This results in a two dimensional, floor plan representation of the structure in the Simulex32 model. The next step is to define exits, stairwells and links people will move through. These are inserted manually. Once this has been done distance maps are developed by the program in order to identify distances to exits from all points within the represented structure. People may then be characterised and entered into the file, in preparation for simulations to commence. Characterisation options include basic size demographics, speed parameters which can be assigned to follow normal, triangular or uniform distributions, and predetermined exit selections can be assigned.

The algorithms used in Simulex32 are based on real life data. Simulex32 allows for the following inputs.

Up to 50 exits, 100 stairwells and up to 100 links may be included in a model. The size, orientation and location of these are all individually assigned. As mentioned previously it is possible to vary the characteristics of the population, altering the demographics and assigning exits to individuals or groups. However, as the number of distribution maps that can be used is limited to 10, it is difficult in a stadium structure to assign stairwells to individuals in the same way.

The demographics of the population can be assigned using predetermined populations; such as commuters (30% average, 30% male, 30% female, 10% children) or by assigning a group as female, male, children or average. This determines the body size of the individuals.

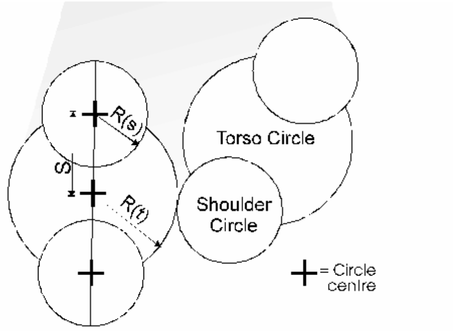


Figure 11: Simulex32 Body Types From (Thompson 1996)

The four different body types have the following dimensions:

Body type	Average	Male	Female	Child
R(t) (m)	0.25	0.27	0.24	0.21
R(s) (m)	0.15	0.17	0.14	0.12
S (m)	0.10	0.11	0.09	0.07

Table 5: Simulex32 Body Type Dimensions From (Thompson 1996)

The population can also be assigned average response times with different distributions. Overtaking, queuing, and to some degree redirection are all built into the model. As individuals get closer their speed reduces with unimpeded walking speed being randomly distributed between 0.8m/s and 1.7m/s.

Egress Paths

Exits - As mentioned previously Simulex32 allows for up to 50 exits. Exit size, position and orientation are determined by the user. Through developing distance maps different groups or individuals can be assigned exits to use or by default they will select exits by the shortest path.

Stairwells - Up to 100 exits may be included in a model. Stairwells allow the user to define width and length as well as orientation and position. Rise and run are preset and standard for all stairs.

Links – Links are used to associate floors with stairs. The width of links is set by the user and may be independent of stair width to allow for doorways into the stairs. More than two links may be associated with one stair – allowing for multiple floors to enter a single stairwell. The model allows for up to 100 links.

People - Modelling people in Simulex32 is to some degree customisable. Both the demographics and the response times of individuals or groups of individuals can be assigned within certain limitations.

Demographics - The people simulated in the Simulex32 model are assumed to be able bodied and are all capable of a full range of speeds dependant on density. The speed of individuals with an unhindered (>1.5m) interpersonal distance is randomly determined using a normal distribution. Speeds and other properties of the Simulex32 evacuation model are based on evacuation drill data and do not necessarily reflect the movement present in actual fires. It is assumed that during trials optimum speeds are reached as there are minimal obstructions and environmental stimuli to interfere with the evacuation. As such Simulex32 ‘should’ offer optimal evacuation times. Walking

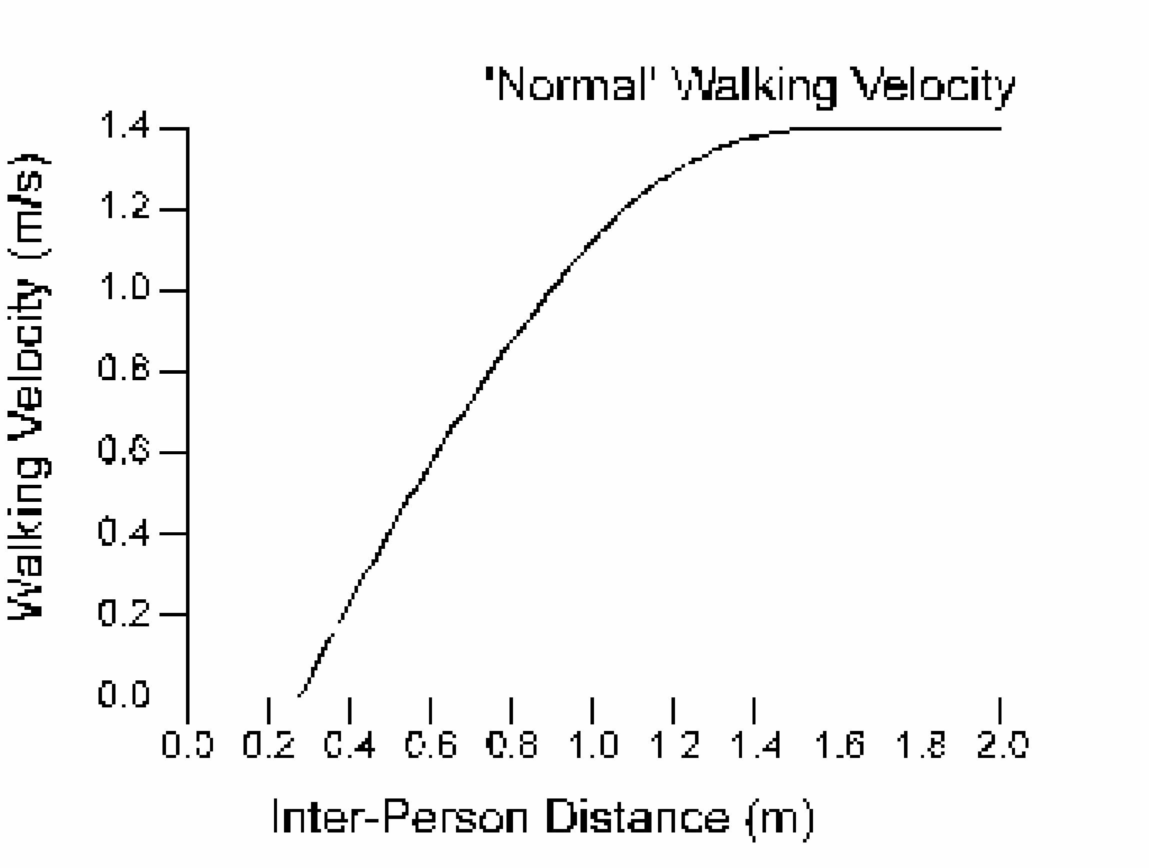


Figure 12: Simulex32 Walking Velocities (Thompson 1996)

velocities vary with density for densities with <1.5m interpersonal distance (Figure 12).

Response time - Response times may be preset by assigning a uniform, triangular or normal distribution curve to groups or individuals. Response times are then randomly assigned to those individuals in that population. It is interesting to note that a Weibull distribution has been identified by evacuation researchers as most closely matching evacuation drill data by several researchers[129]. Weibull distributions are determined by the shape parameter, this allows greater flexibility in fitting a curve to data. Weibull curves can therefore be used to fit data that is shifted from the mean as opposed to distributions, such as the normal curve, that are symmetrical about the mean. This allows for 'tailing off' that is commonly observed when the last people leave a structure.

Assumptions

In modelling the chosen stadia certain assumptions were made. These were made progressively in attempts to make the simulations run smoothly. While it is not normal to 'tweak' a model when accurate input data is available, in this case unrealistic results were achieved when accurate floor plans and population distributions were input. Simplifications were made to reduce the occurrence of anomalies. Eliminating anomalous behaviour reduced simulation times making the results more credible.

Only one stadium was modelled in its entirety. Initially the upper, corporate levels were modelled separately to the bowl. Vomitories between the bowl and concourse proved to inhibit egress far more than stairwells between the other levels and the concourse. Consequently, to reduce the processing time of the full model, the upper levels were simplified. Corporate levels were altered so that rooms became simple boxes with no obstacles for occupants to negotiate. Openings were changed to the same width as the stairwells. This was a valid simplification as early attempts to model egress showed that the passages immediately prior to the stairwells were the limiting factor in achieving evacuation from the upper levels rather than the width of doorways. The simplification did not impact on egress times for those levels. This simplification served two functions. It reduced processing time of the model without impacting on the flow rate from the upper floors and made the output images from the simulation more difficult to identify with a specific stadium, maintaining its anonymity. The following three figures illustrate how the passageway immediately prior to entering the stairwell impacts on movement.

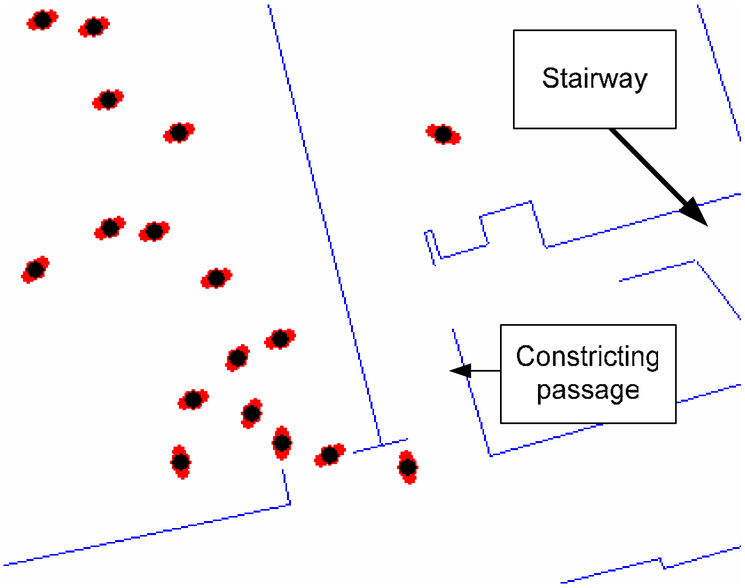


Figure 13: 5 seconds into the simulation a room near the stairway is emptying

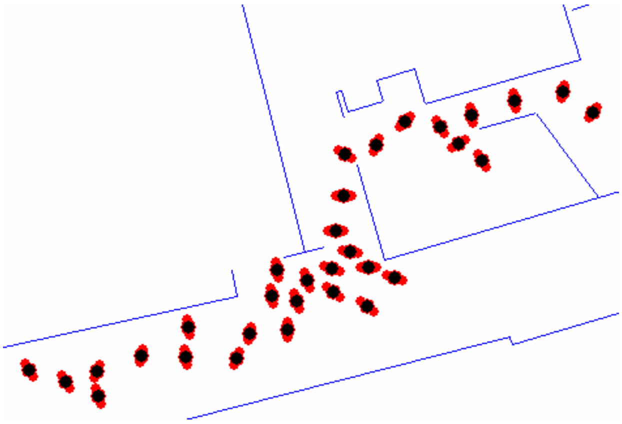


Figure 14: 19s into the simulation all rooms have emptied and all occupants are in the outer passageway enroute to stair ways.

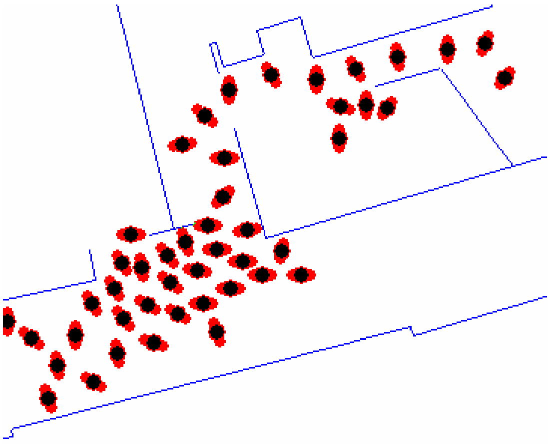


Figure 15: 35s into the simulation congestion in passageways immediately prior to stairwells determines the rate of egress

4.4.3.2 AutoCAD

All CAD drawings used in modelling for this study were developed or modified using AutoCAD 2000. Files inserted into Simulex32 were in DXF2000 format. All non-essential information was stripped from the DXF files prior to inserting the floor plans into Simulex. Files were modified where necessary in order to improve the performance of the Simulex32 modelling.

4.4.4 Data Processing

Video footage, hand calculations and egress simulations were compared in order to determine how well they correlate. This was performed using standard spreadsheets to produce data summaries. Figure 13 shows the information obtained. Not all egress paths produced sufficient information to fill all fields on the sheets. This was due to the suitability of the pathway, and viewing limitations.

Observational Data	Unit			Unit
Capacity of Stadium (g)	people	Width of path (W)		metres
Attendance at event (q)	people	Boundary layer (b)		metres
Time to clear stadium (tc)	minutes	Effective Width (W_e)	W-2b	metres
Flow Rates				
Time to clear gate/path/stair (h)	minutes	Specific flow	speed x W_e	people/s/m effective width
Total usage of gate/path/stair (y)	people			
Time to reach max F_s (t)	minutes	Maximum Specific Flow (F_s -max)		people/s/m effective width
Total usage at max F_s (x)	people	Population in area W_e x L		people
Density at max F_s	people/m^2			
Time to reach sustained F_s	minutes	Sustained Specific Flow (F_s)		people/s/m effective width
Duration of sustained F_s	minutes			
Density at sustained F_s	people/m^2			
Queuing time	seconds	Calculated Flow (F_c)	F_s x W_e	people/minute
Queue density	people/m^2			
Boundary layer maintained				
Individual Speeds			time/L	
Travel distance (L)	metres	Mean speed		m/s
Terrain		Maximum speed		m/s
Total no. individuals tracked		Minimum speed		m/s
Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)				
Fraction to leave through gate pre max F_s (A)		x/y		-
Fraction of populous to use gate (B)		y/q		-
Total to leave through gate post max F_s (C)		y-x		people
Estimated populous to leave pre max F_s (f)		x/B		people
Estimated populous to leave post max F_s (r)		q-f		people
Est. min. egress time for gate (Tg)		$(C/ F_c) + t$		minutes
Est. min. egress time for populous (Tp)		$((C/ F_c)/(h/tc)) + t$		minutes
Est. min. egress time for full stadium (Tf)		$((g/q) \times (C/ F_c)/(h/tc)) + t$		minutes
Evacuation Estimates (based on established research)				
Anticipated F_s (Fruin)	a=1.9 (people/m^2)	k=1.40(flat), 1.16 (stair) (m/s)	k	people/s/m effective width
Anticipated F_c (Fruin)		F_s (Fruin)xW_ex60		people/minute
Anticipated F_s (Poyner)	a=1.9 (people/m^2)*	k=1.8 (flat) (m/s)	k	people/s/m effective width
Anticipated F_c (Poyner)		F_s (Poyner)xW_ex60		people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)		F_s /k		people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)		F_s -max/S		people/m^2
*actual value unavailable, estimated as being the same as for Fruin				

Figure 16: Master data sheet

5 Results

Eleven venues were visited and studied. They have randomly been assigned pseudonyms A-K. Where particular stadia are identified, the associated information is readily available in the public domain and was not necessarily obtained during field observations. Video footage of people movement was obtained for 23 egress paths within these stadia. Multiple events were attended at three of the stadia. Not all video footage was of suitable quality to obtain consistently reliable results. This was due to a number of factors including; obscuration of view, inappropriate angle to the flow, and complexity of movement.

In summary, video data obtained can be broken down as follows:

- Individuals speeds of egressing patrons were obtained from 8 locations
- Crowd densities were obtained from 7 locations
- Specific flow data was obtained from 8 locations
- Total egress times of general admission patrons were obtained for 13 events

Results have been divided into two sections. The first contains fire protection information gained from observations and interviews. This is displayed as tables on the following pages. The first table (table 6) provides general information about the stadia and anticipated response capabilities. The tables following that (tables 7 and 8) identify the components of the fire protection systems that were present. There is a common key to tables 7 and 8.

Table 7 is concerned only with aspects of fire protection that are connected directly to the fire service. It details whether active fire protection is present in various locations within stadia. The active protection referred to includes manual call points, sprinklers, heat detectors and smoke detectors.

Table 8 identifies the range of fire protection used in protecting the stadia. Not all areas of stadia were protected by all types of fire protection. For example fire resistant glazing was only present in areas such as lounges and suites with large vision panels. In this case they provide protection against fire spread such as that of the Texas Stadium fire described in the literature review.

The second section of the results contains data obtained for specific egress paths from video analysis, calculations and computer simulations. Specific flow data has been calculated for one minute periods at five second intervals. A brief description of locations that were videoed, including those that were not suitable for video analysis is provided. A rough sketch is included to aid visualisation of the egress scenario that was observed.

Results from Interviews and Survey sheets											
Stadium	A	B	C	D	E	F	G	H	I	J	K
Stadium Egress time post game (min)	21	16	18	9	24	19	38	15 est.	8 est.	<10 est.	12 est.
Crowd Coordinators	Contractors	Contractors	In House	In House	In House	Contractors	Contractors	Contractors	In House	In House	In House
Fire Service Presence (before/after/during event)	Mostly	Sometimes	Always	Never	Never	Never	Always	Always	Never	Never	Never
Fire service accommodated for in main control room	Yes	Yes	Yes	No	No	No	Yes	Yes	No	No	No
Number of Separate Fire Control Rooms	1	1	1	2	2	1	1	1	1	1	1
Distance to nearest Fire Service	0-3km	0-3km	0-3km	0-3km	0-3km	0-3km	0-3km	3-5km	5-0km	0-3km	5-10km
Expected Response Time	<5min	<5min	<5min	<5min	<5min	<5min	<5min	<10min	<10 min	<5min	<10min
Foreseen Delays	Traffic	Nil	Nil	Traffic	Nil	Traffic	Traffic	Traffic	Nil	Nil	Nil
Anticipated Evacuation Time	8 min	<8 min	8 min	<8 min	8 min	10 min	>15 min	<8 min	8 min	?	?
Foreseen Delays	nil	nil	bottle-neck	nil	preferred route	space limitations	bottle-neck, alerting	nil	nil	nil	preferred route
Alternate fire engine access/fire control room	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes
Full radio coverage for staff	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes
Trained fire wardens	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Event type fire drills carried out regularly	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Non-event type fire drills carried out regularly	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Fire Service Approved Evacuation Schemes	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes

Table 6: Stadium Survey Sheet 1 – Background Information

Active Fire Protection connected to Fire Service											
Stadium	A	B	C	D	E	F	G	H	I	J	K
Concessions - fixed	Y	Y	Y	Y	Y	N/A	N	Y	Y	Y	Y
Concessions - mobile	Y	Y	Y	N/A	N/A	N	N	Y	N/A	N/A	N/A
Kitchens	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Offices	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y
Storage areas	Y	Y	Y	N	N	N	N	Y	Y	Y	Y
Players areas	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y
Restaurants	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Lounges	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Suites	Y	Y	Y	Y	N	Y	N	Y	Y	Y	Y
Temporary stands	N/A	N	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Outdoor permanent stands	N	N	N	N	N	N	N	N	N/A	N/A	N
Covered permanent stands	N	N	N	Y	N	N	N	Y	N/A	Y	Y
Control Rooms	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Car parking	Y	Y	N	N	N	N	N	Y	N/A	N/A	Y
Concourse	N	Y	N	Y	N	N	Y	Y	Y	Y	Y
Ticket Booths/Turnstiles	N	N	N	N	N	N	N	N	Y	Y	Y
Surrounding grounds	N	N	N	N	N	N	N	N	Y	N	Y
Toilet Facilities	Y	Y	Y	Y	N	N	Y	N	Y	Y	Y
Embankment/Terraces	N/A	N/A	N	N	N/A	N	N	N	N/A	N/A	N/A
Scoreboard/Big Screen	Y	Y	Y	Y	?	Y	Y	N	Y	Y	Y
First Aid/Police Rooms	Y	Y	Y	Y	?	Y	N/A	N	Y	Y	Y
Gathering Places/Landmarks	N/A	N	N	N	N	N	N/A	N/A	Y	N	N/A

Table 7: Stadium Survey Sheet 2 – Active Fire Protection

Fire Protection Used at Stadium	Interview and Observational Information from Stadia that were Visited										
	A	B	C	D	E	F	G	H	I	J	K
Structural fire protection	Y	Y	Y	Y	Y	Y	*	Y	Y	Y	Y
Fire resistant glazing	?	?	?	?	?	?	?	N	Y	Y	Y
Fire doors	Y	Y	Y	Y	Y	*	*	Y	Y	Y	Y
Fire Cells	Y	Y	Y	Y	Y	*	*	Y	Y	Y	Y
Addressable detection system	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Smoke detectors	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y
Smoke extraction system	*	Y	Y	N	Y	N	N	Y	Y	Y	Y
Smoke curtains	Y	Y	N	N	?	?	N	N	?	?	?
Sprinklers	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Direct link to fire service	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
Risers	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Hose reels	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y
Extinguishers	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Manual call points	Y	Y	Y	Y	Y	Y	*	Y	Y	Y	Y
Sounders	Y	Y	Y	Y	Y	Y	*	Y	Y	Y	Y
Backup lighting/power	N	N	Y	Y	Y	Y	N	Y	Y	Y	Y
Fire exits	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Reflective Exit signs	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Lit Exit signs	Y	Y	N	Y	Y	N	N	Y	Y	Y	Y
Evacuation signage	Y	Y	Y	Y	Y	N	N	Y	Y	Y	Y
Reflective/Marked egress paths	Y	Y	N	N	N	N	N	N	Y	Y	Y
Muster points	?	?	?	Y	Y	N	?	Y	?	?	Y
Public addressable televisions	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Public addressable sound system	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
CCTV	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y

Key	
Y	Present in some or all sections of the stadium at time of visit
N	Not present in any section of the stadium at time of visit
N/A	Not applicable to this stadium
*	incomplete/some disabled at time of visit
?	unknown/not certain at time of visit

Table 8: Stadium Survey Sheet 3 - Methods of Fire Protection used at Stadia

5.1 Fire Protection Information

From table 6 it is evident that there is wide variation between the stadia and their approach to fire preparedness. Five of the stadia have some level of fire service presence in event operations. This ranged from maintaining a presence in the operations control room through to quizzing fire wardens, inspecting the occupancies and filing reports on their findings. Most stadia were located very close to a fire station and their expectations for how long it would take for the fire service to respond was reflected by this. Despite the proximity; it was recognised by fire station personnel, fire safety officers and or stadium management that at five of the stadia there was the potential for delayed response due to traffic problems.

Several stadia had multiple access points for the fire service to approach the fire control room from and two had multiple fire control rooms. The reasons given for these were to mitigate against access problems due to patrons or traffic, to allow better access to different parts of the stadium, because the fire control room had been relocated and to better facilitate response in the event of a large fire.

For most of the stadia there was a marked difference between the anticipated evacuation time and the time taken for regular post game egress (based on past observations of interviewees). This was most obvious in stadia C, E, F and G. Stadium G took the longest to clear post game and recognised that this was a problem as far as patron enjoyment was concerned. They anticipated that an evacuation could take longer than might be expected but did not see this delay as life threatening, nor had any work been done to reduce the time taken to clear the grounds. Stadia C, E and F credited the difference as being due to stragglers and autograph hunters. However, of these three stadia only E had conducted event type fire drills to verify their anticipated evacuation time. The basis for determining anticipated evacuation times quoted by interviewees varied. Some were quoted from evacuation plans, others were not. Several stadia indicated that they had attempted to comply with the eight minute acceptable evacuation time recommended in the Green Guide.

From table 7 it is evident that several stadia rely heavily on people alerting the fire service rather than on the activation of fire protection systems to alert the fire service of a fire. This is due in part to a history of false alarms and in part to the age of the structures. All of the modern structures used EWIS to monitor fire protection systems but few of the older structures had this installed. For those stadia that do not rely on fire protection systems to alert the fire service there is the potential for a fire to develop unnoticed in many areas if it occurred in non event times or during a small scale event. The stadium most vulnerable to this is stadium G.

In contrast to stadium G, stadium I has adopted the opposite approach where virtually the entire grounds are protected by an active system connected to the fire service. Stadium I has identified gathering places that people tend to congregate around external to the buildings and has installed active fire protection in these areas too. Stadiums I and K had the most extensive fire service connected active fire protection of those stadia visited.

From table 8 it is evident that stadia utilise a wide range of fire protection devices. All stadia have incorporated their public address systems into their fire protection and evacuation plans with most using closed circuit television monitoring (cctv) to identify and observe suspicious activities. Not all devices were used in all areas. Most notable was the absence of manual call points in areas that were not readily visible to security. Stadium G was the only stadium without smoke detectors. This was due to the smoking policy of the stadium. Stadium G was the only stadium that had not become smoke-free at the time of this study. All other stadia had adopted or were in the process of adopting smoke-free policies.

Overall most areas of most stadia were equipped with comprehensive fire protection. The notable exception being stadium G. Stadium G is in the process of upgrading some of its facilities and it is anticipated that the level of fire protection will improve as part of that process.

One area where half of the stadia could improve is in the holding of event type fire drills. There are two strategies used by stadia to implement evacuations; total evacuation or staged/partial evacuation. For an occupancy of potentially 20,000 or more both strategies require a degree of coordination and practice. The main deterrents to holding fire drills were given as the cost of bringing in sufficient staff and pretend patrons to hold a drill, the disruption to an event and television coverage if a drill was held during an event, disruption to patrons and the potential for confusing incoming patrons if a drill was held prior to an event. Two stadia overcame these objections by using school aged students on non event days and providing a tour or catering as way of payment. They felt the cost of bringing in event staff for the drill was not excessive.

Information on the adoption of international documents and guidelines in combining crowd management, fire protection and evacuation planning has not been laid out in a table. This is because there was great variation in how guidelines had been incorporated into stadium management. No stadium had adopted a single set of guidelines in its entirety and several had only applied guidelines to certain areas of the stadium or certain aspects of coordinating egress movement.

Stadia adapted a range of documents and guidelines in order to meet their crowd management needs. This was dependant on the awareness of management and consultants to the existence of such documents. No guidance is provided in New Zealand with regards to suitable sources of such information. Consequently the application of these guidelines varied.

Because crowd management and evacuation planning are closely linked there is an implication that evacuation planning can be impacted by crowd management strategies. This is recognised internationally and has led to the creation of such documents as the Green Guide. Advanced crowd management strategies are not considered as part of meeting the provisions of the New Zealand Building Code but are alluded to in meeting obligations under the Fire Safety and Evacuation of Building Regulations. From table 5 it is apparent that not all stadium have met this obligation.

In reviewing the application of adopted documents, primarily NFPA 102 and the Green Guide, deviations from the guidelines were apparent. At one stadium crush barriers had been installed as part of following the Green Guide’s recommendation on managing festival seating areas. However, they did not comply with the installation layout as set out in the Green Guide and followed a layout that is recognised in the current Green Guide as being inappropriate. This deviation from the Green Guide recommendations had not been picked up. The layout has recognised implications on safety of high density crowd movement and therefore potential impacts on egress and evacuation.

At various stadia there were instances where a document was quoted as the reason for the adoption of crowd management or evacuation planning strategies, but upon investigation these were found to be inconsistent with the quoted document. It is thought that in some cases these deviations or partial adoption may be detrimental to actual evacuations in the affected parts of the stadia.

5.2 Specific Egress Paths

5.2.1 Egress Path 1

Egress path 1 was part of a pathway near one of the main entrance-exits to the stadium. The pathway had a row of bollards across it. Not all bollards were in place at the end of the game. Egress was monitored between two bollards.

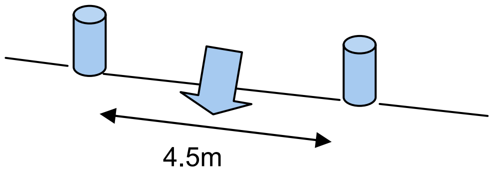


Figure 17: Sketch of egress path 1

Egress path 1 took a relatively long time for the flow of people to abate completely. This might indicate it to be a preferential exit from the grounds for all areas of the stadium. This would be a reasonable assumption to make based on the proximity of public transport and car parking and that the specific flow profile is similar to that produced in modelling the evacuation of final exits for a complete stadium. The specific flow remained lower than predicted by Fruin and the egress continued for over 25 minutes indicating a long travel path.

At no point was crowd density sufficient to use the entire exit way. The maximum number of people who crossed the egress point simultaneously was five. People generally crossed the effective width in groups of two or three. Although most people maintained a boundary layer around the bollards some people hurdled them or stopped beside them to wait for others. This data reflects free motion with relatively wide variations in specific flow. The specific flows observed are relatively low. This is due to the low density rather than slow movement on the part of the egressing patrons.

In comparing figure 18 and 19 it should be noted that, as described earlier on page 65, figure 19 is not derived directly from figure 18. Figure 18 reflects data collection that has been binned into 5 second intervals. Figure 19 shows the specific flows, calculated for one minute periods at 5 second intervals. This makes periods of consistent flow more obvious and enables mean flow values to be established more easily.

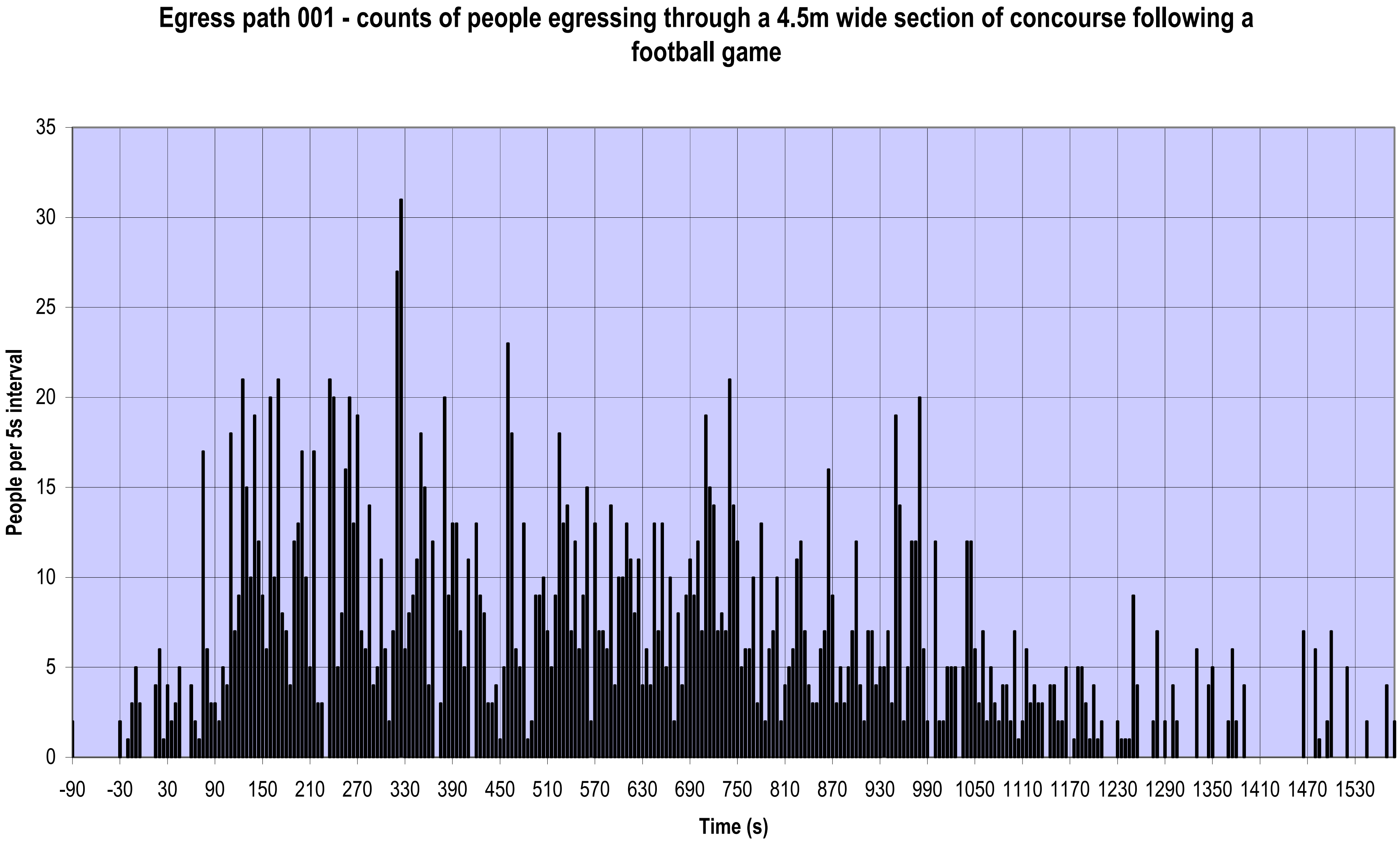


Figure 18: Egress Path 001 – egress as a function of time

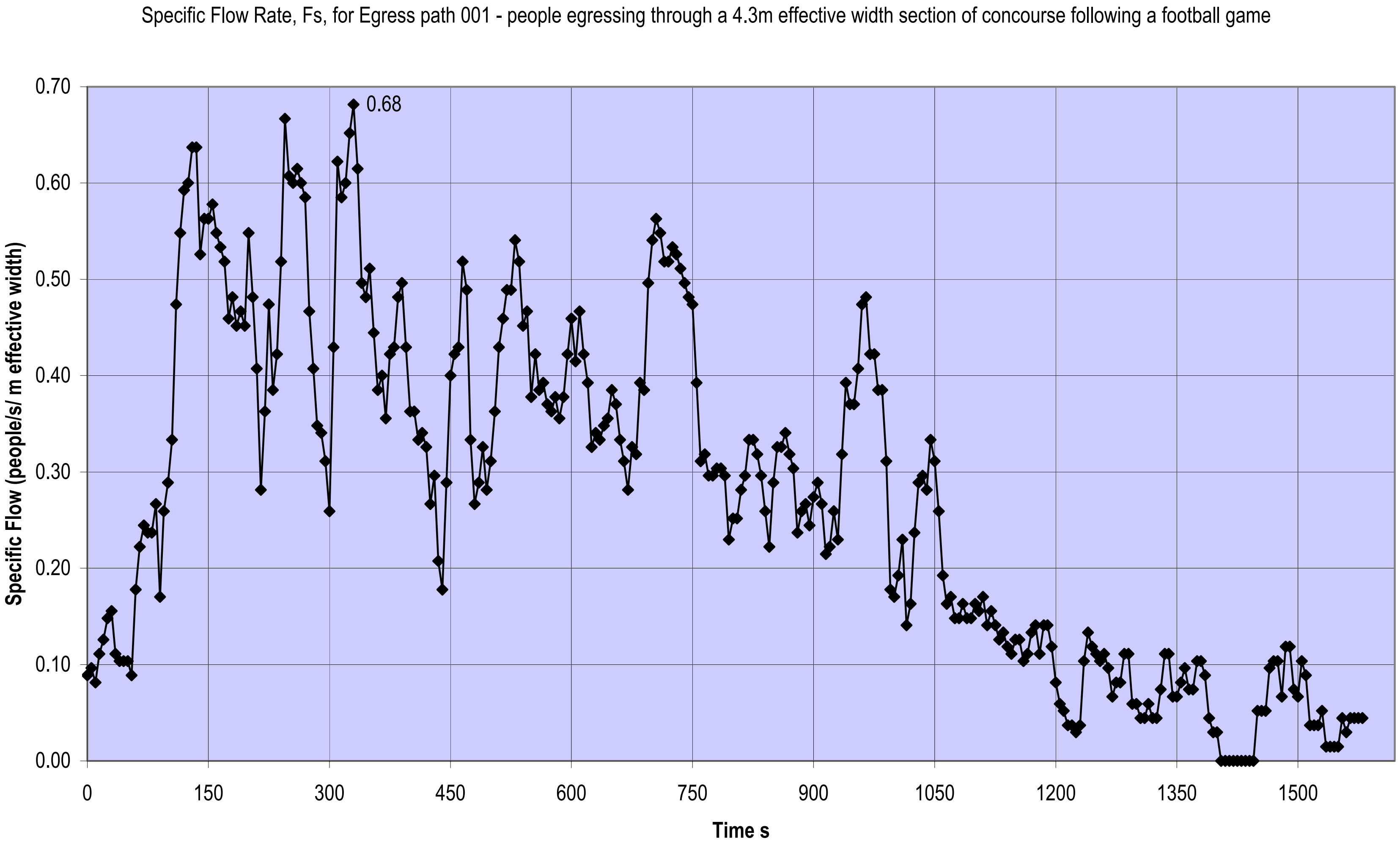


Figure 19: Egress Path 001 – specific flow as a function of time

5.2.2 Egress Path 2

Egress path 2 went across a concourse area between a vomitory and a staircase. The double headed arrow indicates the monitored path. People exiting the vomitory moved away in three directions. Most moved along the concourse to their left. The remaining occupants were divided between following the concourse to their right and exiting via the staircase. Only those using the staircase were monitored in this part of the study.

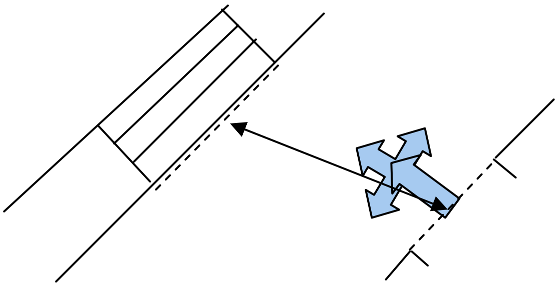


Figure 20: Sketch of egress path 2

Egress path 2 was monitored in order to assess walking speeds of egressing patrons but also served to support the theory that people do not always egress via the shortest route. A very low number of patrons exited the vomitory and crossed the concourse to the exit. Speeds varied considerably. Some people were almost running while others moved very slowly. Density remained low throughout the egress period so this data reflects free motion (figure 21).

Distance travelled was estimated. The measured distance was taken from the centre of the vomitory to the centre of the base of the staircase. This was the shortest path to exit the stadium from that vomitory but relatively few people used it. Reconnaissance of the grounds revealed that this was the exit closest to the taxi stands but one of the furthest from other public transport and the car parks. It is suspected that this may have influenced exit choice.

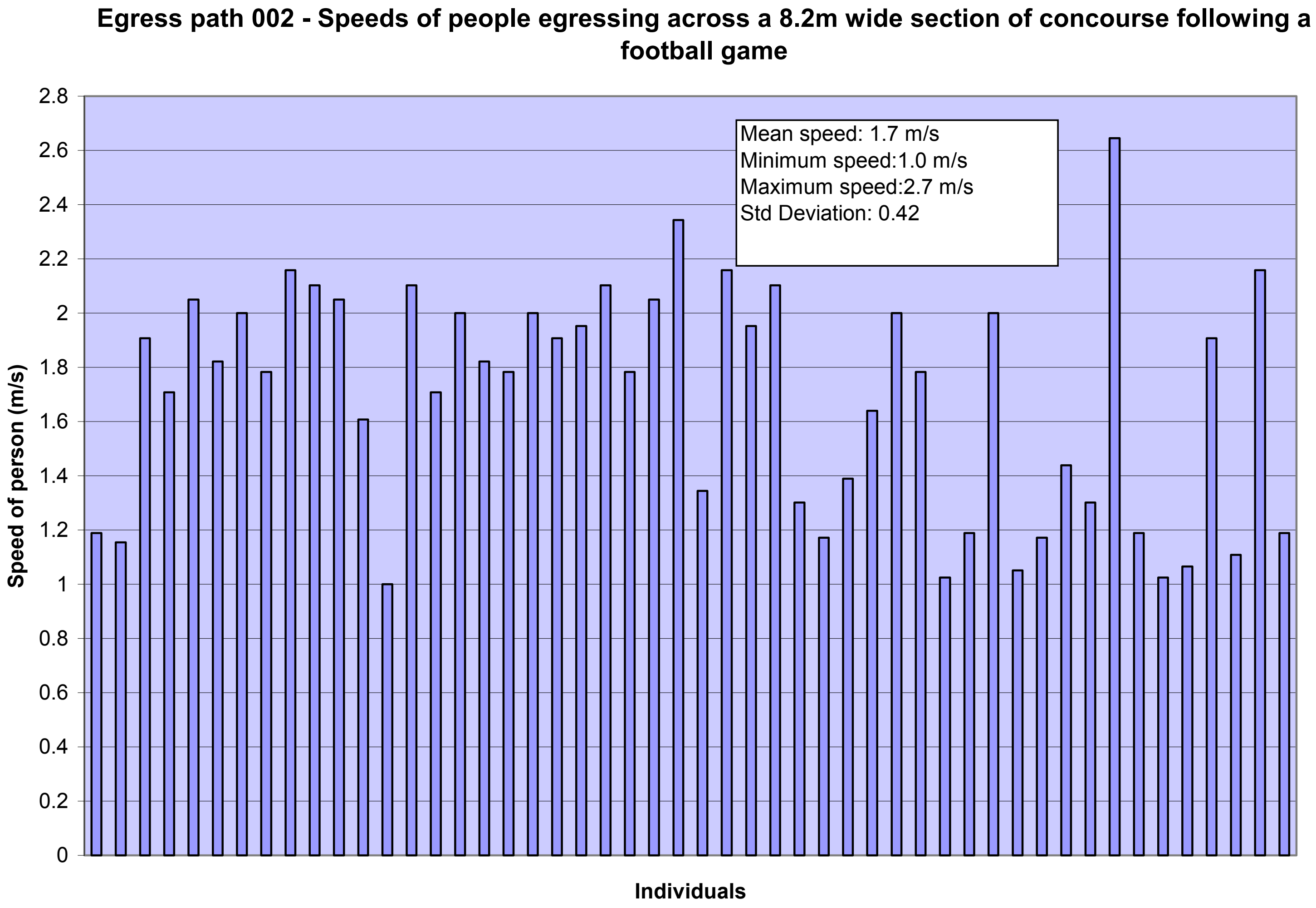


Figure 21: Egress Path 002 – egress speeds

5.2.3 Egress Path 3

This egress path involved movement down a divided staircase. In this instance the staircase was divided evenly in two by a central handrail. On side A of the stair a person with a walking stick had difficulty descending the stairs. Other patrons offered assistance. This created a congestion point or bottle-neck on one side of the staircase, reducing the effective width to C. C was variable and not measured. Travel times were recorded for individuals to descend only when people approached both sides of the stair within 1 second of one another.

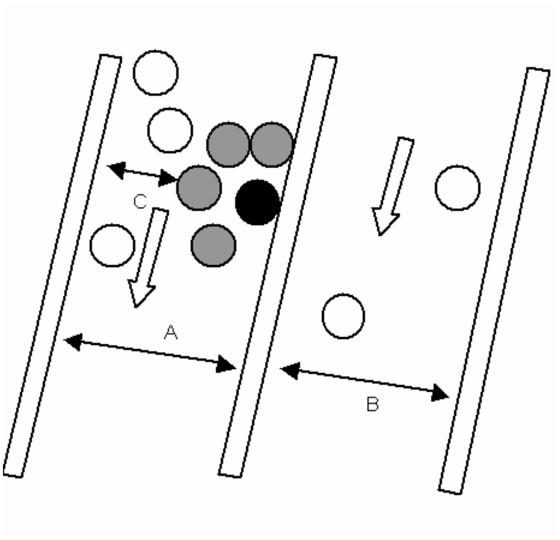


Figure 22: Sketch of egress path 3

Egress path 3 was unusual in that it presented the opportunity to observe a temporal disparity in movement on structurally identical stairs. A temporary congestion point was generated through slow movement of a member of the crowd. Speeds were compared for people initiating descent of the stairs at approximately the same time. Variance in speeds indicates that patrons using stair A were slower than for stair B. The graph on the following page (figure 23) shows that once the congestion point was established speeds reduced from >1m/s down to <0.4m/s. The mobility impaired patron took approximately ten times as long to descend the stairs as able bodied patrons on uncongested stairs (see figure 24). These results indicate the potential for temporarily congested flow to have a major impact on egress movement. This could have significant implications for stadia hosting functions that attract a high proportion of mobility impaired patrons.

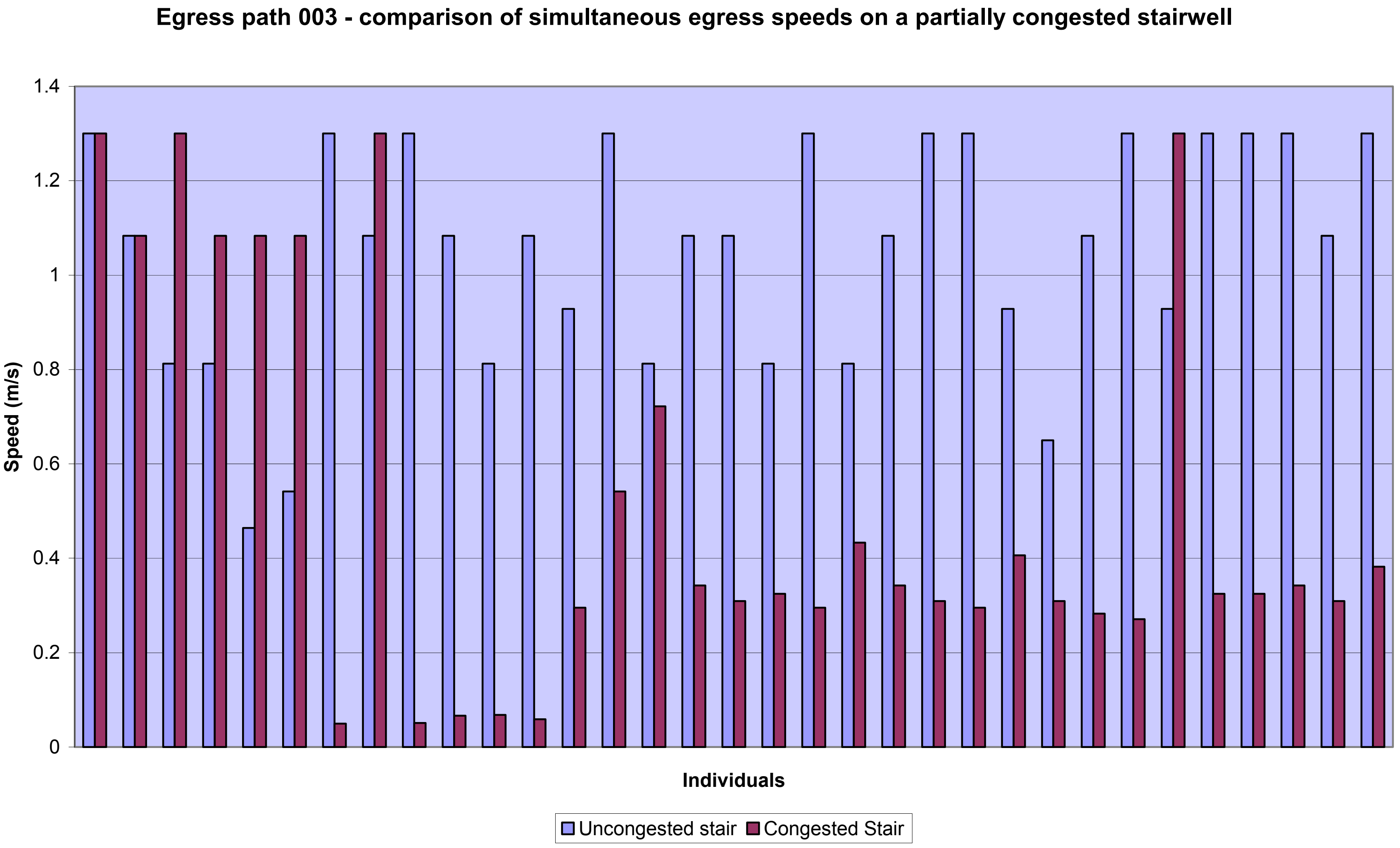


Figure 23: Egress Path 003 – egress speeds

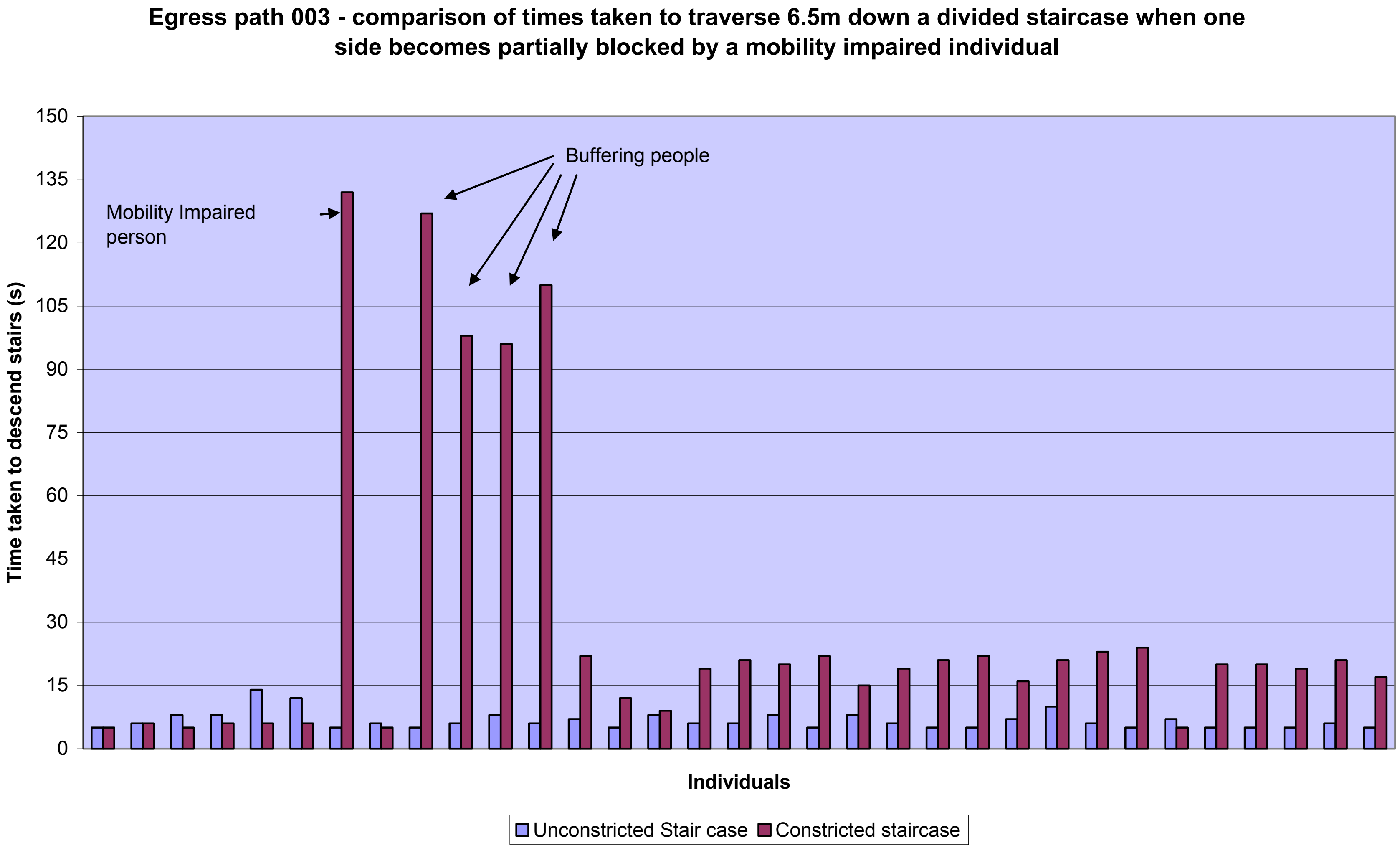


Figure 24: Egress Path 003 – egress duration

5.2.4 Egress Path 4

Egress path 4 produced a main body of activity within the first 2.5 minutes. Usage of this path was over relatively quickly compared to the total egress time for the stadium. An unusually large number of people used this egress path while other potential egress paths nearby remained relatively unused. This path was one of the main ingress paths before the game and that may have influenced egress path selection. Speeds (figure 28) were calculated from the time to travel between the dotted lines. This represents a distance of 3.5m. Densities were calculated at the time individuals crossed the first line. Speeds were relatively high for the densities recorded.

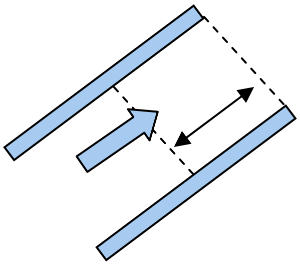


Figure 25: Sketch of egress path 4

This was one of the main ingress areas of the stadium and its egress usage may be a reflection of that. The contrast between maximum and sustained specific flow values (figure 27) may indicate that there was greater independent movement within this crowd than for others of lower effective width. The effective width in conjunction with familiarity with the path, due to this being a main ingress path, may have influenced speed. It appeared more as if people were swept along by the high density rather than experiencing restricted movement. This was a flat simple layout with no corners. Knowledge to that effect may have made people more assured about moving quickly at that order of density.

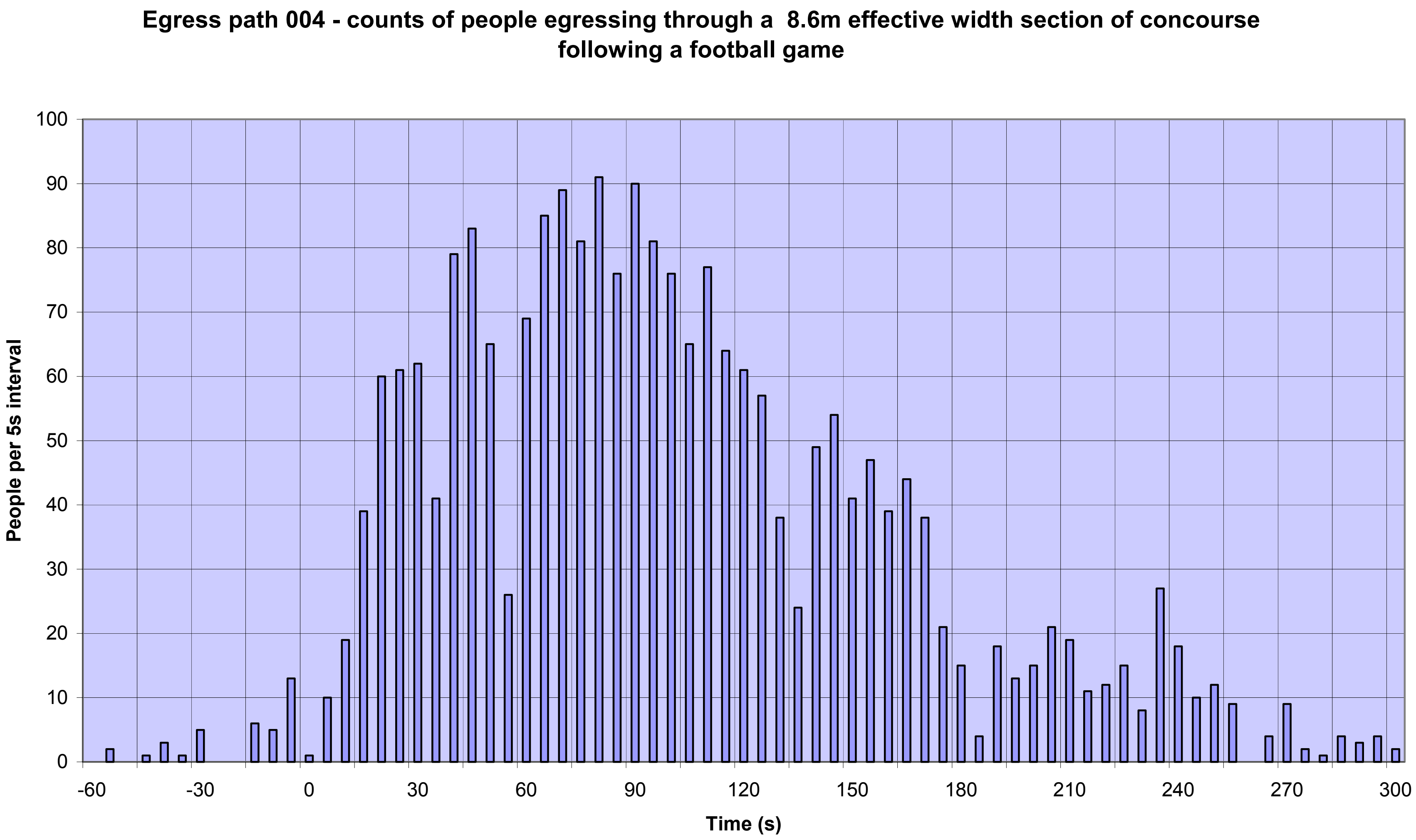


Figure 26: Egress Path 004 – egress as a function of time

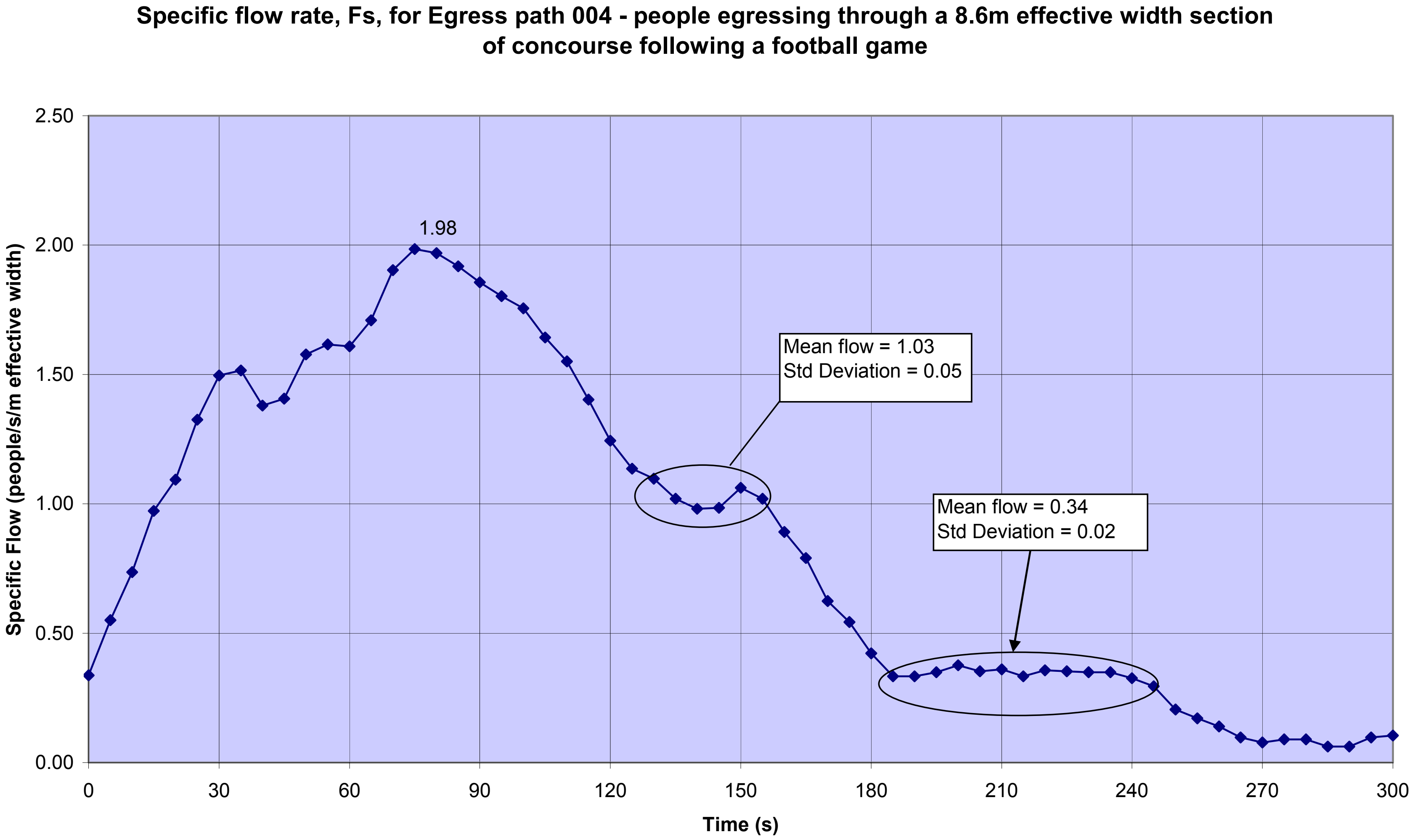


Figure 27: Egress Path 004 – specific flow as a function of time

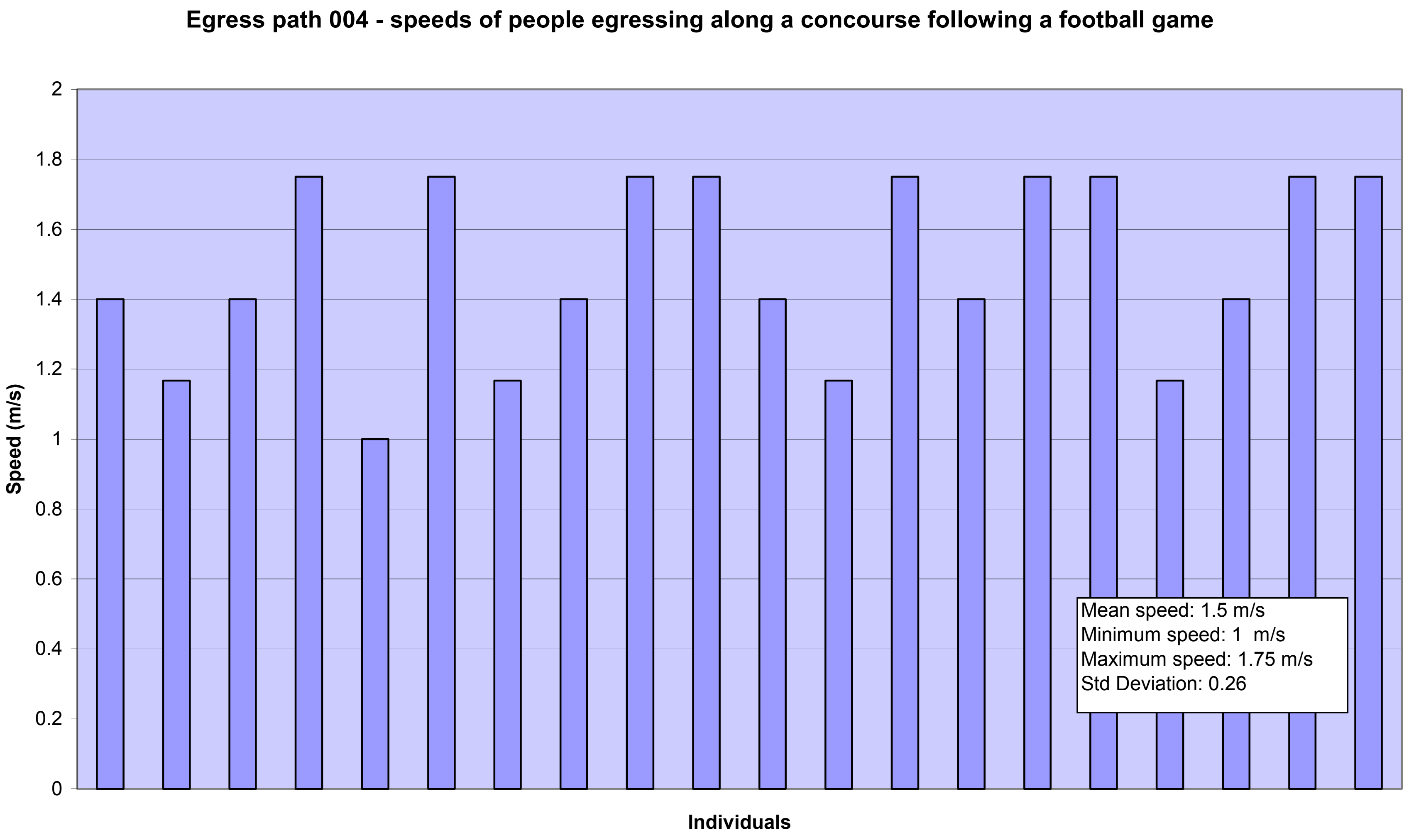


Figure 28: Egress Path 004 – egress speeds

5.2.5 Egress Path 5

This egress path was a ramp. It was intended to track people from the start of the ramp to where it met a level surface. Unfortunately due to the angle and lighting egress movement on this ramp was difficult to discern from the video footage. Consequently results were not recorded. It was noted that few people used the handrails, unlike observations of people on stairs. This may be one attribute to ramps that makes movement on them more akin to walkways than stairs.

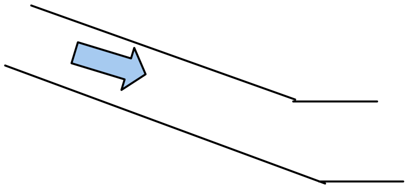


Figure 29: Sketch of egress path 5

5.2.6 Egress Path 6

This egress path was a vomitory amongst bleachers. The intent was to monitor the flows D, C and B into A. Once egress started a queue developed and people spread across the bleachers obscuring the egress flows. No results were discernible from the recorded footage.

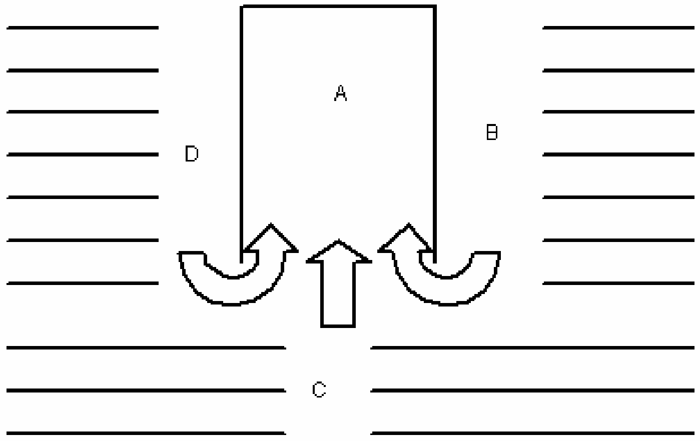


Figure 30: Sketch of egress path 6

5.2.7 Egress Path 7

Egress path 7 was a staircase. Egress was monitored from the landing to the ground. The length of the handrail was taken as the distance travelled. Egress appeared to occur in waves as if the rate of flow was determined higher up the stair or at a point along the egress path leading to the stair.

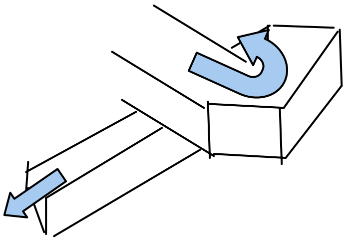


Figure 31: Sketch of egress path 7

The waves of activity that were observed are reflected in the way the specific flow fluctuated (figure 33). This may indicate that people in the area feeding the staircase waited for densities to decrease before entering the staircase. Both the anticipated specific flow and the density were greater than the figures suggested by Fruin[130] for this effective width. The density is very similar to that observed on walkways in other egress paths. This may be influenced by egress movement approaching the stairs and or by the size of the staircase. Presumably the greater the length of the staircase the greater its influence on densities of occupants.

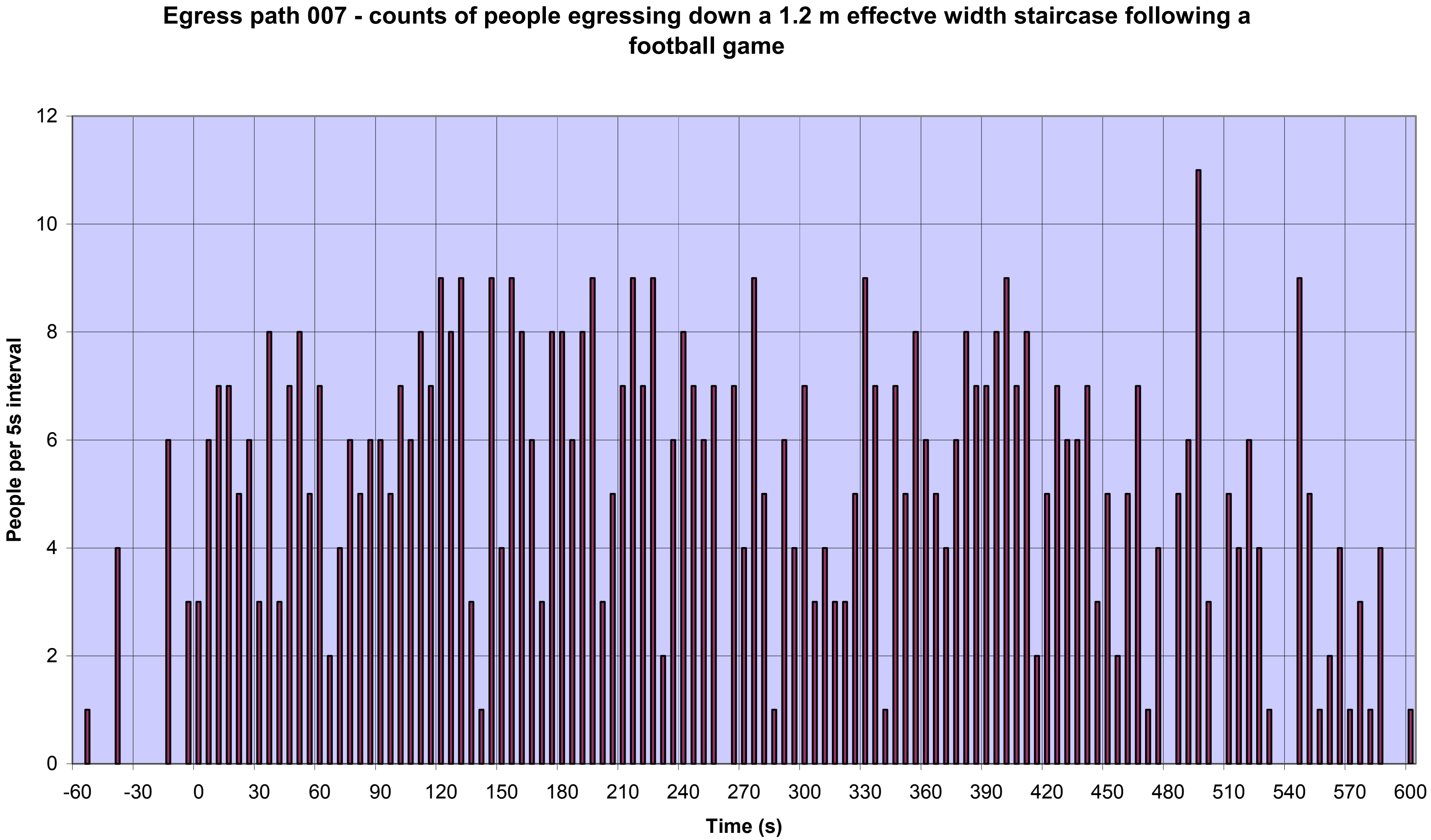


Figure 32: Egress Path 007 – egress as a function of time

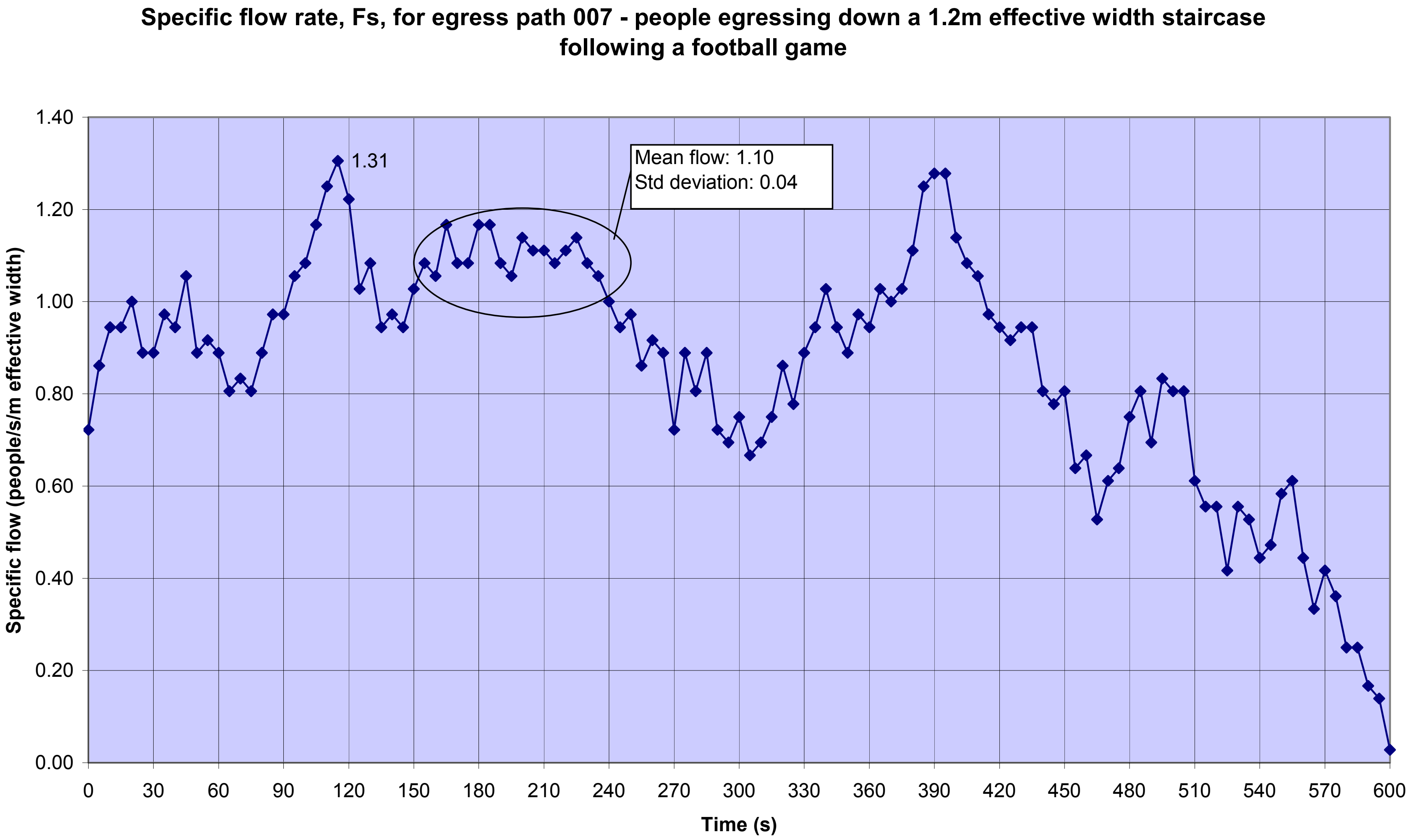


Figure 33: Egress Path 007 – specific flow as a function of time

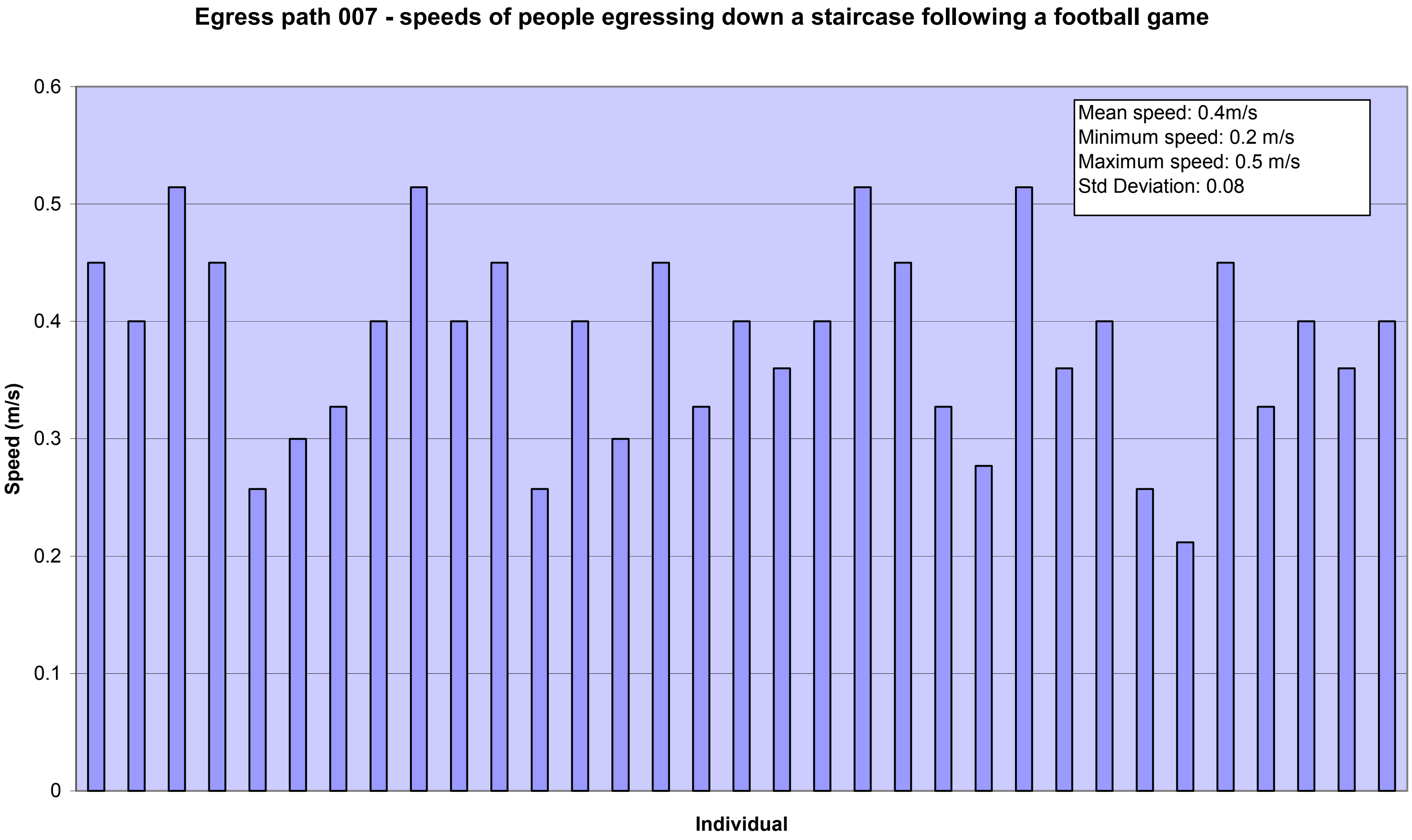


Figure 34: Egress Path 007 – egress speeds

5.2.8 Egress Path 8

Egress path 8 was bordered by a fence and a garden. Egress along this path appeared constant until the end. The flow stopped relatively quickly. The nearby egress paths were much wider than egress path 8 and better lit. It is hypothesised patrons selected these alternate routes in preference to egress path 8 once they had cleared. Because this was one of several routes leading to the final exit movement was most likely slow due to one of these other routes having preferential flow through the final exit.

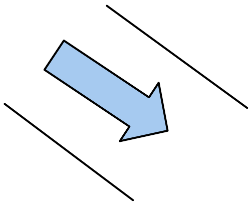


Figure 35: Sketch of egress path 8

Egress counts for egress path 8 (figure 36) appear to indicate pulses of movement within the crowd. This was not obvious on initial observation and is not reflected in the specific flow data (figure 37). Speeds of individuals within the crowd remained fairly constant throughout (figure 38). The sustained specific flow remains relatively low for the majority of the path use but the associated densities were considerably higher than those predicted for optimum specific flow by either Poyner et al or Fruin so this is not unexpected.

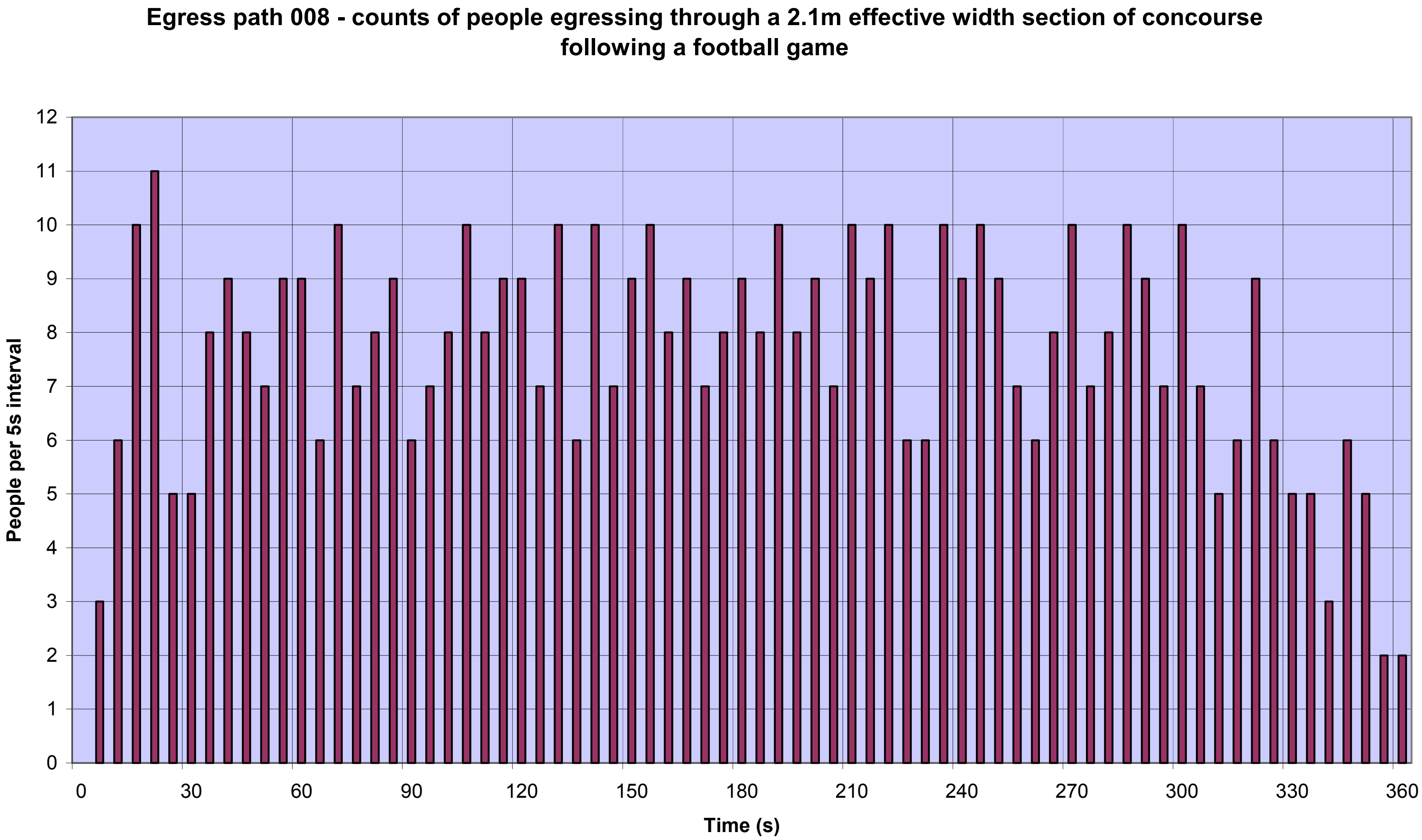


Figure 36: Egress Path 008 – egress as a function of time

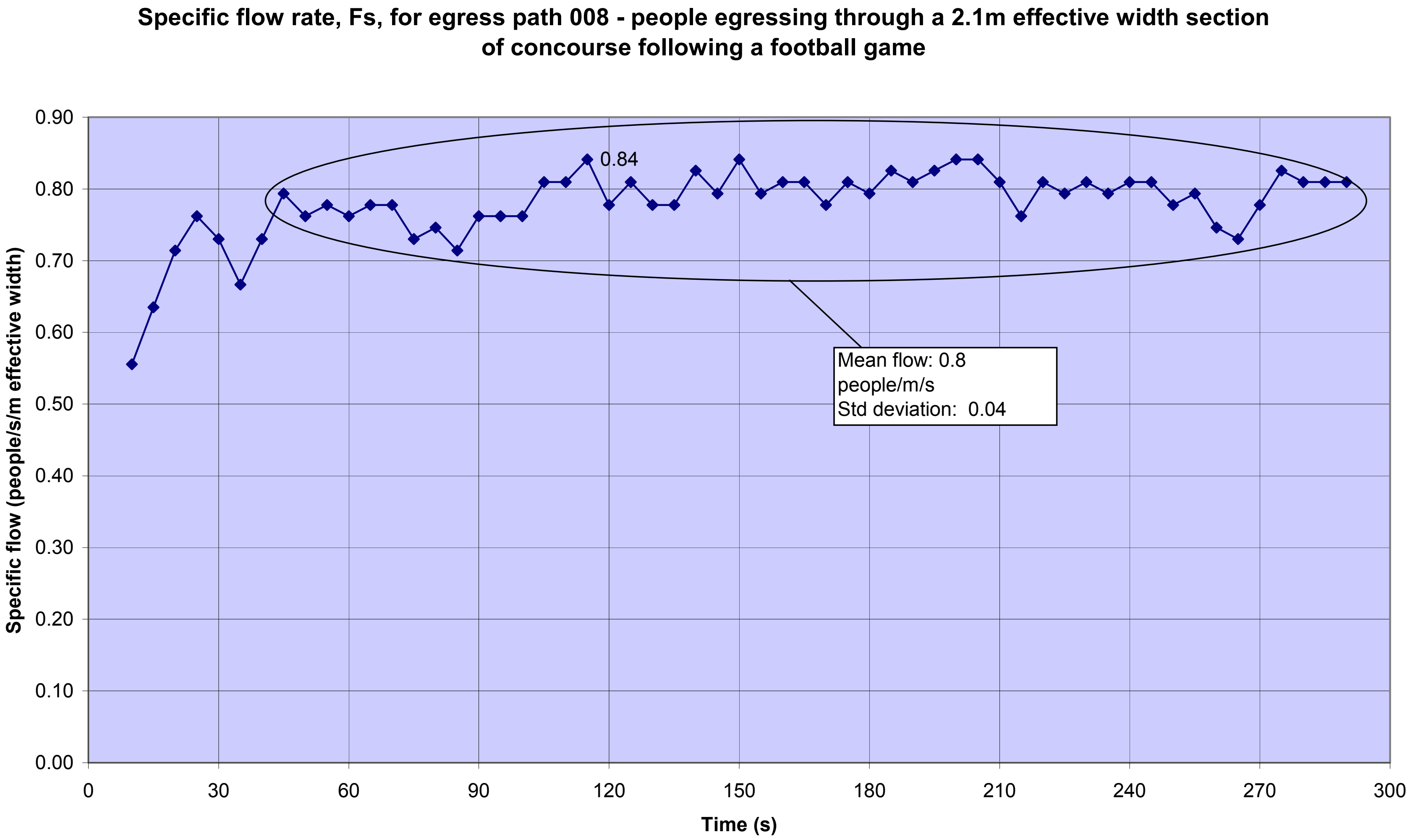


Figure 37: Egress Path 008 – specific flow as a function of time

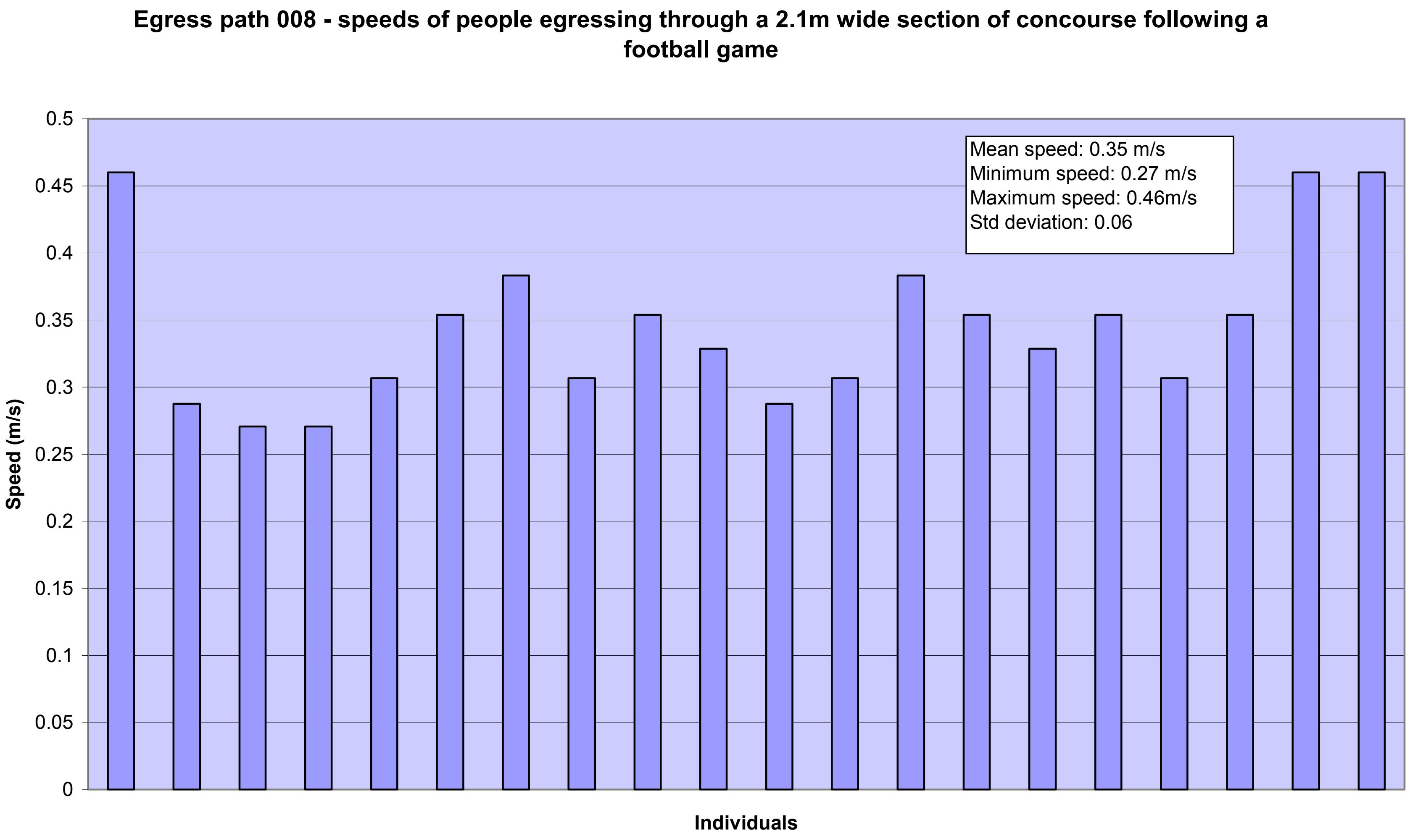


Figure 38: Egress Path 008 – egress speeds

5.2.9 Egress Path 9

Egress path 9 involved the intersection of a staircase and a walkway. The intent was to monitor egress across the base of the staircase. Unfortunately flow along the walkway to the side of the stair obscured the view of this. Rather than persevere another path (Egress path 10) was selected.

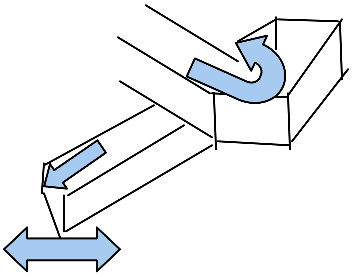


Figure 39: Sketch of egress path 9

5.2.10 Egress Path 10

Egress path 10 was located in a different area of the same stadium as egress path 9. This egress path was not monitored until six minutes after the game finished. Because of this a full profile of the path was not recorded. This was an interesting path because it narrowed due to a vehicle that had been parked along side it and a bend in the path. Counts were taken across the narrowest point and densities were calculated for the entire narrow section (marked by dotted lines).

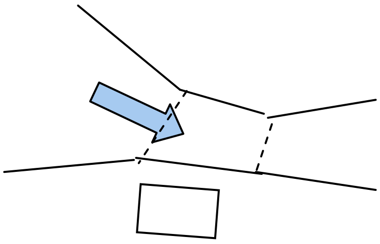


Figure 40: Sketch of egress path 10

Consistent flow was maintained for a large proportion of the time egress path 10 was monitored. This may indicate that due to the narrowing of the path specific flow was modified by increasing density. The densities measured for this pathway were not discernible at the narrowest point as distinct from the whole area of monitored travel. Both specific flow and mean speeds increased markedly towards the end of this paths usage indicating that the density for the majority of the monitored period was high enough to impact on movement along this pathway. The recorded speeds were relatively slow indicating that movement was inhibited. The effect of the narrowing path may have been exaggerated by the vehicle’s shape. Protrusions such as rear view mirrors may have exaggerated the observance of a boundary layer. This is speculation as a view of proximity to the vehicle was not obvious from the video footage. Regardless of the reasons a high density low speed crowd movement was observed.

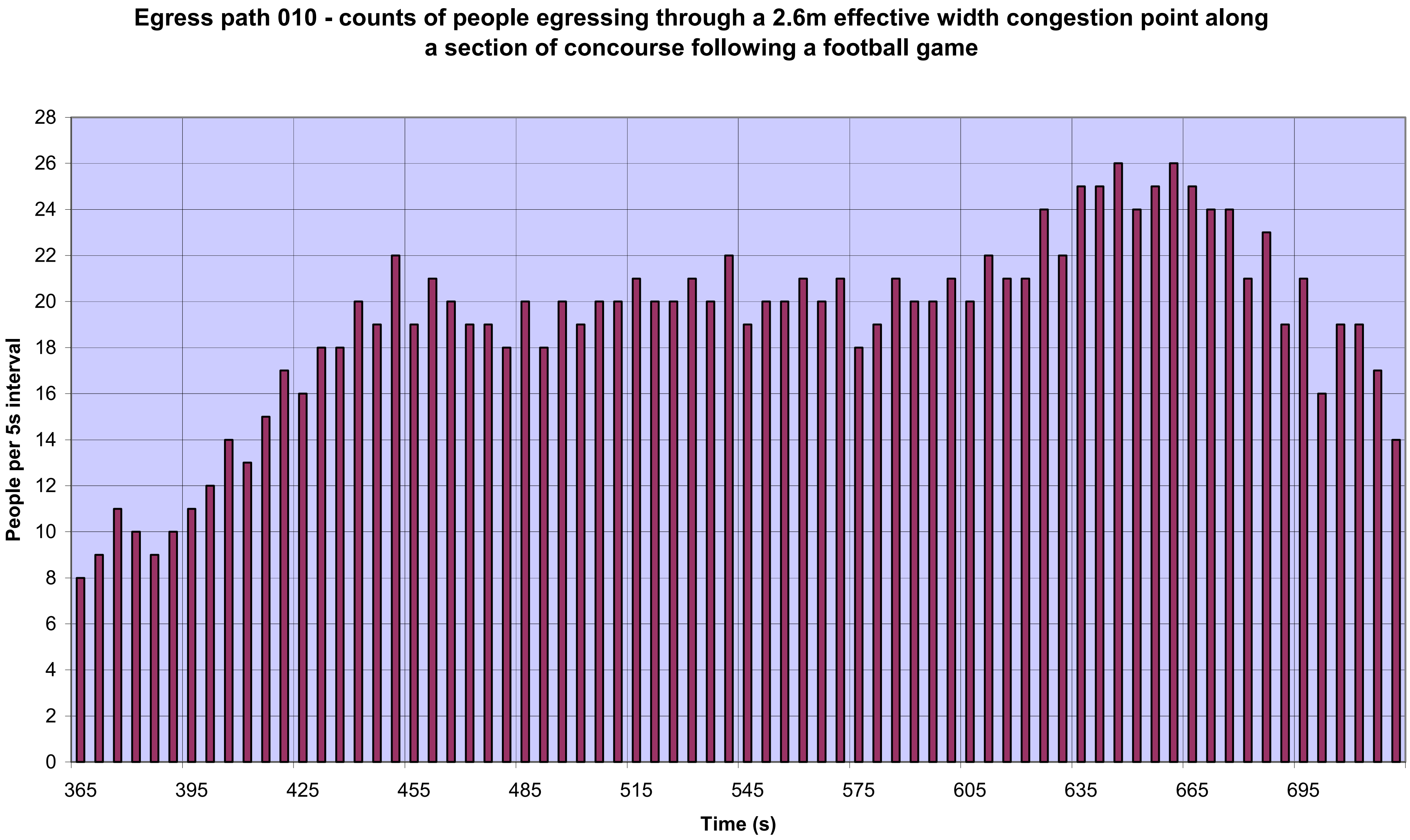


Figure 41: Egress Path 010 – egress as a function of time

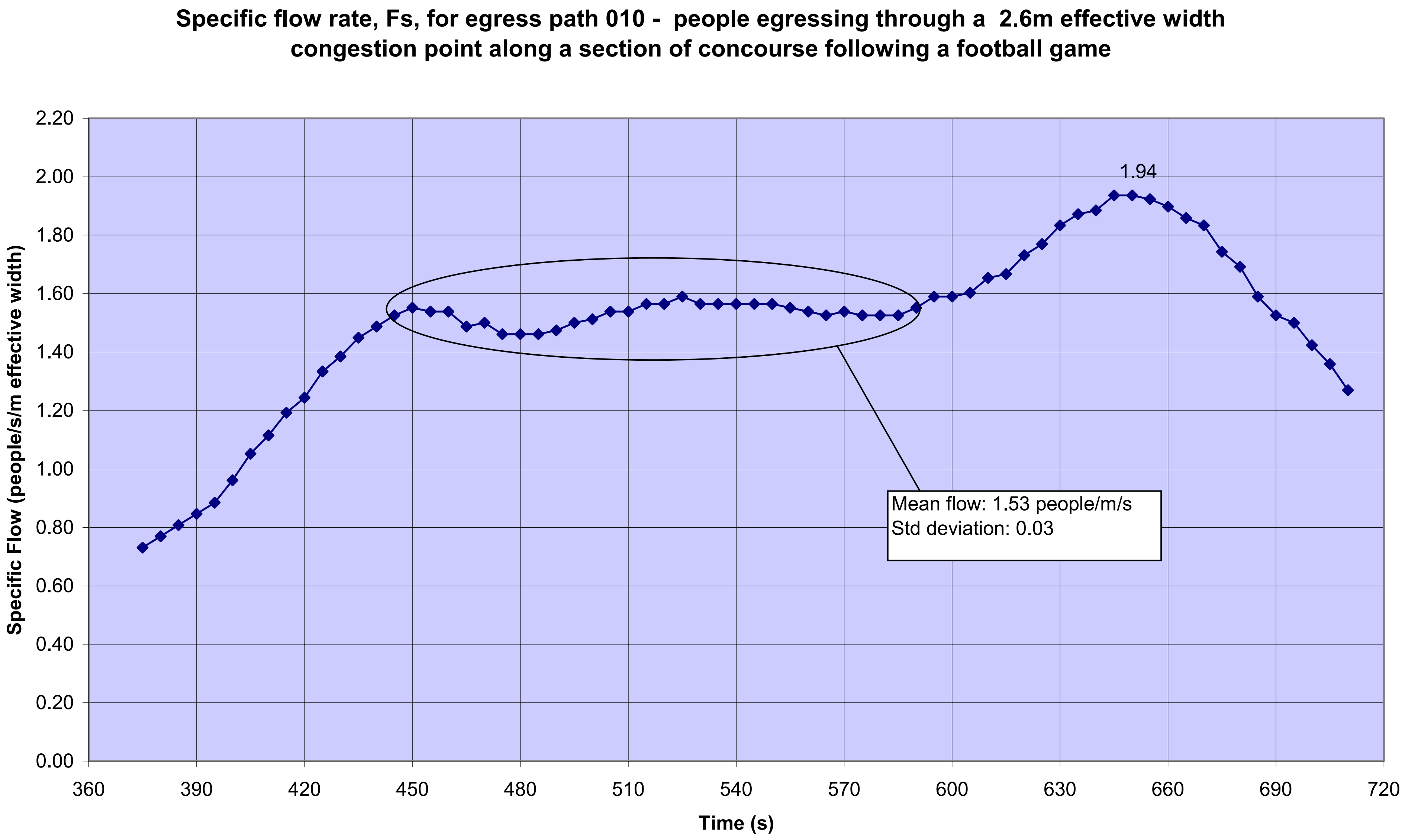


Figure 42: Egress Path 010 – specific flow as a function of time

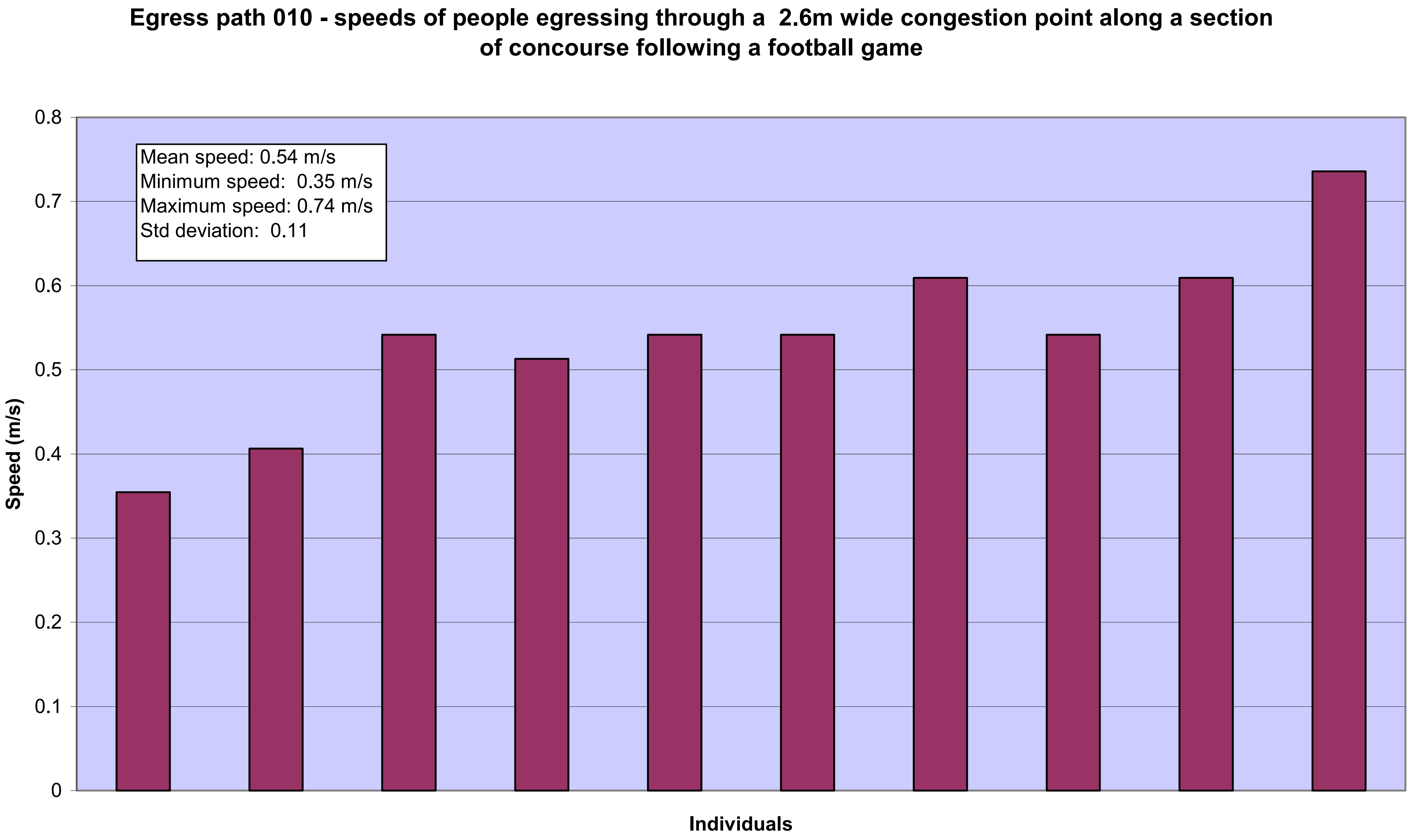


Figure 43: Egress path 010 – egress speeds

5.2.11 Egress Path 11

Egress path 11 was not strictly observation of *an* egress path. Rather, it was observation of egress preferences and influences from inside the arena. From the interior of the stadium the time to clear different sections of the bowl were recorded in order to determine if any part of the stadium experienced any notable congestion. This was done in order to try and glean greater understanding of observations from concourses. It also served to offer some insight as to the believability of simulated egress from the stadium. The stadium attendance was well below capacity and not all sections were occupied.

Stadium management provided floor plans of the stadium and these were used to map out the occupied areas. The stadium was divided into nine zones (I-IX). Up to four levels of seating were available in the various stands around the stadium so zones were subdivided into levels. Of the resulting sections only sixteen were in use during the game. The times for each section to empty were noted (table 9).

Zones observed	Level 4	Level 3	Level 2	Level 1
I				10.25pm
II	10.25pm			***10.28pm***
III	10.25pm	10.24pm		***10.30pm***
IV				***10.29pm***
V	10.24pm	10.23pm	10.24	10.26pm
VI	10.26pm			
VII				10.27pm
VIII	10.24pm			10.24pm
IX				10.27pm

10.27 all clear except italicised bold. All clear in 8 minutes

Table 9: Egress Path 11 Zone Clearance

No queuing was observed at any of the vomitories. There was a six minute difference between the first and last section clearing. The majority of the occupants had left the bowl in less than 5 minutes. The oldest occupied stand (Zones II-IV on Level 1) was the slowest to clear. The vomitories for this stand are located further back from the arena than in any of the other stands. The increased path distance will have contributed to the longer egress time. In most cases people left through the nearest vomitory to their seat. A minority of people walked to other vomitories. This action may have been more pronounced if there had been congestion at any of the vomitories.

5.2.12 Egress Path 12

Stadium management suggested that the intersection of a stairwell and vomitory at this egress point would be suitable for recording merging flows. Unfortunately neither the stairwell nor the vomitory experienced sufficient flow to obtain any useful data. The reason that this egress path was not heavily used on this day was unknown.

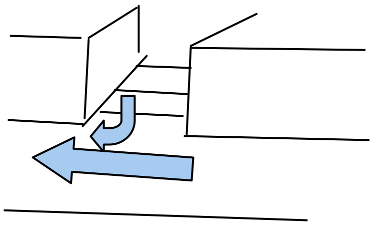


Figure 44: Sketch of egress path 12

5.2.13 Egress Path 13 and 14

Egress path 13 monitored the same area as an egress path 14 but was filmed during half time rather than post game. Flow in this video footage went in two directions and was near retail concessions. Speeds were recorded for a section of the concourse (indicated by dashed lines in figure 45). Movement along the concourse occurred in two directions and a recessed area with concessions provided two way flow to and from the concourse. The flow was complex in this area hence it was monitored at both half time and full time. The direction of flow was more varied during half time (Egress path 13). This was probably due the large area of seating that was serviced by the concessions.

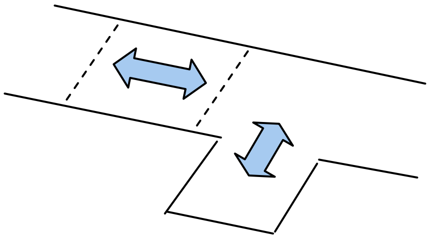


Figure 45: Sketch of egress path 13 & 14

Egress path 13

The most interesting feature of this profile is that Egress path 13 produced higher flow rate values than egress path 14. This may be due to people accessing the concessions and returning as opposed to the end of the game when return movement is uncharacteristic.

There was a discernable decrease in movement towards the middle of half time which was discernible in both speed and specific flow data. This may be attributable to queuing at the concessions.

Egress path 14

Egress path 14 experienced a wide range of speeds with the fastest movement occurring towards the end of the egress. Notably greater speeds were achieved post game (egress path 14) than at half time (egress path 13) despite egress path 13 having higher flows.

The maximum specific flow in both egress path 13 and 14 was lower than for most of the other egress paths observed. In both egress paths 13 and 14 a large proportion of the crowd appeared to be milling rather than egressing. This, and the multidirectional flow, may have contributed to these results being lower than those observed in other egress paths.

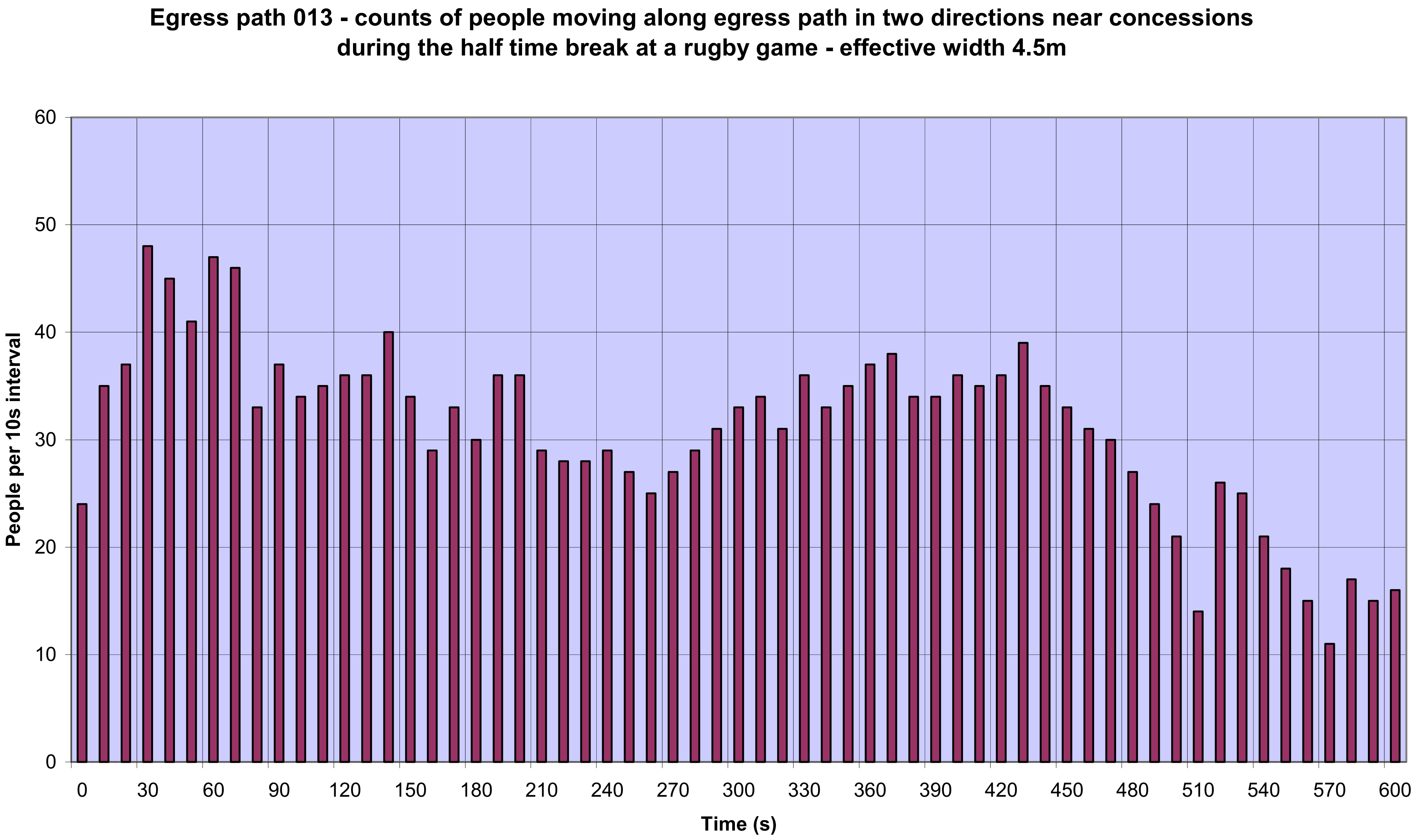


Figure 46: Egress Path 013 – egress as a function of time

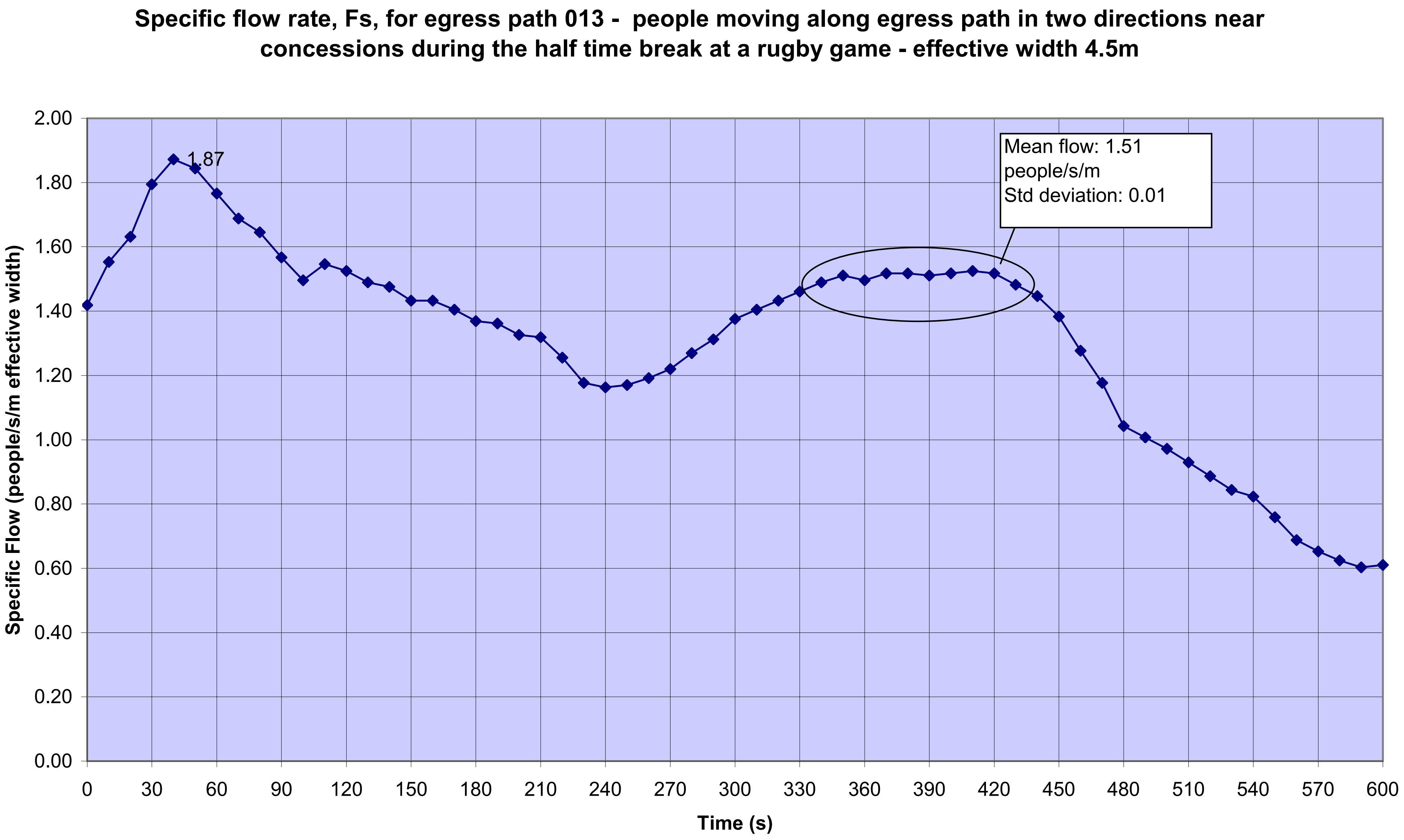


Figure 47: Egress Path 013 – specific flow as a function of time

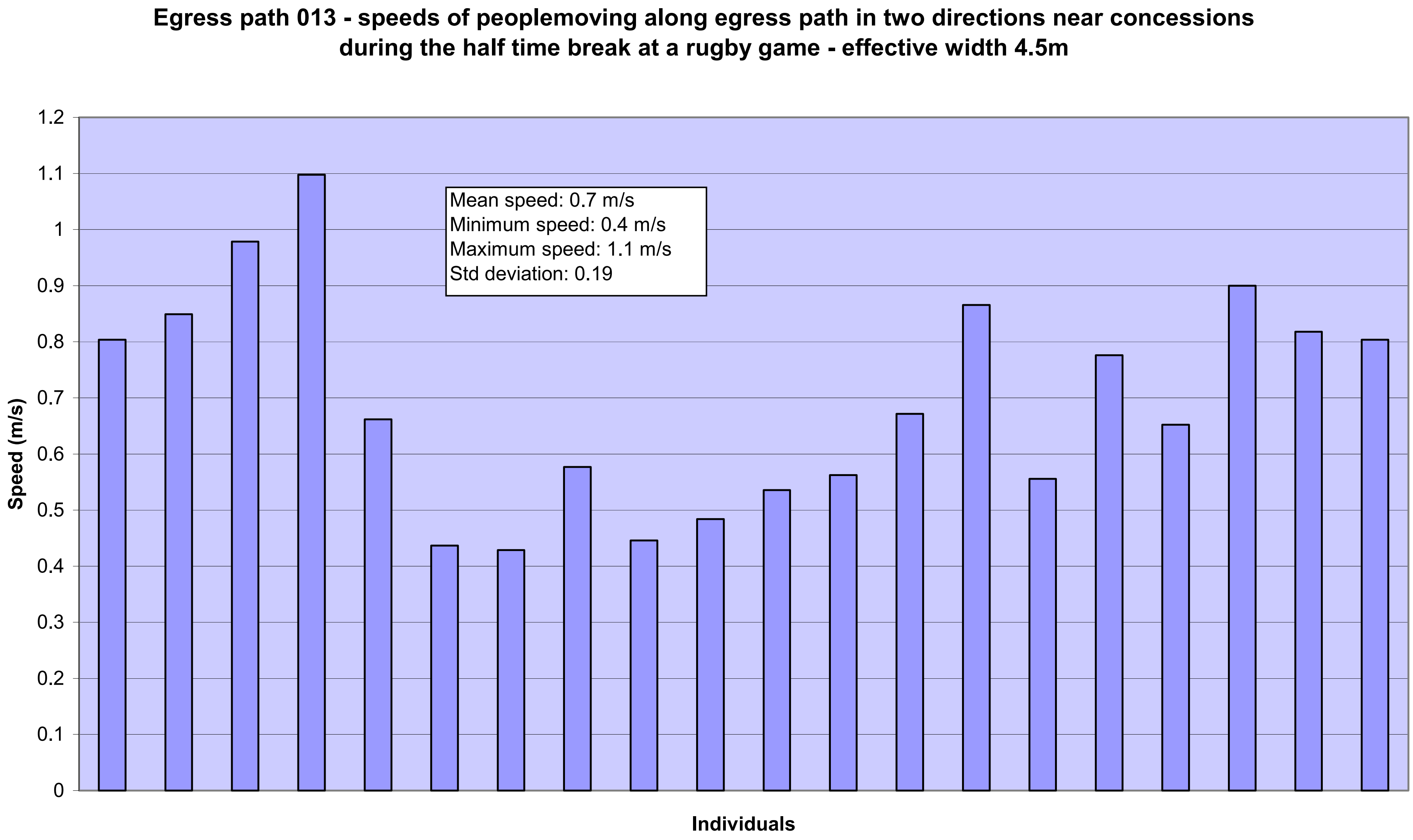
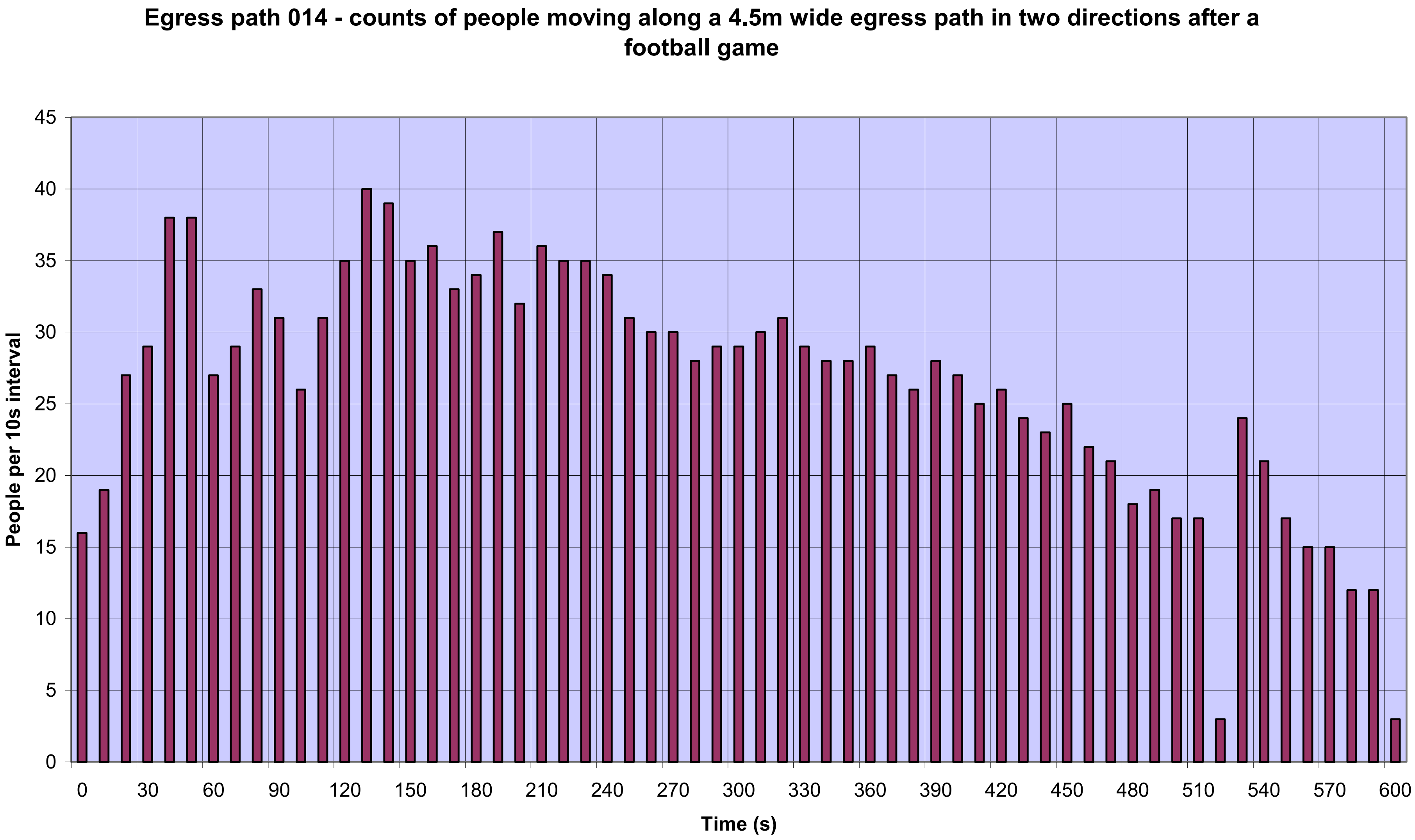


Figure 48: Egress path 013 – egress speeds



Egress path 014 - counts of people moving along a 4.5m wide egress path in two directions after a football game

Figure 49: Egress Path 014 – egress as a function of time

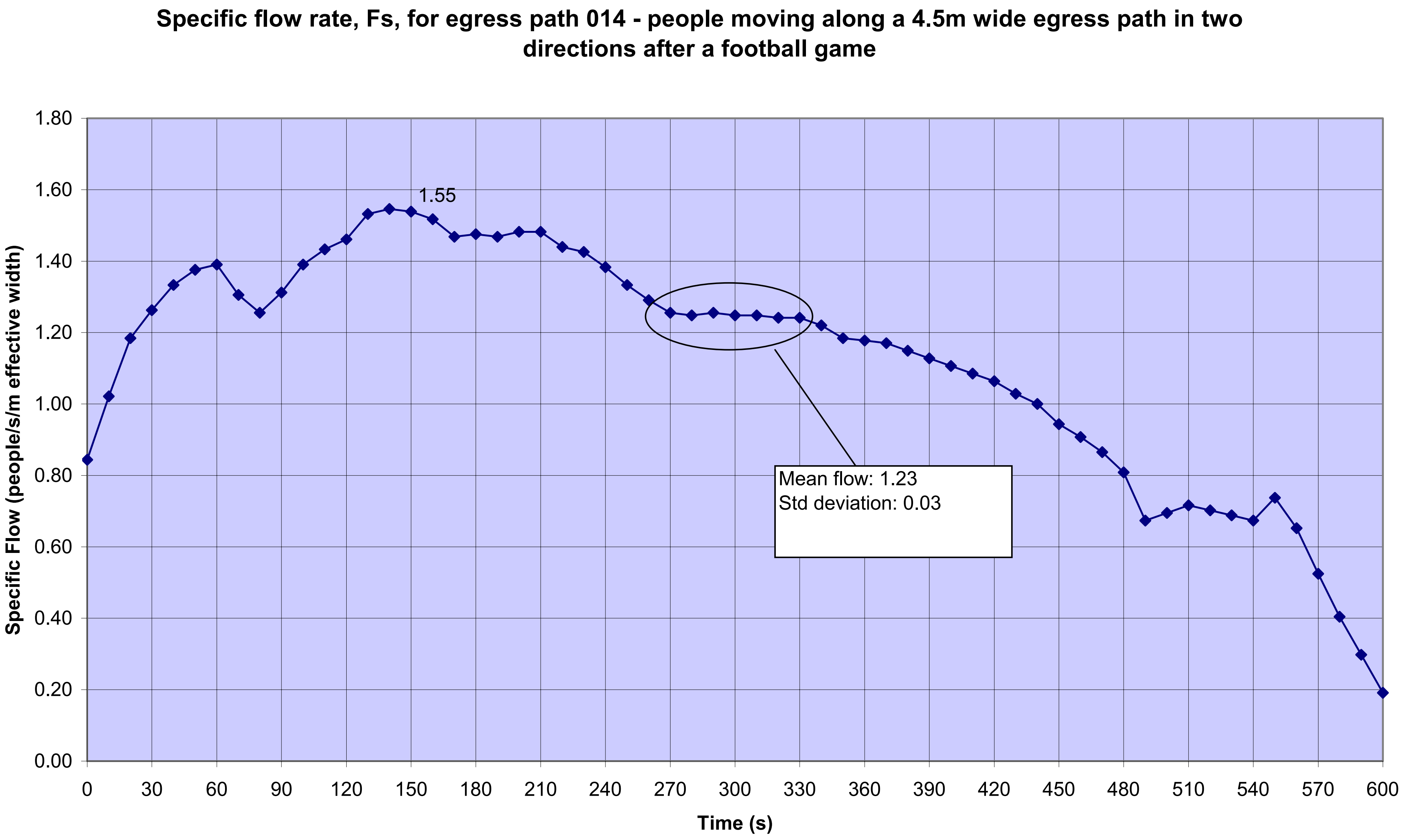


Figure 50: Egress Path 014 – specific flow as a function of time

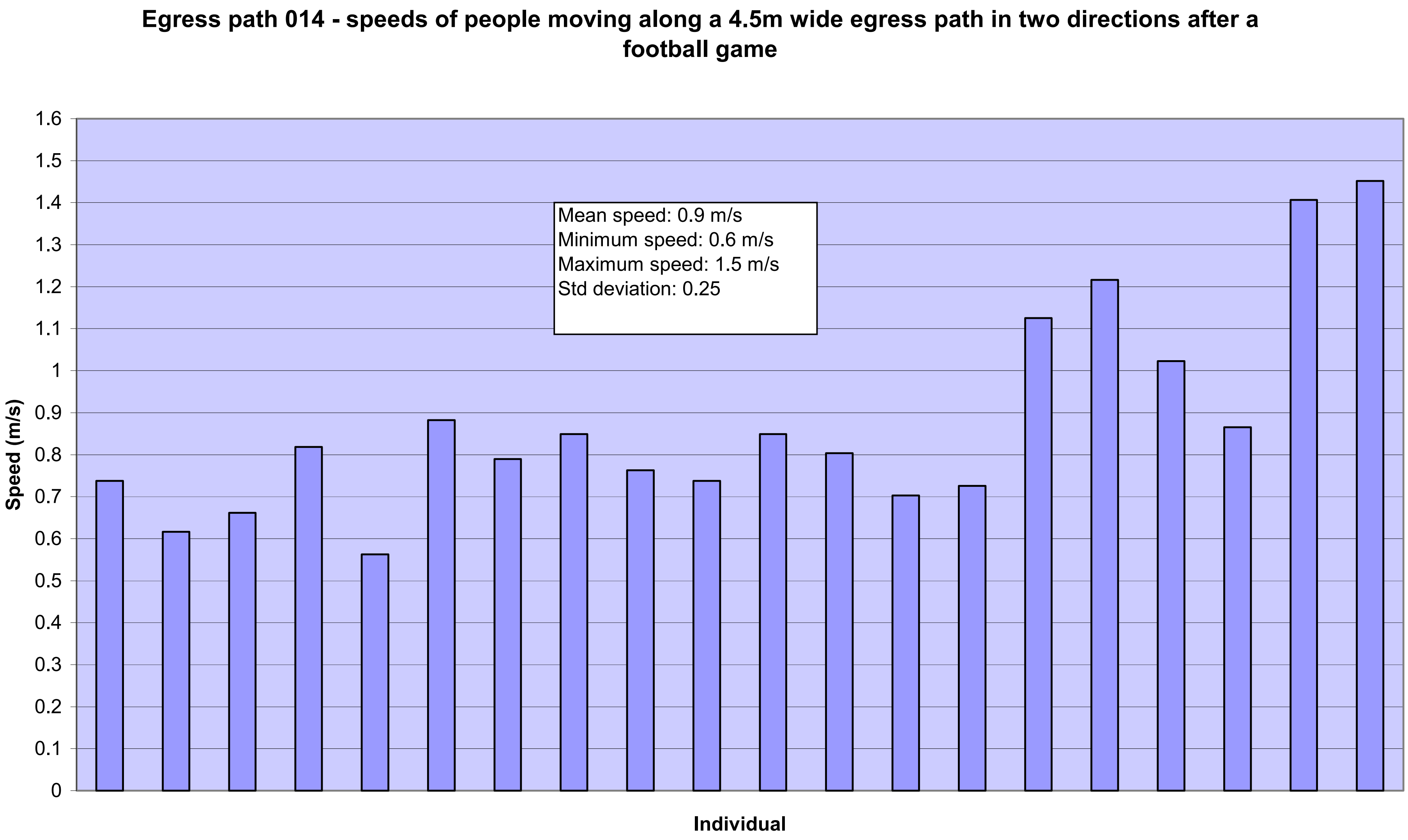


Figure 51: Egress Path 014 – egress speeds

5.2.14 Egress Path 15

Egress path 15 was an intersection between terraces and concourse. Egress through the intersection was monitored. A large proportion of the crowd on the terraces walked past this egress point and queued to exit onto the concourse at a point closer to the final exit. Flow through this exit was never slowed to the point of queuing.

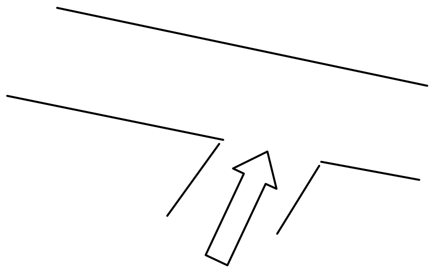


Figure 52: Sketch of egress path 15

The maximum flow rate at egress path 15 was rapidly reached (figure 54) and a high flow was maintained from that point for approximately 3 minutes. This egress path exhibited the highest sustained specific flow of any of the observed walkways. It also closely matched calculated flow using the Green Guide. The flow of people with time dropped off markedly after 3.5 minutes. The reason for this may be that preferential pathways had cleared and these alternate routes were used.

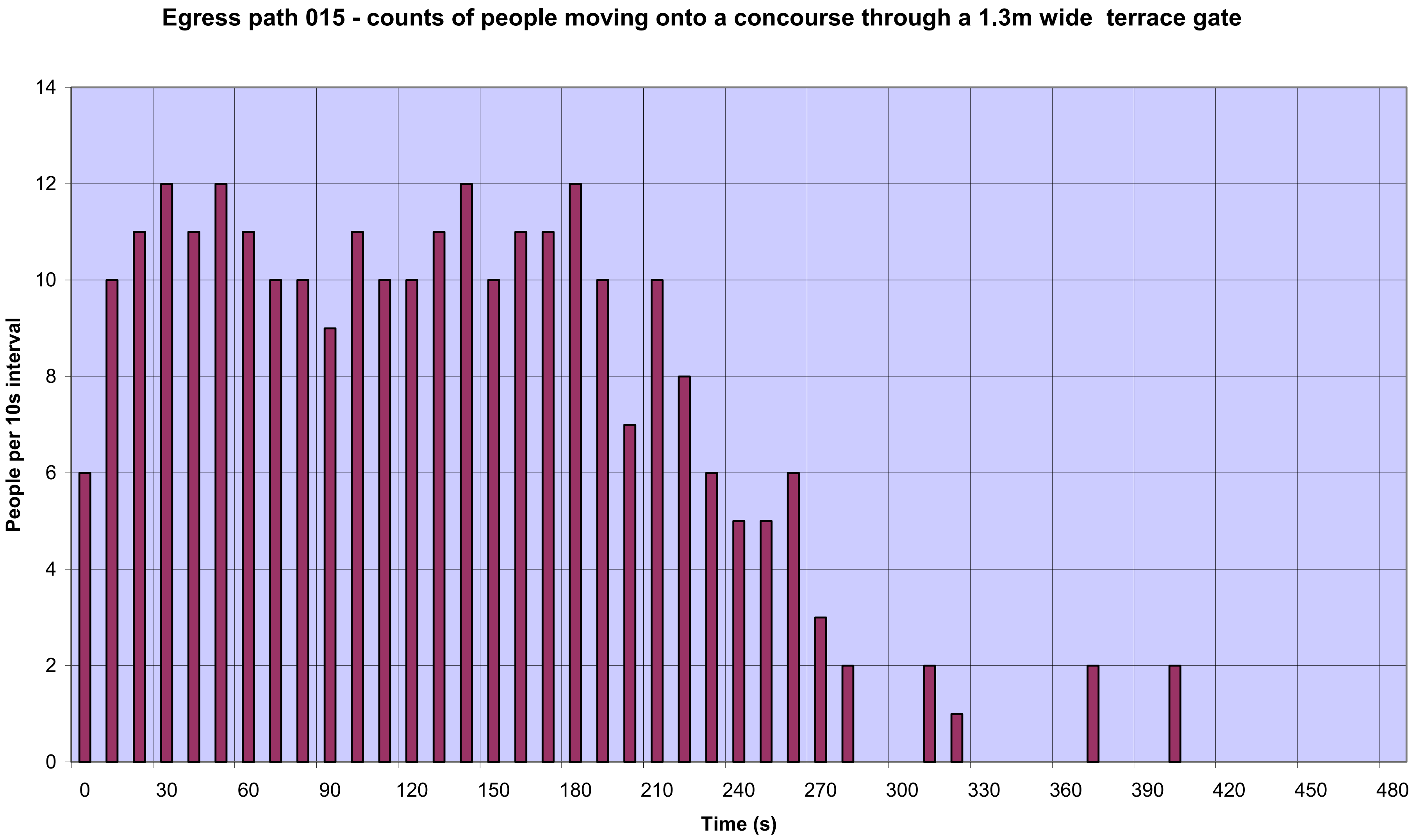


Figure 53: Egress Path 015 – egress as a function of time

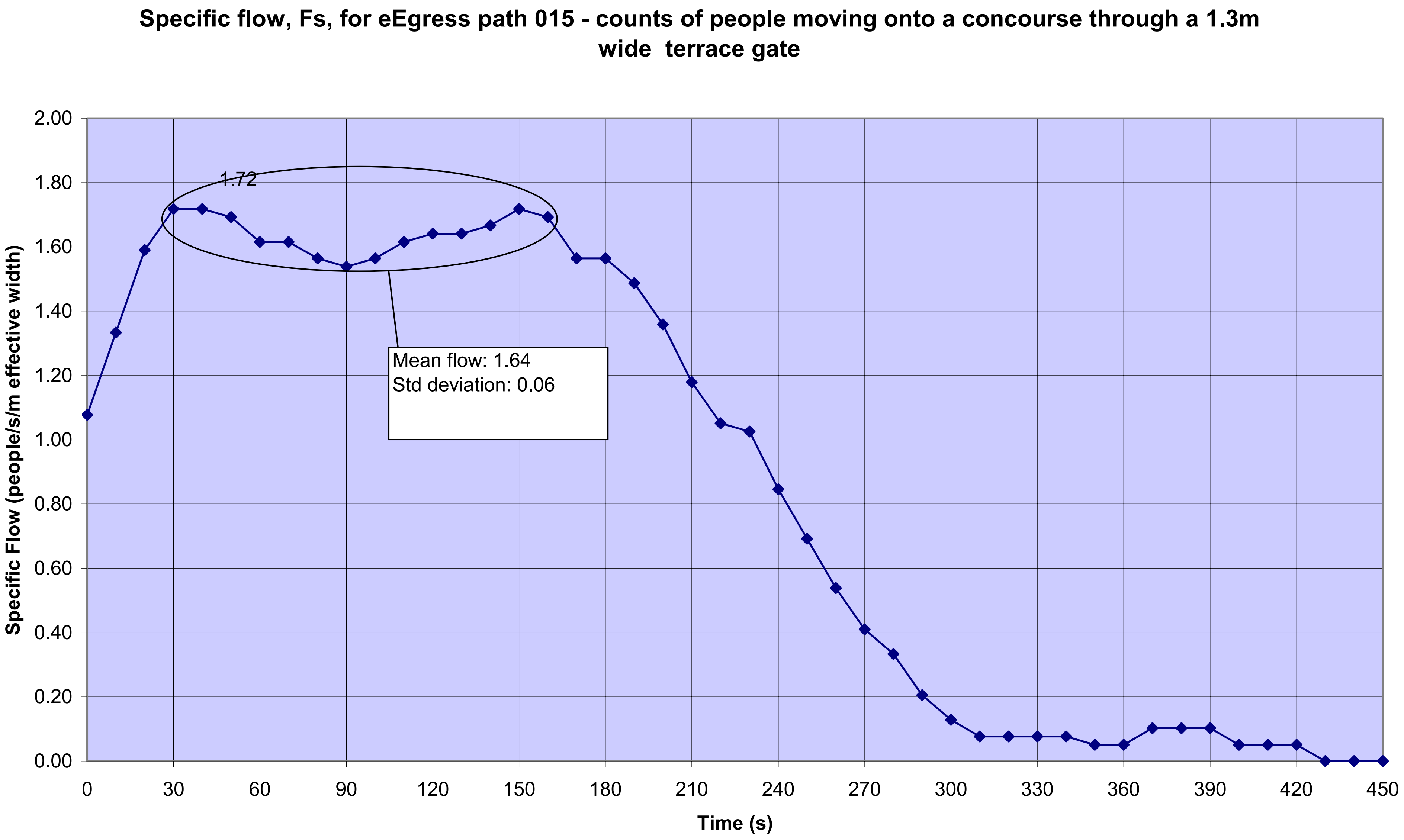


Figure 54: Egress Path 015 – specific flow as a function of time

5.2.15 Egress Path 16

Egress path 16 involved the intersection of a vomitory with a concourse at half time during a game. Relatively little movement occurred through this vomitory. There was insufficient movement to warrant analysis.

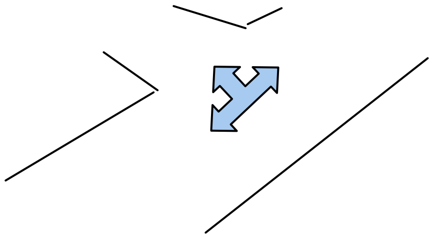


Figure 55: Sketch of egress path 16

5.2.16 Egress Path 17

Egress path 17 was post game observation of a walkway between a stand and the arena. This was one of the few incidents of queuing that were observed. The cause of the queuing was a temporal congestion point generated by a football player at the edge of the arena engaging fans. Due to the angle of observation and density of people it was not possible to discern milling fans from egressing patrons. Because of this density of the moving crowd and flow rates could not be acquired from the video footage of movement past the congestion.

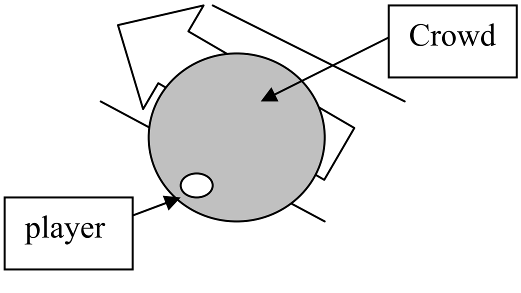


Figure 56: Sketch of egress path 17

5.2.17 Egress Path 18

Egress path 18 concerned patrons egressing through a vomitory. Data was recorded of the number of people who exited. This egress path was specifically simulated using Simulex32. It was represented as a link (indicated by the double headed arrow in figure 57) between the inside of the bowl and the concourse. A comparison of simulation data and actual data is described in section 5.2 Simulation.

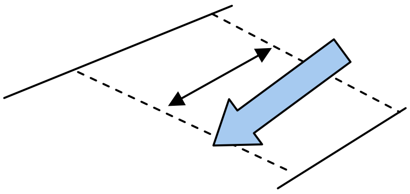


Figure 57: Sketch of egress path 18

Actual egress through this vomitory was relatively low. Sustained flow was not observed and it cleared within six minutes. The observed egress exhibited quite a high specific flow with the maximum specific flow being reached relatively quickly. This may have been due to the vomitory's distance from the main exit. Although the specific flow is high, other observed specific flows were similar and the value is not outside the expected range.

5.2.18 Egress Path 19

Egress path 19 was similar in layout to egress paths 4 and 8. Patrons experienced free movement but the two points selected for measuring the travel distance were difficult to discern on the video footage. Consequently this data has not been analysed.

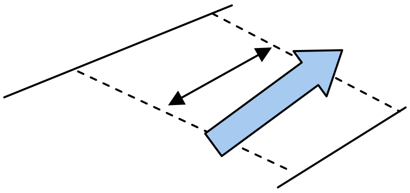


Figure 58: Sketch of egress path 19

5.2.19 Egress Path 20, Egress Path 21

This egress point was observed during half time (egress path 20) and at full time (egress path 21). At this intersection flow from one direction interfered with flow from another direction. Egress at this stadium took longer than any other. This was due mainly to congestion at this point.

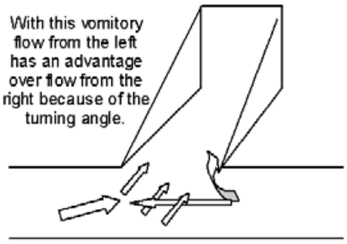


Figure 59: Sketch of egress path 20 & 21

Analysis of this path was not possible due to its complexity. Movement at the intersection consisted of crossed flow, merging flow and queuing. Similar congestion patterns were observed at half and full time although the congestion was far more pronounced at full time.

5.2.20 Egress Path 22

Video footage of this egress point was accidentally erased before it could be analysed. This egress path had a similar layout to egress path 9.

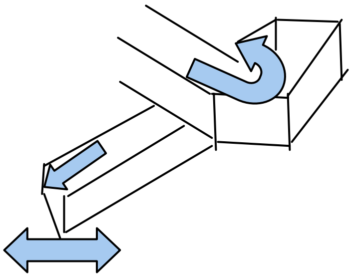


Figure 60: Sketch of egress path 22

5.2.21 Egress Path 23

Egress path 23 was observed outside a stadium, along a street. Following a football game crowd movement along the footpath between a street sign and a lamp post was observed (figure 61). This was done to determine if there was any behavioural difference between people inside the stadium and those outside the stadium. It was found that there were differences. The most obvious difference was that people inside the stadium appeared to focus on their path whereas people outside the stadium often looked around assessing the surroundings. Another difference was that people did not adhere to the pathway. Rather than remain on the footpath many walked on the road or across the road into slow moving traffic. Movement in the stadium was far more structured and considerate of others than was observed outside of the stadium.

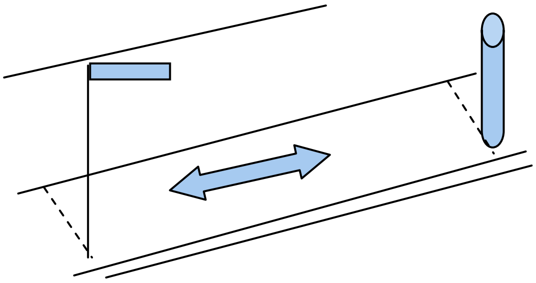


Figure 61: Sketch of egress path 23

5.2 Simulation

Three stadia were initially selected for modelling and calculations comparison with observational data. It was envisaged that one stadium would be simulated in its entirety, one stadium's embankment/terrace area and associated shared pathways would be modelled and one stadium's slowest evacuation point – cross flow near a vomitory (egress path 20), would be simulated.

Problems Encountered

- Evacuation simulations of the embankment and of egress path 20 proved beyond the capabilities of the simulation software.
- Evacuation of the embankment would not run due to the high population density – people from different directions converged and jammed up within the first few seconds. Modelling of egress path 20 succumbed to similar problems.
- Complete evacuation of the third stadium proved more successful, but only after the floor plans were modified. An outline of the modelling results of this stadium are summarised on the following pages.

Simulation of a Vomitory (egress path 18)

In comparing egress measurements from observation and simulation (figure 62) there is a significant difference between the anticipated specific flow and the observed specific flow. The simulation only achieved 25% of the cumulative egress observed for this vomitory. The maximum specific flow was significantly lower in the simulation than that which was observed.

Calculated egress flow values based on the effective width (1.4m) produce values that are more conservative than were viewed. Simulation produced more conservative results again.

	Observed	Calculated (Fruin)	Calculated (Poyner)	Simulation
Maximum F_s (people/second/metre effective width)	1.88	1.40	1.80	0.82
F_c (people/minute)	158	118	151	69

Table 10: Estimated flows for egress path 18

The observed egress was closest to calculations based on values from Poyner et al's study, which are advocated in the Green Guide. This stadium's egress paths were developed using Green Guide values. Observed egress times from the stadium as a whole closely matched the recommended values given in the Green Guide.

In reviewing the simulated data it was determined that other vomitories closer to the final exits of the stadium were chosen in preference to this one. Hence individuals within the model moved around the interior of the bowl, past this vomitory, and congregated around vomitories that were closest to final exits rather than using the most proximate vomitory to their starting position.

In comparing simulation data for an entire stadium with that observed for the same stadium, the simulation was found to be grossly conservative in anticipating exit usage rates. The main reason for this was the disproportionate use of vomitories. As outlined in previous examples, patrons at stadia exhibit a tendency to select the shortest route to their desired exit but this is not carte blanche. Ease of access to the shortest route reduces the proportion of people that behave in this manner. The simulation does not take this into account and so more people select the shortest route than is observed. In the simulations performed this meant that some vomitories were not used in preference to others. This led to overloading of the preferred vomitories to the exclusion of others nearby. A disproportionate number of occupants in the simulation moved around the seating area and selected the vomitories that were closer to the nearest final exit rather than selecting the nearest vomitory and moving around the concourse as is observed in an actual egress. This accounts for some of the variations between the observed and simulated usage of egress path 18. If there had been more final exits evenly placed about the stadium the effect of shortest route selection would have been less pronounced and the simulation would have more closely matched reality. Stadia are generally built with a few very wide final exits rather than many smaller ones in order to better utilise space, and direct flow.

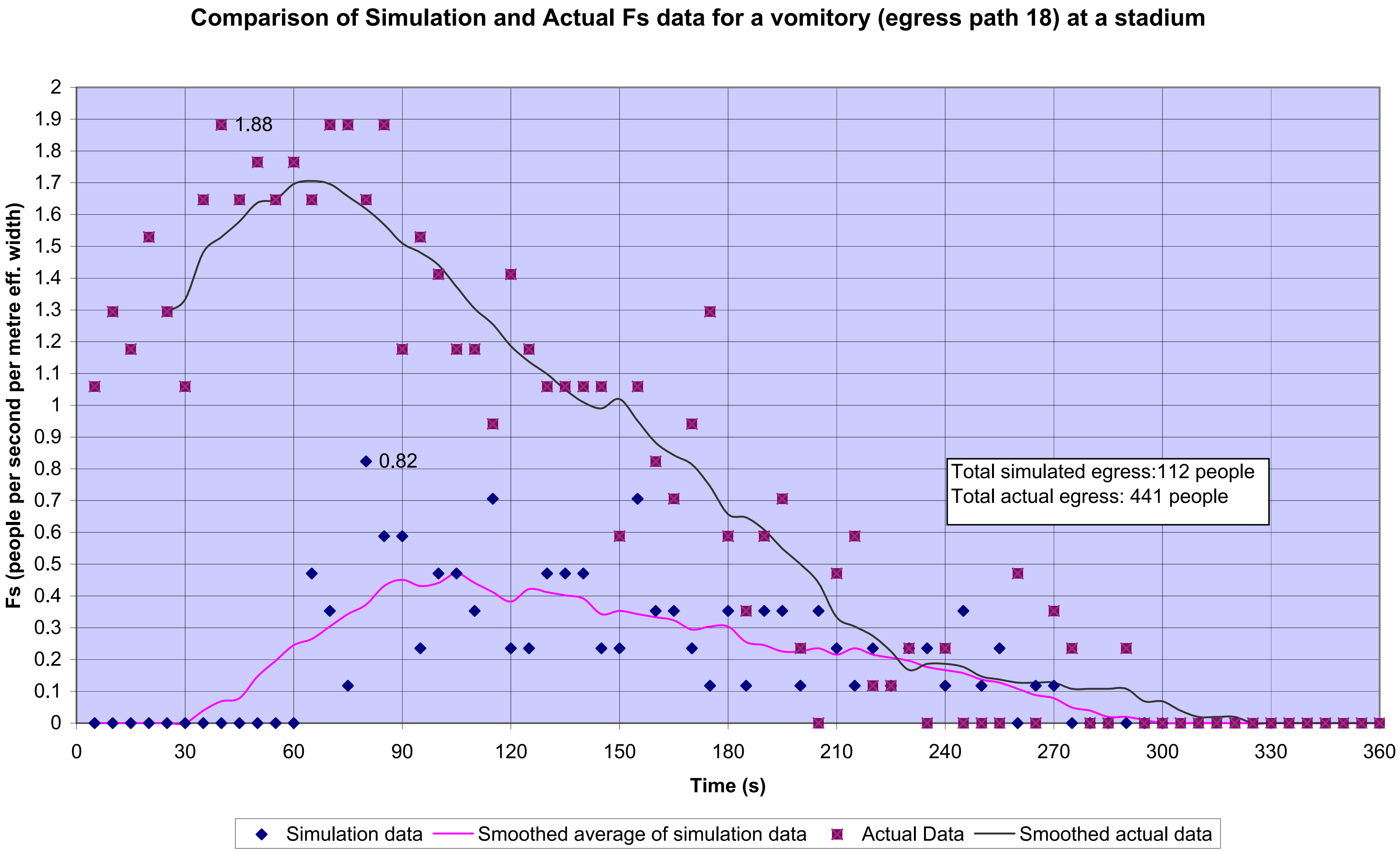


Figure 62: Egress Path 018 – specific flow as a function of time

Complete evacuation simulation of a stadium using Simulex32.exe:

Vomitory B_18 (label in model simulation) is shown with its associated area of the bowl and concourse, 10 minutes and 34 seconds after evacuation was initiated (figures 63, 64 and 65). The dots represent people as if viewed from above. Approximately one third of the stadium had evacuated at this point. The total time for this evacuation simulation was over 38 minutes. The stadium on which this simulation was based often clears in less than ten minutes following a rugby game and its anticipated evacuation time is less than eight minutes.

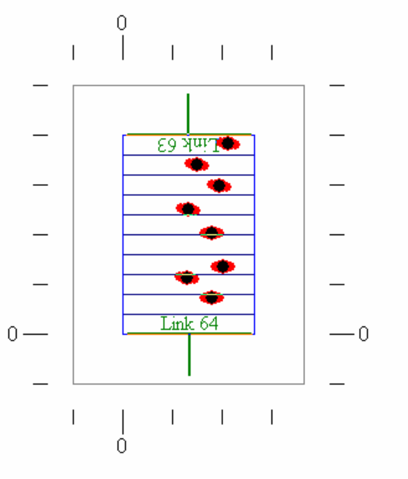


Figure 63: The vomitory is represented as stairs with Link 63 linking to the bowl and Link 64 linking to the concourse.

Figure 64: In the bowl patrons are visibly congregating around the vomitories with vomitories closer to the exits attracting a greater share of the population.

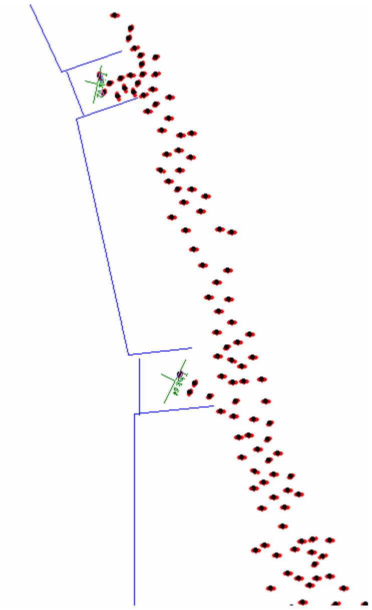


Figure 65: The concourse shows people flow from Vomitory B18 and a neighbouring vomitory into the stream of evacuating patrons.

In order to facilitate the software, the floor plan of the stadium was modified. This is most obvious where seats have been removed from the bowl area (figure 64). Bottle-necks are visible where aisles open into the vomitory areas. Simplifications made to other areas of the floor plan included the exclusion of furniture and other obstacles from dining and lounge areas and removal of barriers in hallways that connect corporate suites. This was done so as to shorten path lengths and improve utilisation of stairwells.

The graph on the following page (figure 66) shows the specific flow values across all exits from the stadium. It is of note that the time taken for this simulated egress was over twice that recorded following the observed football game at this stadium. Other data obtained from the simulation regarding usage of paths was also unrealistic in that extreme queuing occurred and conflicting flows were generated where merging flows normally occur.

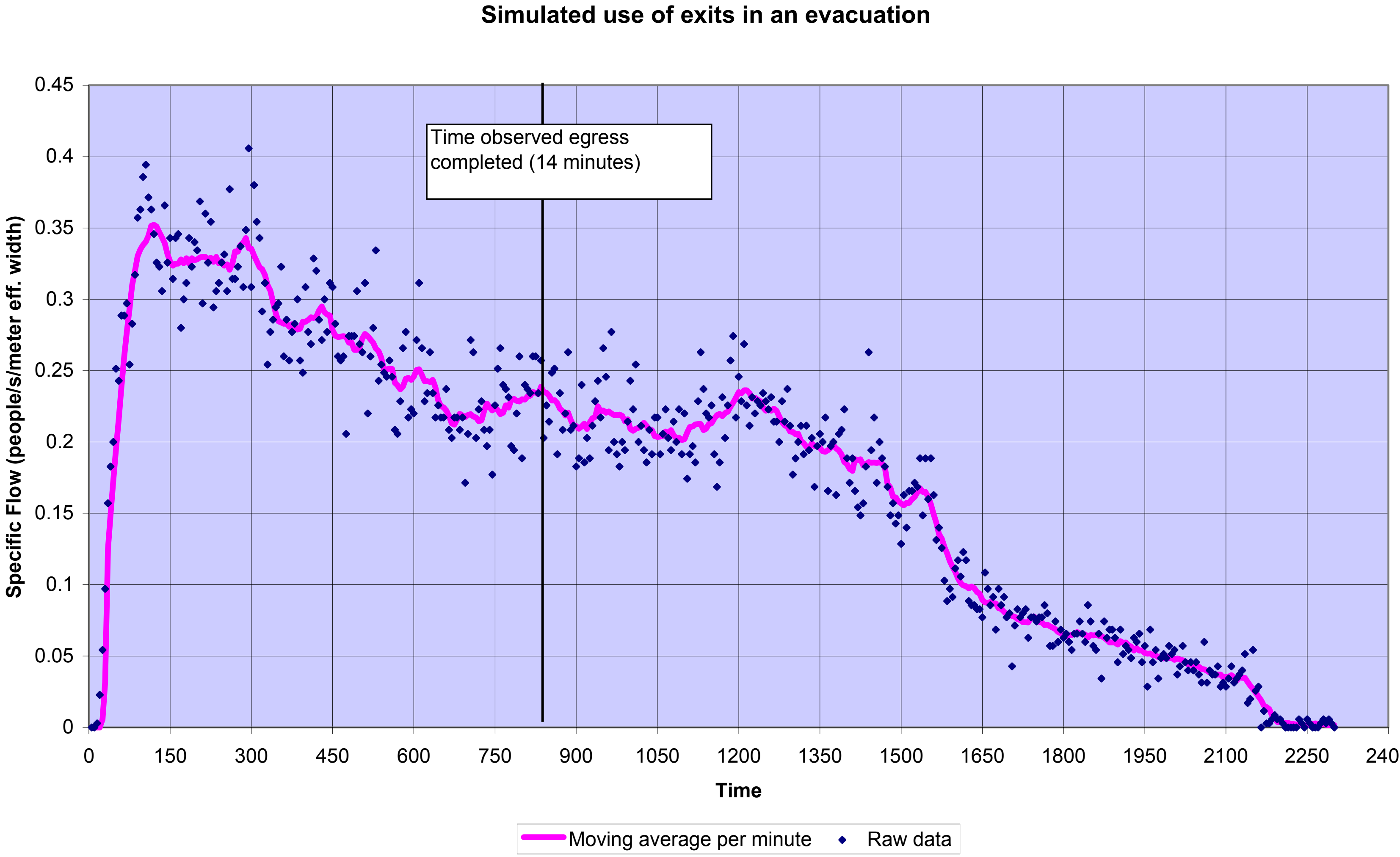


Figure 66: Exitways – simulated specific flow as a function of time

6 Analysis and Discussion

Analysis and discussion of the findings of this study have been divided into three sections:

- general observations about stadium considerations for egress management and fire protection
- comparison of results obtained from different egress paths calculations and simulations
- a discussion of software limitations that were encountered and their implications.

6.1 General observations

In observing egress and operational management at stadia, in both Australia and New Zealand, it was found that all stadia have developed or adopted some components of fire protection and or egress management that work particularly well. That being said many also have some components that could be improved. All stadia are different because of their location, design history and functionality but some general observations can be made regarding fire protection, egress movement and management, and the hazards associated with fires at stadia.

6.1.1 Stadium considerations for egress management and fire protection

In general fire protection and evacuation procedures are the domain of stadium operations managers in New Zealand and Australia. Almost half of these contract out the role to security, health and safety or building compliance organisations. This delegation of control to an external agency has in the past, and may in the future, lead to problems with emergency egress management. This problem arises because stewarding staff may not have a suitable working knowledge of documented evacuation procedures. Similarly they may not be aware of the influence of actions, such as locking certain gates, may have on the effectiveness of an evacuation. This problem has been identified at a number of stadia. Management at these stadia have responded to try and minimise this problem by encouraging a greater degree of communication and consultation between the agencies that coordinate stewardship, normal operational procedures and emergency procedures.

Some stadia have taken this a step further by assigning stewardship of an area to the same stewards each time. By doing this, stewards become particularly familiar with their area and what is required to facilitate safe egress through it. As stewardship in many areas may only be required 10-12 hours a month it can take some time for a steward to appreciate crowd movement through an area, emergency egress plans for that area and features that must be monitored and maintained. These features include fire doors that get jammed open, emergency gates that become obstructed by vehicles, cabling or being locked and fire protection devices that are commonly tampered with.

All but one of the stadia viewed use an emergency warning intercommunication system (EWIS). This has enhanced the relationship between stewardship and emergency operations. EWIS allows operations to direct investigation of incidents and emergency movement by integrating information flow to stewarding staff and to the public. This is further enhanced by the ability to use television screens around the stadium to provide information and instruction to patrons.

Management considerations regarding the logistics and implications of evacuations are greater than they were in the past. This is partially due to facilitating a range of event types with differing evacuation needs and partially due to the delegation of crowd management to contractors. The implications of interrupting live television broadcasts also plays a role in evacuation planning for some stadia. This has led to the evolution of two types of evacuation strategy. Some stadia adopt a total evacuation policy whereas others have developed partial and or staged evacuation schemes. Both strategies have their advantages.

One of the issues with total evacuations is where to put the people. Many stadia do not have large areas of land attached to them adjacent to the stadium. Unlike the end of a game or event when people move away from the stadium, evacuated patrons require assembly or muster areas to wait while the cause of the evacuation is attended to. If no suitable areas are available then surrounding roads may become blocked as traffic is disrupted by the crowd. Few stadia would consider bringing patrons onto the arena for a number of reasons:

- The arena is often protected from wind by the surrounding stands and may expose occupants to smoke and radiant heat hazards from a large fire.
- Arenas are not designed to accommodate mass movement into or out of them.
- The pitch can be damaged by trampling.

Other issues include the implications of stopping an event. Disrupting events and televised broadcasts for false alarms can have flow on effects for stadium selection in hosting future events.

The advantages of a total evacuation are based on its simplicity:

- It is easy to communicate instructions to occupants.
- It is very similar to the movement that occurs during normal egress.

In contrast, staged evacuations or partial evacuations provide more options. A partial evacuation involves selected zones within a stadium moving at different times. The most vulnerable zone is evacuated first, then if necessary the adjoining zones. A staged evacuation works the same way but involves evacuating zones until the stadium is empty. This is an extreme version of a partial evacuation.

The disadvantages of a partial evacuation are that it:

- Requires greater training of stewarding staff.
- It is more complex than a total evacuation.
- Involves giving different messages to different occupants.
- Is quite different to normal stadium egress and has greater potential for confusion.
- May be hard to initiate if the game is still in play and no obvious signs of danger are apparent to occupants.

Its advantages are that:

- The most vulnerable patrons can be focussed on and removed from the danger quickly.
- There is less initial disruption to the majority of patrons
- People in surrounding zones can be prepared to move, reducing their premovement time.
- People can initially be evacuated to other areas of the stadium reducing the need for large muster or assembly areas.
- Disruption to the event is minimised.

Both strategies have their uses, although the partial evacuation affords greater flexibility and may be perceived as more desirable from a management perspective.

Other management related issues of concern that were identified in the course of this study were:

- **Staff awareness** - Contractors are used to perform a wide range of functions at stadia. This is because of the vast difference between event and non event requirements. Staff awareness of emergency procedures varied between stadia. By questioning stewarding staff and other staff on evacuation procedures it was established that some stadia go to great effort to ensure staff are prepared for evacuations whereas others do not, relying on contractors to brief their staff on the day. At a number of stadia staff were seen locking gates, and restricting the clear width of exit ways while they took breaks. When questioned, these staff were unaware of the implications of their actions. Fire doors were jammed open and gates were opened into the oncoming crowds. At one stadium management removed and confiscated door jams from the same fire door three times. This type of practice was not true of all stadia. Some stadia provided staff with maps of evacuation routes for their areas and routinely quizzed the personnel on evacuation procedures and the importance of maintaining clear routes. One stadium insisted that all contract security staff (hired by the stadium or event organisers) familiarise themselves with the entire grounds, evacuation procedures and all exits before they were permitted to perform any security or ushering tasks.

- **Maintenance -** Although the majority of areas in visited stadia were in good condition, some venues included areas that had been poorly maintained or only partially modified. These neglected areas were found predominantly in sections of older stadium buildings. The level of maintenance afforded these structures varied.

  Problems identified included:
  - poor maintenance records of fire protection devices
  - unsprinklered corporate levels
  - Fire protection systems that had been disconnected from the fire service.
  - Disconnected manual call points in hallways
  - Structural protection had not been maintained in areas that were out of sight (see example in figure 67).
  - Rubbish and broken furniture that had been allowed to accumulate or stored in gaps behind older stands.

Figure 67 Poorly maintained structural protection of I beam in hallway between suites and players area

All of these problems have the potential to impact on preventing fires from occurring or reducing fire spread within the stadium and ensuring life safety. In some stadia management were aware of the problems and in others they had not noticed the deterioration. In either case greater care in maintaining the structures and equipment is warranted.

6.1.2 Design of vomitories - crossed flow and congestion

Vomitories at stadia differ considerably. Only in new structures have vomitories been designed as shown in figures 70 and 71. In some stadia the ability to accommodate extra seating has determined the shape of the vomitory. An example of this is shown in figure 68.

In figure 68 flow from one direction (the left) is severely restricted while flow from the opposite direction (the right) has preference. In this instance it took in excess of 20 minutes for this part of the stadium to clear. Management indicated that it was not uncommon for this area to still be densely populated 30 minutes after a game had finished.

Figure 68: Crossed flow crowd movement – people from the left must turn an acute angle to enter the vomitory.

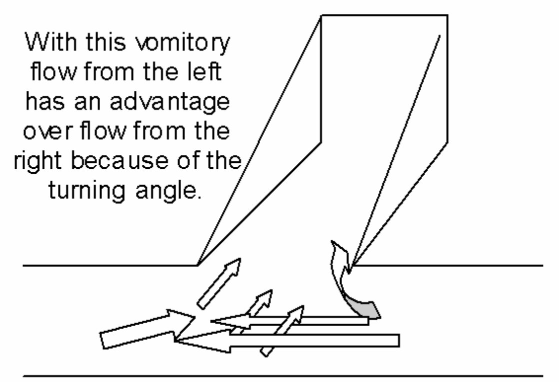
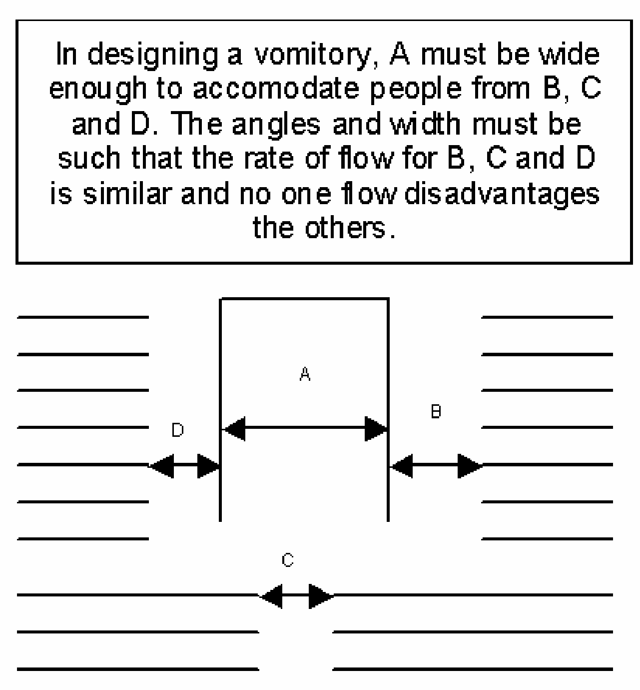


Figure 69: Sketch of cross flow movement directions.

As mentioned previously attempts to model evacuation of this part of the stadium were beyond the capabilities of the software used due to the complexity of movement. Figure 69 attempts to explain this – it is a 90-degree anti-clockwise rotation of figure 68. The right-hand angle at the T-junction is obtuse and the left-hand angle is acute. Although the left-hand flow has the advantage in accessing this vomitory, other vomitories further to the left are less obstructed. People from the right move directly against the flow from the left in an effort to reach other vomitories. This slows movement from the left and further inhibits flow from the right.

The gridlock observed at this vomitory was more extreme than at any other egress point in any of the studied stadia. Although other stadia did not experience this degree of crossed flow congestion during normal egress there were areas where crossed flow crowd movement did occur. This serves to show how congestion in one small area of a stadium can have implications on the effective egress of a large part of the structure. The only way to facilitate an evacuation for this type of layout would be to stagger the evacuation. Patrons to the left and the right of the vomitory would have to be evacuated in two separate stages in order to prevent gridlock. This is not currently part of the evacuation plan for the stadium. The current plan is for a complete evacuation which in this area is inappropriate.



In designing a vomitory, A must be wide enough to accomodate people from B, C and D. The angles and width must be such that the rate of flow for B, C and D is similar and no one flow disadvantages the others.

Figure 70: Ideal vomitory sizing

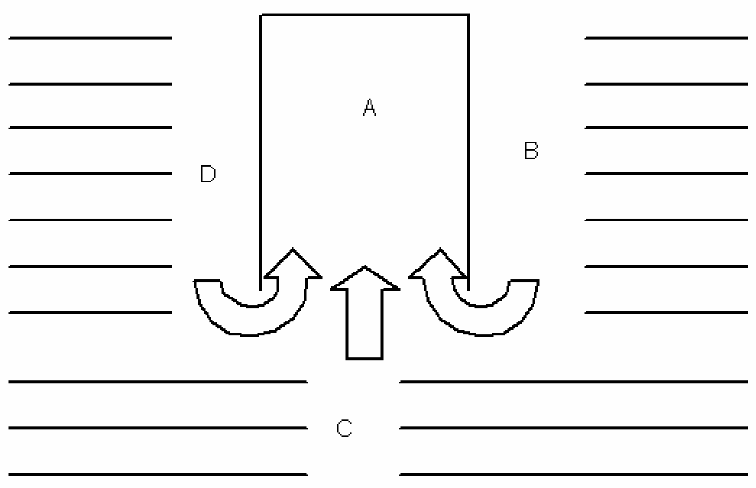


Figure 71: Ideal vomitory egress flow

6.1.3 The potential for smoke hazards to affect egress at New Zealand Stadia

Having viewed stadia throughout New Zealand it could be assumed that smoke emissions from a fire represents a minimal hazard to the majority of patrons. This is primarily due to the size and open layout of these structures. Smoke layer height in concourses and enclosed areas may be assumed to only present a problem once the layer is lower than 2m. In the majority of cases this is unlikely to occur due to high ceilings and open layouts.

The bowl

It is possible for smoke hazards to occur under adverse wind conditions within the bowl of a stadium but only in an extremely large fire. The stadium most vulnerable to this has a completely enclosed arena with no vertical breaks between stands. The nominal distance between the back row of seating and the ceiling of the bowl roof was not found to be less than 2.2 metres in any of the stadia visited. This distance increased 0.2-0.4m each successive row toward the field. A person would have to remain in the back row while the wind blew smoke towards them to be significantly affected by smoke.

Concourses

In the observed concourses ceilings typically sloped, mirroring the rise in seating within the bowl. The height of ceilings varied and the majority were open to the outside allowing free ventilation of smoke. Only one stadium has a fully enclosed concourse. The height of the ceiling was approximately 9m at its peak. The volume of this concourse exceeds 20,000 cubic metres. The concourse is almost entirely concrete and steel. Rubbish bins represent the greatest fire loading within the concourse. Considering the size of the concourse a rubbish bin fire should not present a significant hazard.

Suites, lounges and restaurants

The only areas of the observed stadia that are vulnerable to fire and smoke hazards are the furnished areas such as suites and lounges. These are not normally accessible to the general admission patrons and occupancy levels are lower than for the rest of the stadium. Smoke accumulation in these areas would not pose a problem for the majority of evacuees from a stadium but it could pose difficulties to a minority, such as those in the approximate vicinity of a fire, given certain conditions.

The realisation of smoke and fire hazards in furnished areas was documented by Isner[131]. The Texas City Stadium fire produced conditions where smoke accumulated in hallways potentially blocking egress from surrounding suites. The possibility for this type of incident to occur exists in many New Zealand stadia. The majority of stadia have narrow corridors in the executive levels not dissimilar to those described by Isner. A predisposition for catering staff and media personnel to jam fire doors open to ease access for trolleys and cables creates a suitable environment for the type of smoke inundation that occurred at Texas City Stadium. Education of the implications of these types of action are the best way to change this behaviour.

6.2 Observations specific to crowd flow and egress

There are two ways to compare the obtained egress results:

1. Observed values can be compared between one another.
2. Observed values can be compared within the context of other studies and simulations. In order to compare observed values within this context values obtained from applying standard calculations and documented movement trends have been used.

6.2.1 Egress Flows

The most striking outcome from the results is the wide variation in specific flow values (figures 72 and 73) that were observed. Maximum specific flows range between 1.98 people per second per metre effective width down to 0.71 people per second per metre effective width. On the surface this would appear to be quite a difference but upon examination it is clear that the lowest values are for egress path 1, which never reached sufficient densities for specific flow to be optimised, and for egress path 8, which experienced the highest density at its maximum specific flow of any of the path ways. By discounting these two results the range is narrowed to 1.55-1.98 people per second per metre effective width. All of these values are higher than predicted by recommended maximum specific flow values in Chapter 13 of the SFPE handbook[132].

In comparing the densities of the different walkways (figure 76) there are several interesting features. Firstly, egress path 18 has a notably lower density at maximum specific flow rate than the other egress paths. It was observed that people moved very quickly from this vomitory although speeds were not obtained. It was asserted that this may have been because of the distance that this vomitory was from the main exit. This would imply a speed close to that observed in egress path 4. The next most obvious feature is that three egress paths experienced the same density at maximum specific flow. This is particularly interesting because each of these egress paths was quite different; one was a staircase, one was a narrowing path and one was a concourse with mixed flow movements. Each of these situations had the potential to create higher than usual densities. This indicates that high densities may not inhibit crowd speeds markedly until they become very high. The third point of note is the wide range of densities observed for maximum specific flows. Once again this indicates that flow rates are quite robust across a range of densities and speeds.

The sustained specific flows show greater variation than the maximum specific flow rates (figure 74). This may in some cases be due to a supply of alternate routes allowing diversion of occupant flow from the monitored egress paths to other paths, lowering the density of the observed flow. In other cases the speed with which a sustained specific flow was established may have played a greater role in determining the observed sustained specific flow.

Comparing calculated flows of different egress paths (figure 75) does not provide much meaningful information as paths had different effective widths. These values only become meaningful when compared to calculated values using standard accepted maximum specific flows.

The variations in speeds are only significant in the fact that relatively high speeds were achieved. The highest speed observed, 2.7m/s, was a slow jog. This was observed at a low density egress path. The remainder of maximum speeds (figure 77) and mean speeds (figure 78) vary from slow to moderate walking speeds.

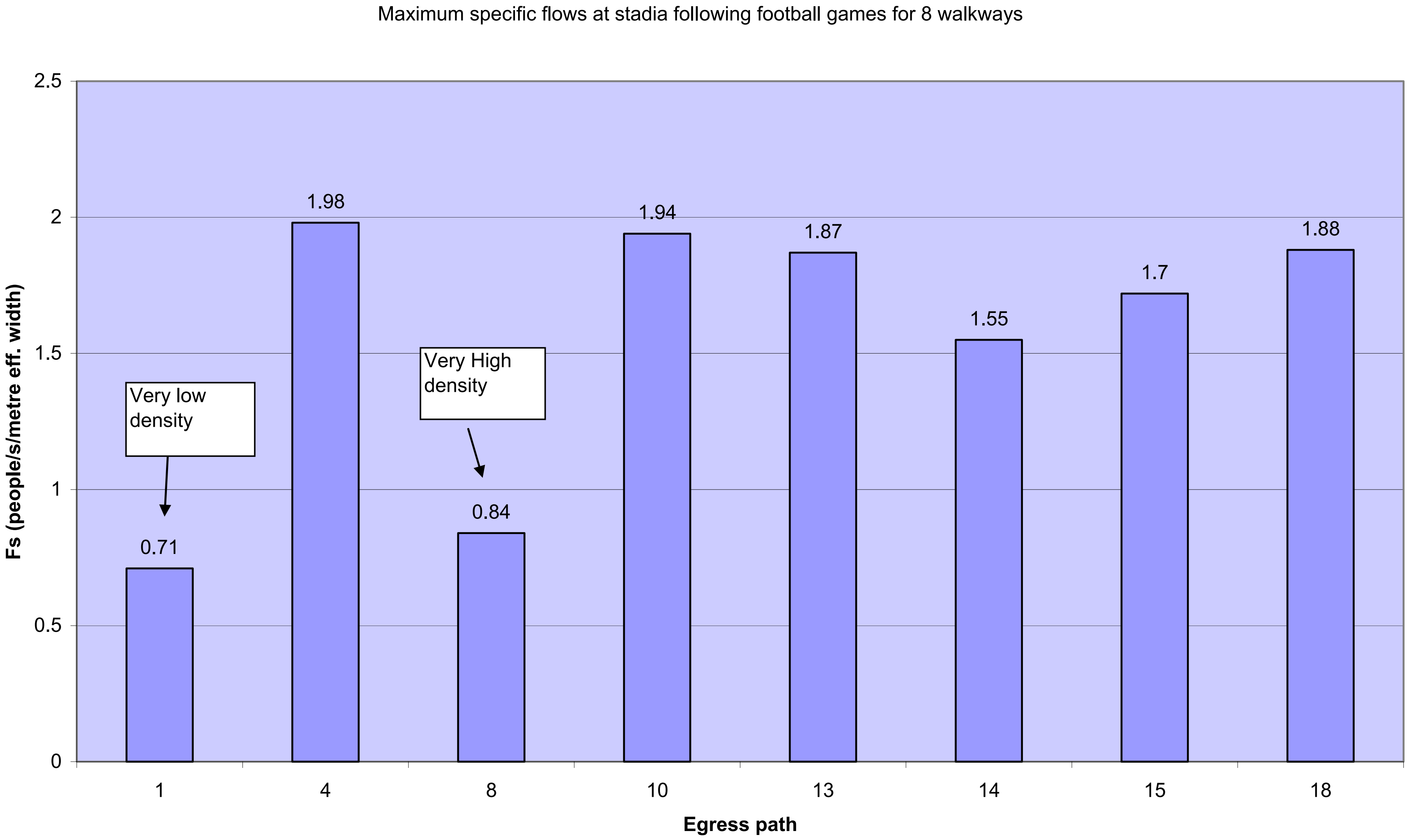


Figure 72: Comparison of maximum specific flow rates for different egress paths

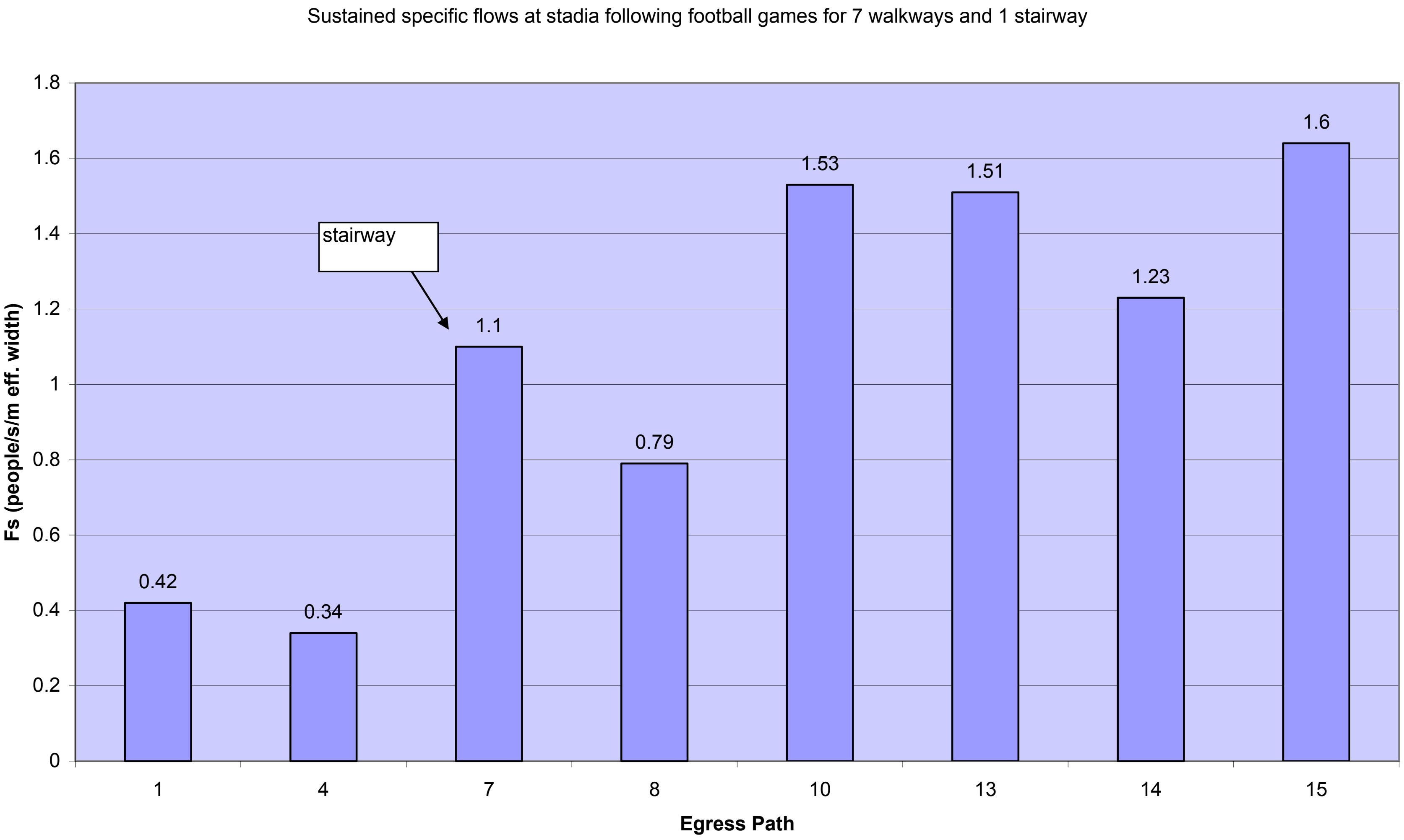


Figure 73: Comparison of sustained specific flow rates for different egress paths

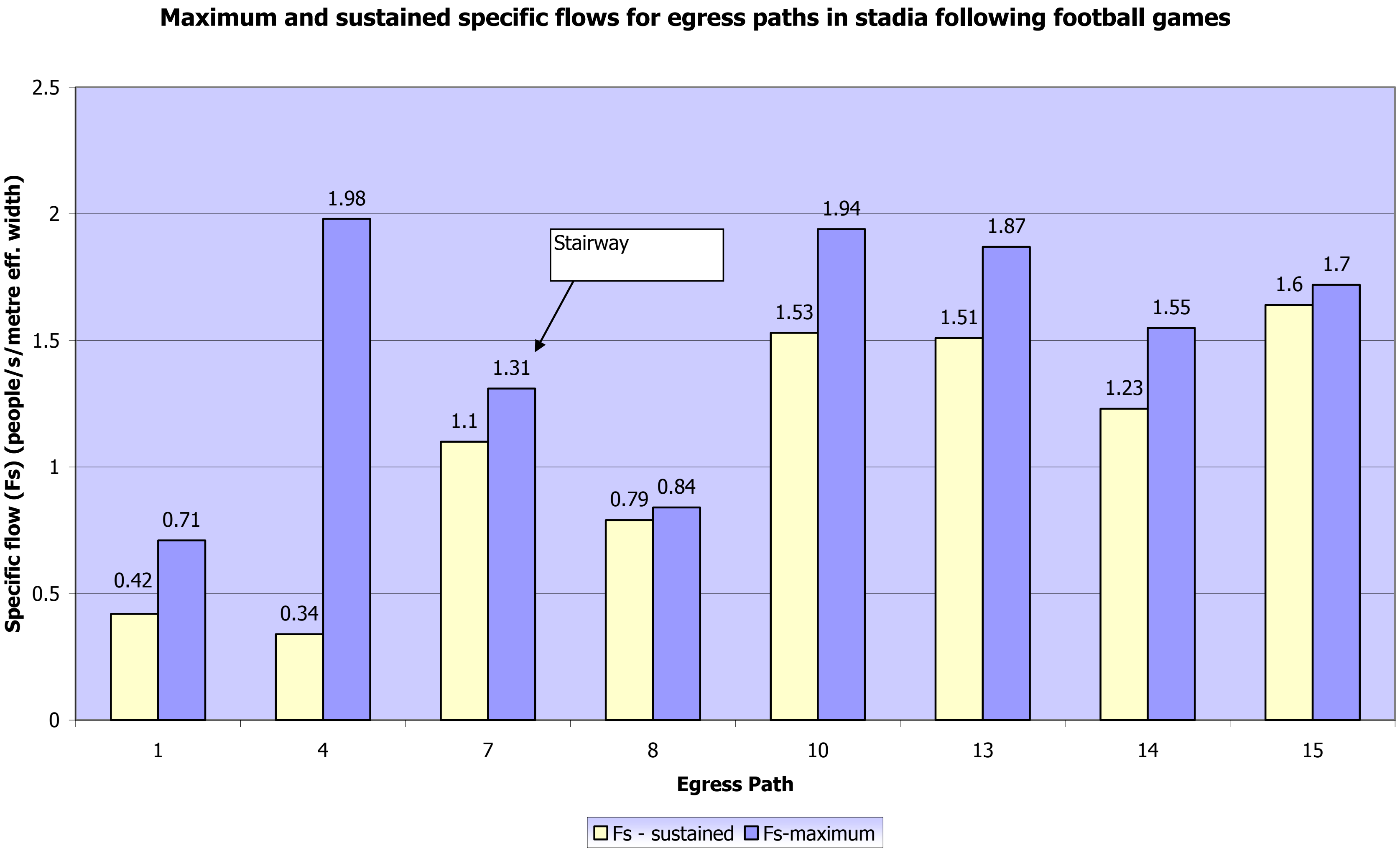


Figure 74: Comparison of maximum and sustained specific flow rates for different egress paths

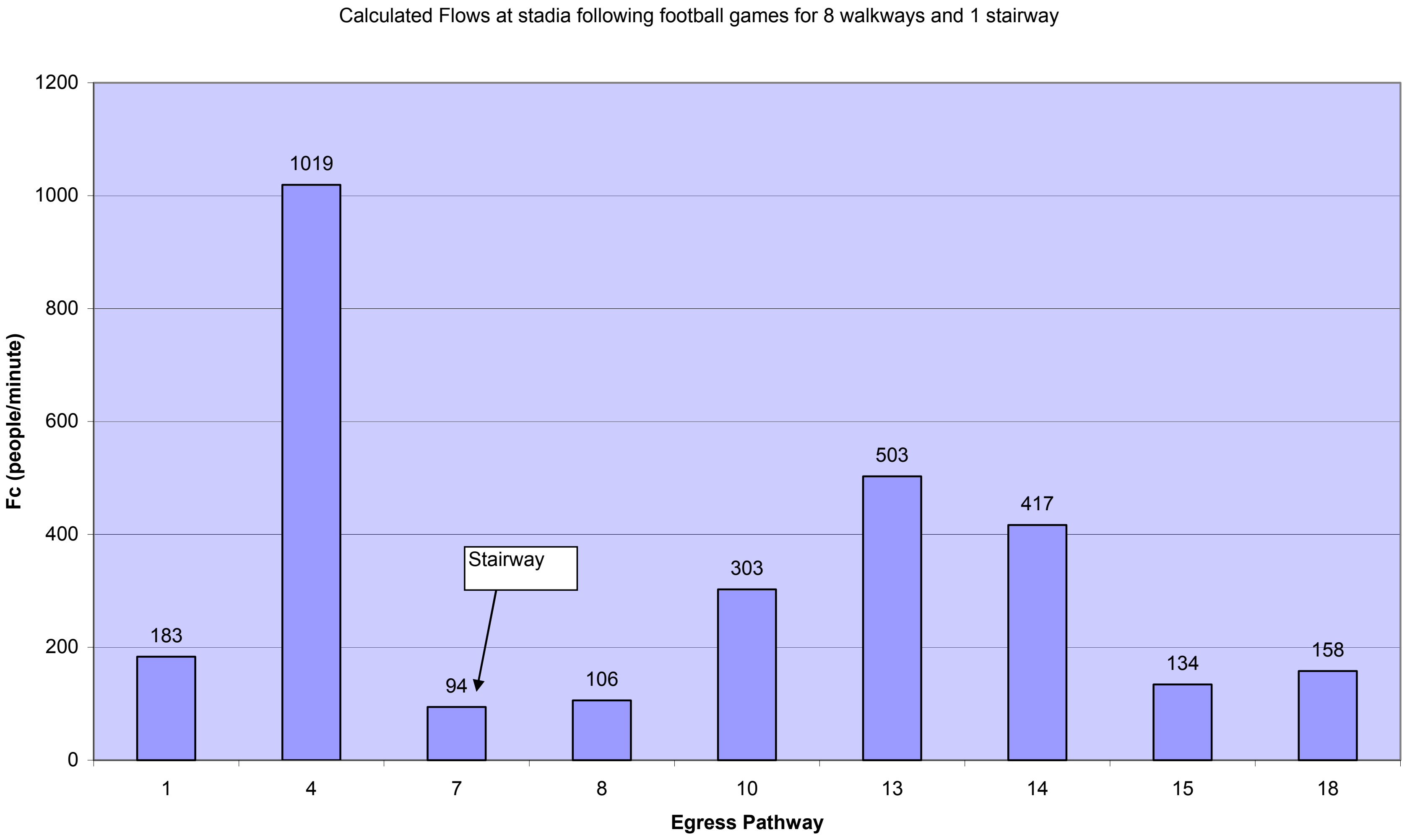


Figure 75: Comparison of calculated flow rates for different egress paths

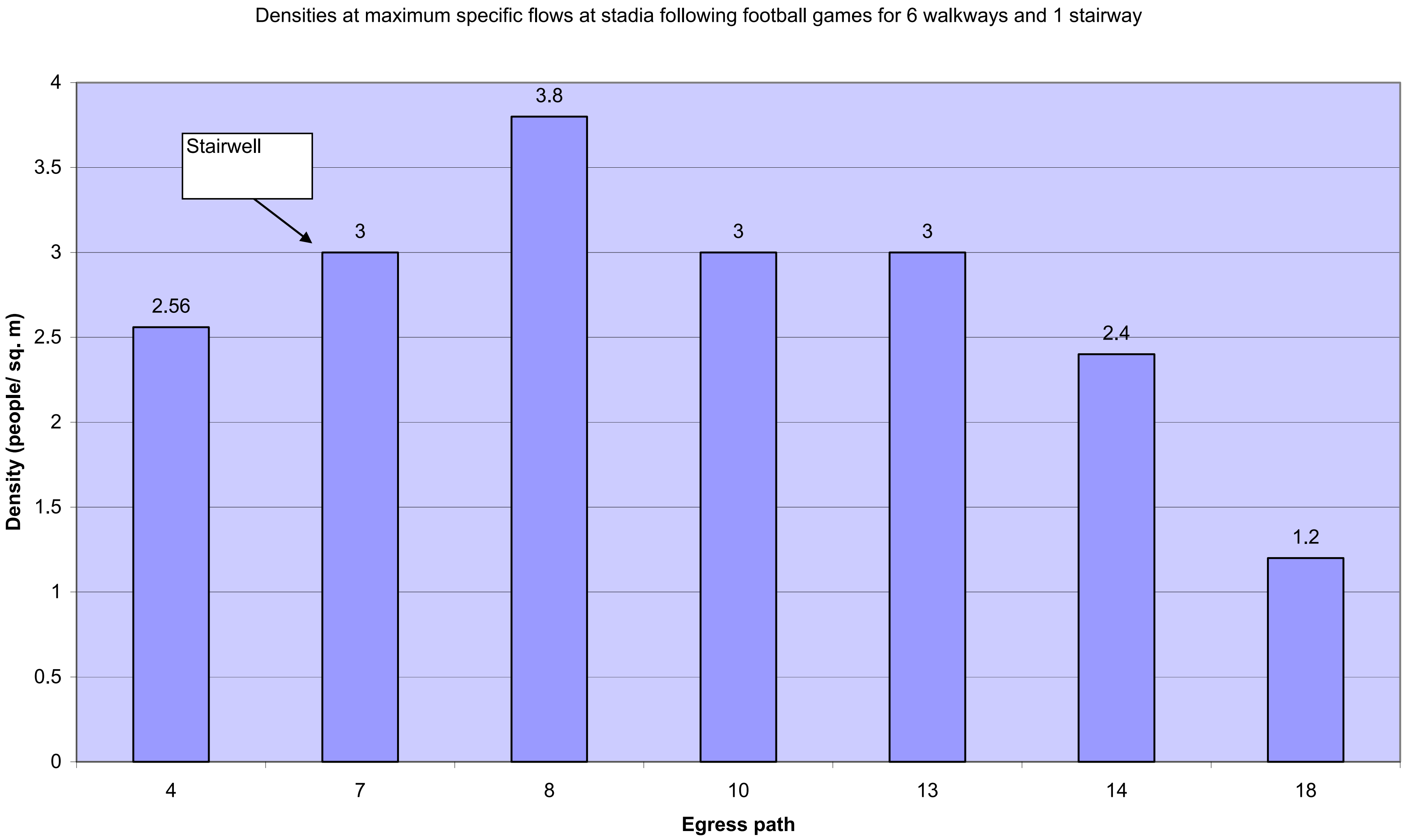


Figure 76: Comparison of densities for different egress paths at maximum specific flow rates

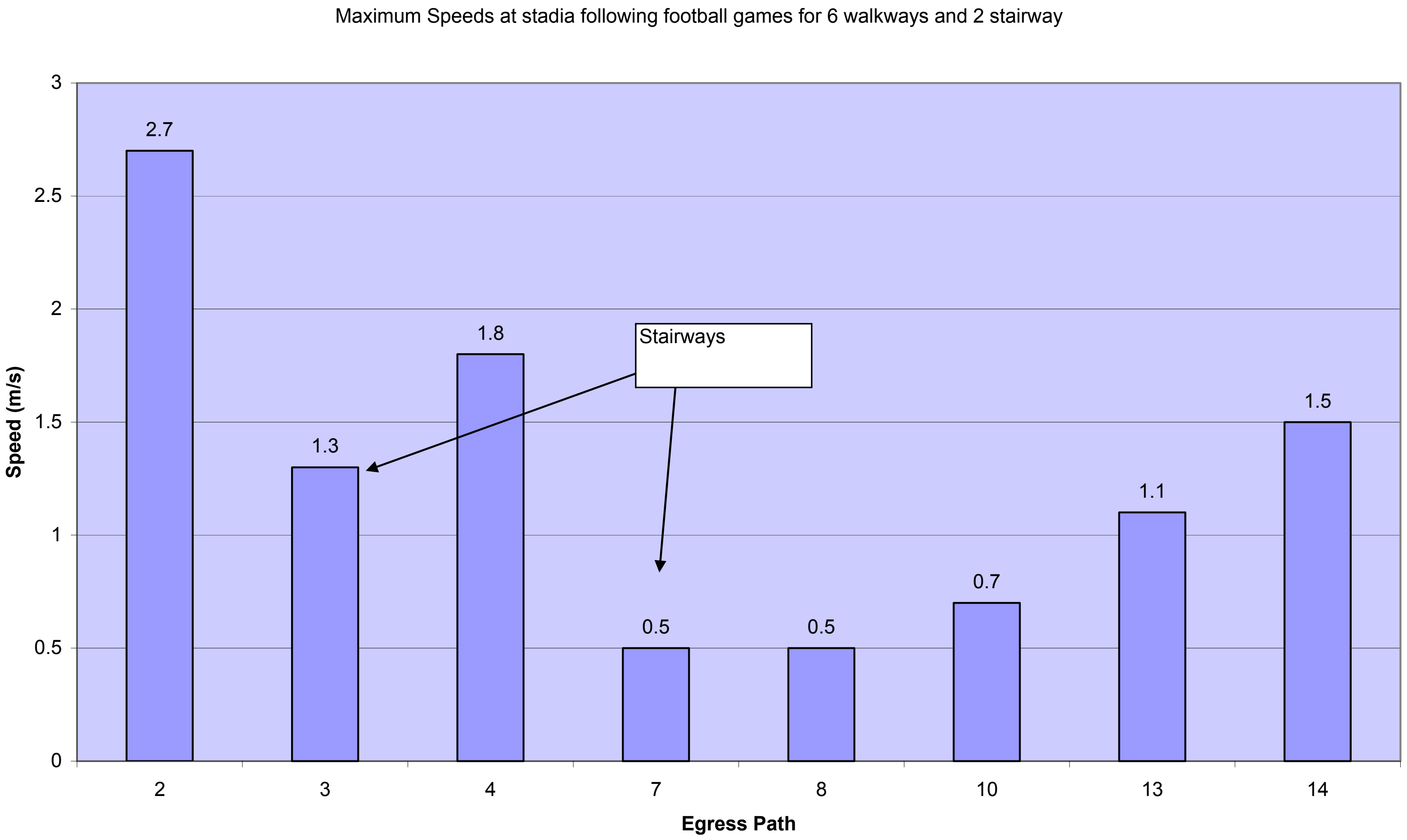


Figure 77: Comparison of maximum speeds for different egress paths

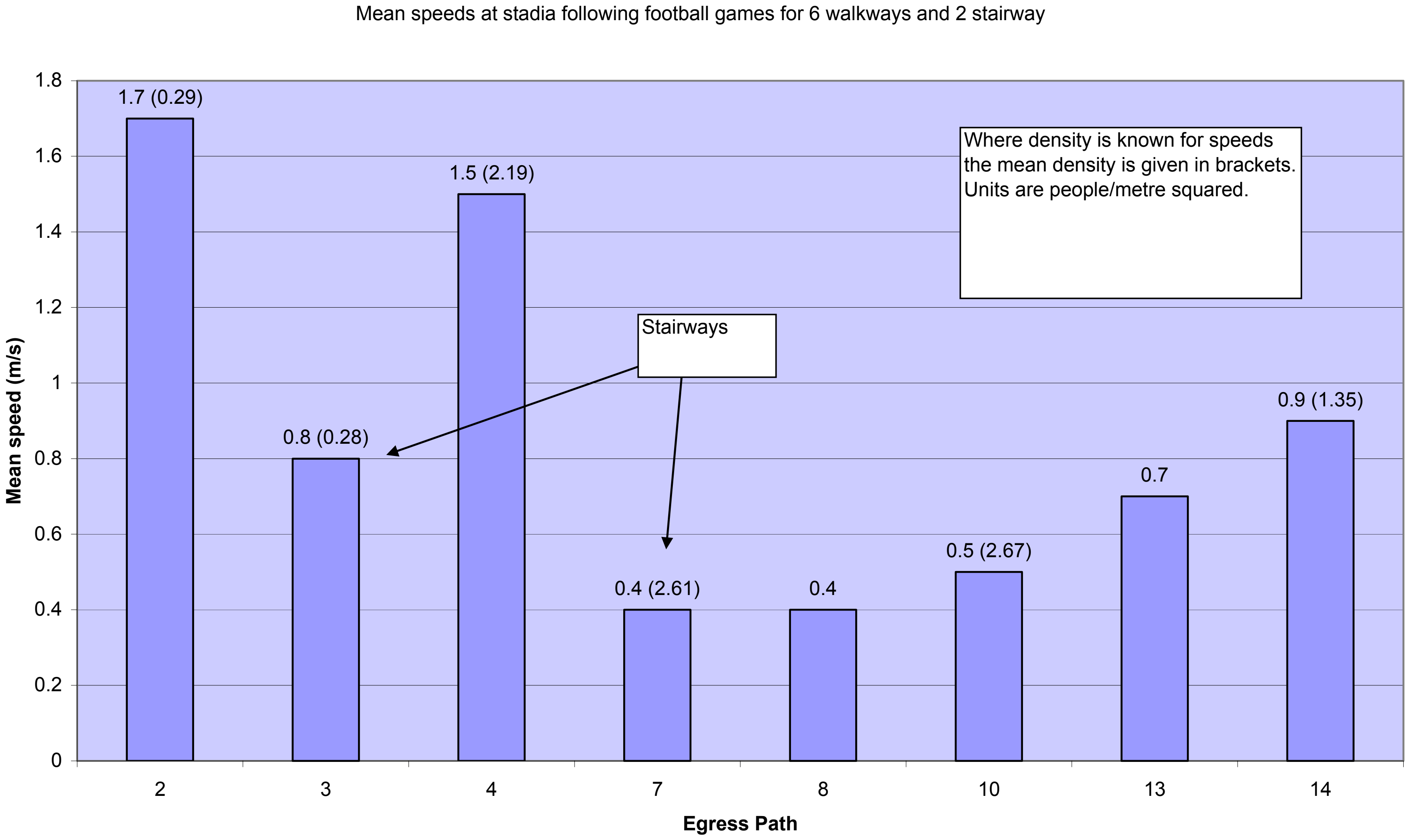


Figure 78: Comparison of mean speeds for different egress paths

6.2.2 Observations from simulation and data flow calculations

Having compared egress movement between different pathways at stadia it is appropriate to put this into the context of recognised crowd movement for more general situations.

The figures on the following pages compare observed flow rates and speeds with documented values.

Specific flow

Crowd flow on walkways (figure 79) plots maximum specific flow against density from literature with maximum and sustained specific flows from this study. The observed maximum specific flow rates were generally much greater than Fruin's level of service suggests. The maximum specific flow rate results are however consistent with Poyner et al and Ando et al's research into specific flows at stadia and train stations respectively. Ando et al purport that once a high density crowd is achieved the density has a diminished effect on flow rates. The Green Guide suggests an optimum specific flow rate of 1.82 people/s/m effective width but notes that higher values can be achieved. This is consistent with what was observed.

The mean specific flow rates observed, with the exception of egress path 8; do appear to loosely correlate to Fruin's observations for maximum specific flow although they are still higher. There appears to be little correlation between the observed mean rates and those predicted by Simulex32 or Predtechenski's work although there are insufficient data points to completely discount this. Within the context of these other researchers observations, the results from this study tend to suggest that stadium crowds move more rapidly and at higher densities than more general crowds.

Insufficient data was collected to identify a trend for stairway movement (figure 80). Only one stairway produced results that could be compared to that of existing research. It is possible that the data from egress path 7 could indicate adherence to Fruin's observations but in the absence of other data this cannot be stated with any conviction. It can be said that specific flow rates on stairs at stadia can be achieved at a higher than predicted rate.

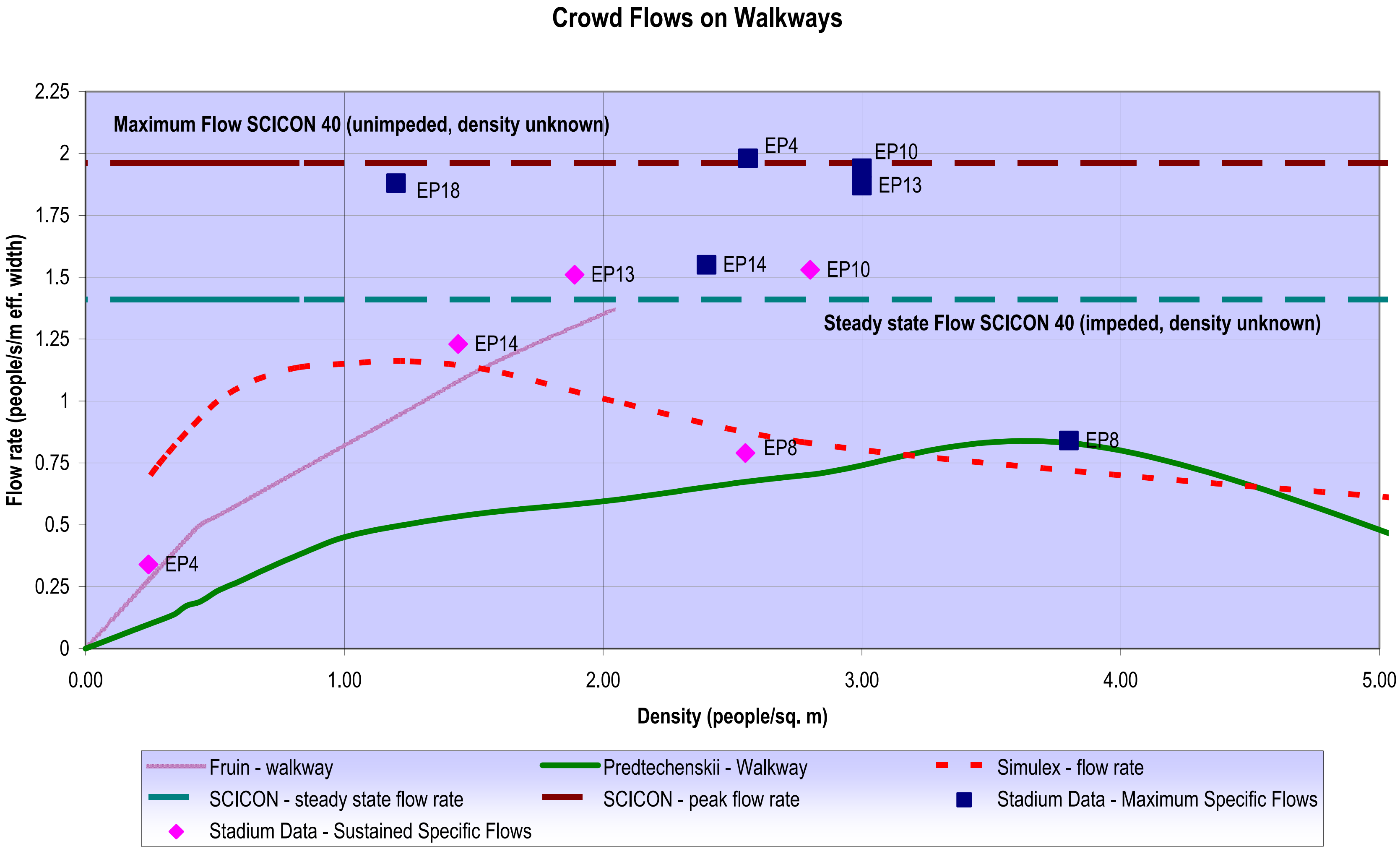


Figure 79: Specific flow values for walkways from the literature and from this study

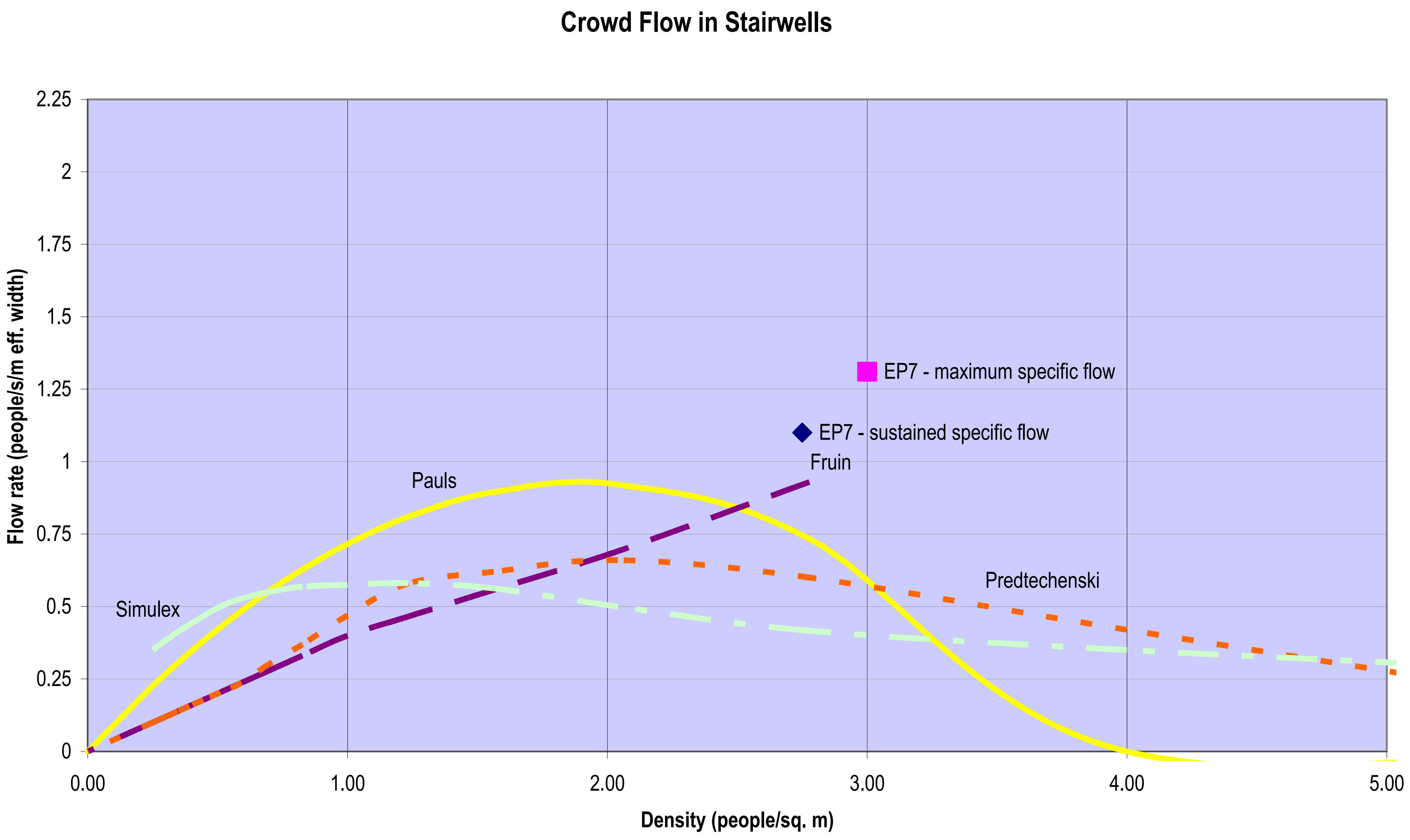


Figure 80: Specific flow values for stairs from the literature and from this study

Comparison of calculated flow rates (figure 81) were achieved using equation 6 and maximum specific flow rates from the Green Guide[133] and the SFPE Handbook[134]. In six of the eight egress paths the calculated flow rates were within 10% of the values suggested using the Green Guide (Poyner et al's work). In only two instances was the SFPE prediction (Fruin's work) within 10% of the observed calculated flow. In two cases, egress paths 1 and 8, the calculated flow using observed data was lower than either prediction. Egress path 1 was under utilised and so this is expected and egress path 8 had too great a density to produce an optimum specific flow value for calculated flow. This tends to suggest that the Green Guide is a more appropriate document for calculating flows at stadia than the SFPE Handbook. It also reinforces the observation that stadium crowd movement is not the same as more general crowd movement.

In plotting observed speeds and densities over established speed density curves it can be seen that the correlation between density and speed holds (figure 82, 83) although once again there is insufficient data to confidently quantify this. Speeds do appear to be greater than those suggested in the SFPE handbook[135] for given densities. Work by Ando et al[136] may explain this. Mean speeds have been shown by Ando et al to vary with age and sex as well as density. Ando et al found young males to produce the highest speeds at measured densities. The observed results from New Zealand stadia may well be influenced by the predominance of this demographic amongst stadium crowd patrons.

Further studies of flow rates at stadia are needed so as to better map out speed-density and specific flow-density relationships for stadium crowds. It may be found that specific flows for stadium crowds remain fairly constant across a band of densities as suggested by Smith[137]. This would indicate that the maximum achievable specific flows for stadia are determined not so much by density but by demographics and sociology. Observations of Egress path 23 would tend to support this hypothesis. Individuals observed outside of the stadium exhibited different characteristics to those inside the stadium. This may be part of the reason that they are able to move more rapidly than other crowds.

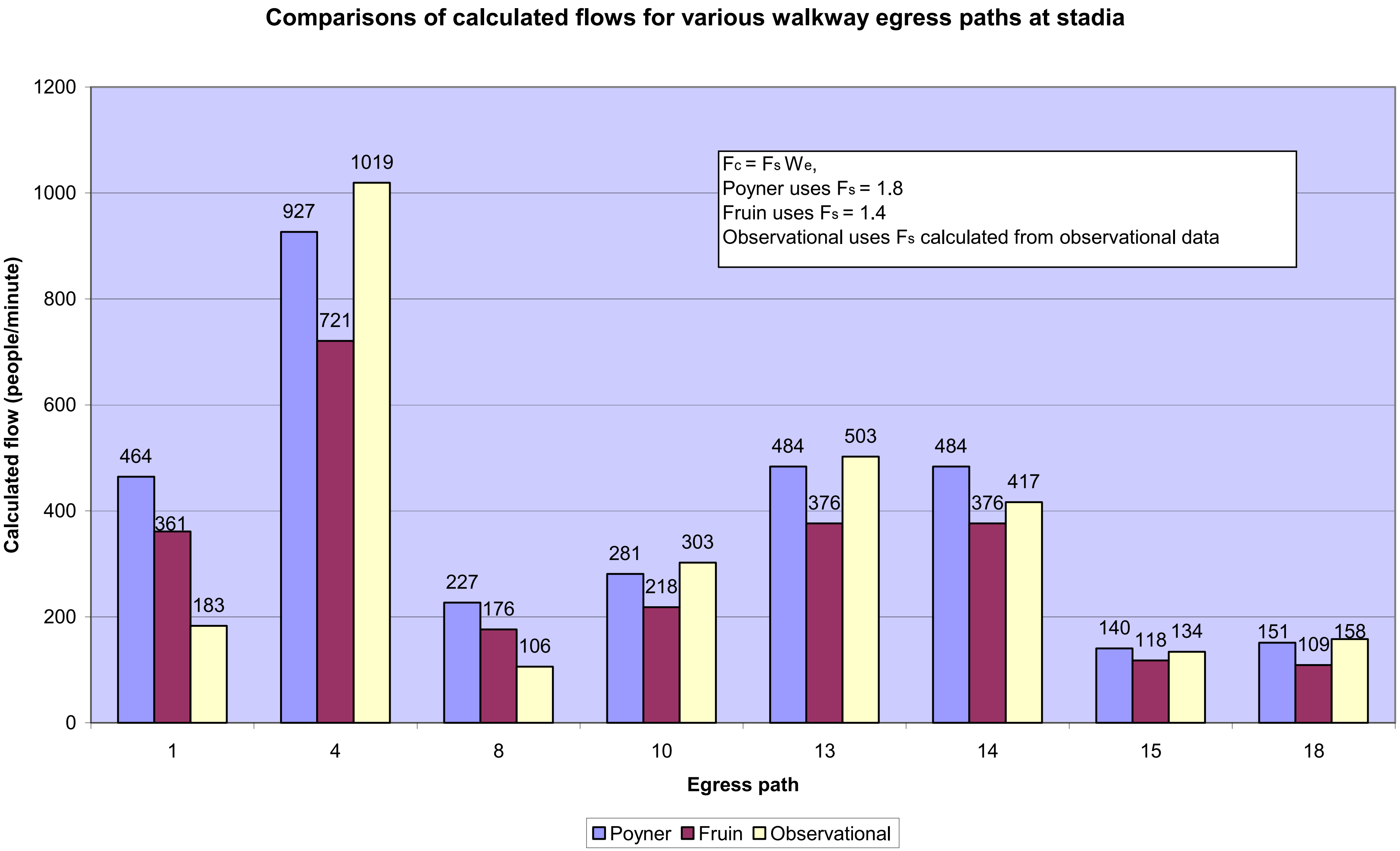


Figure 81: Comparison of calculated flows for different egress paths

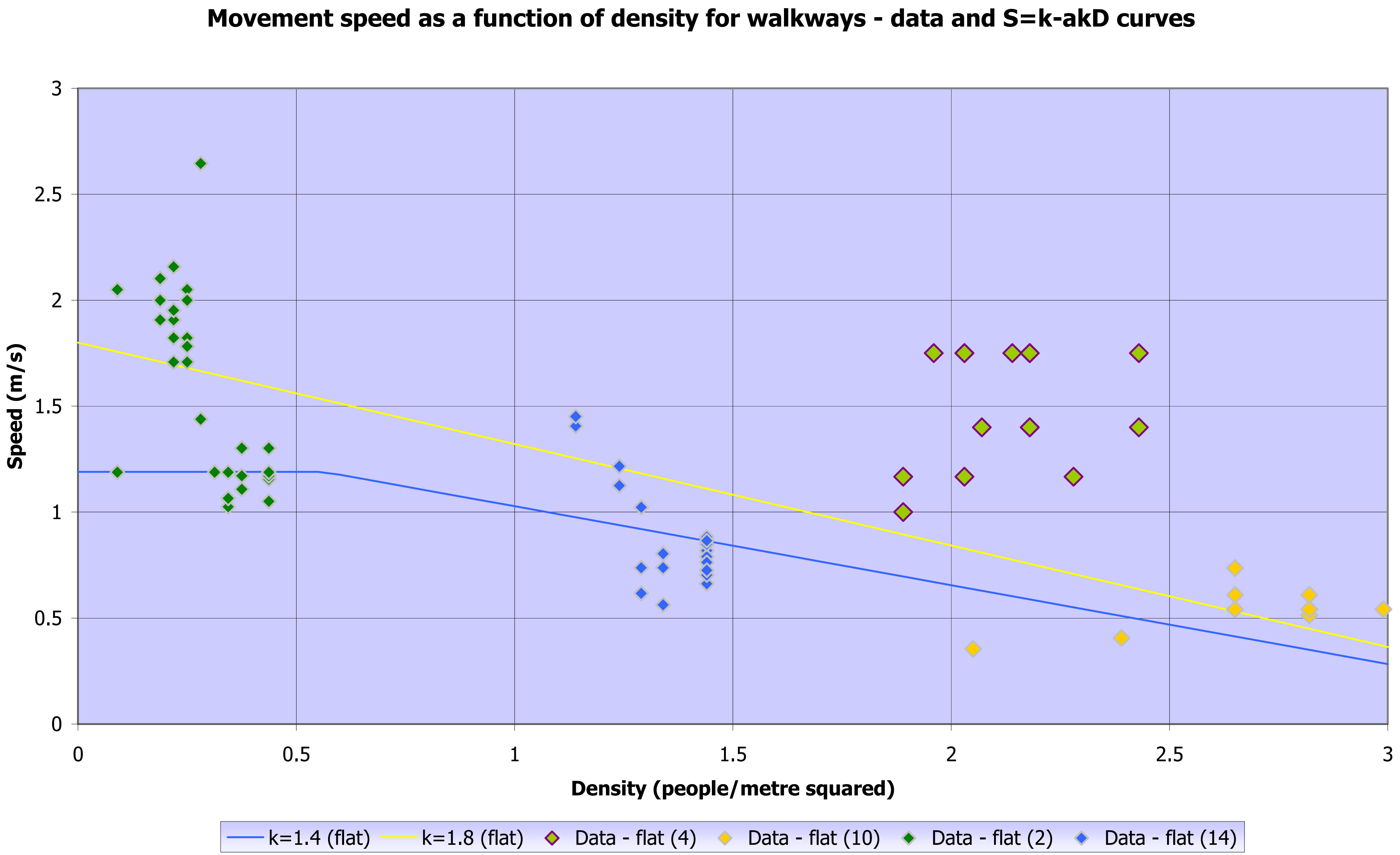


Figure 82: Movement rate as a function of density for walkways

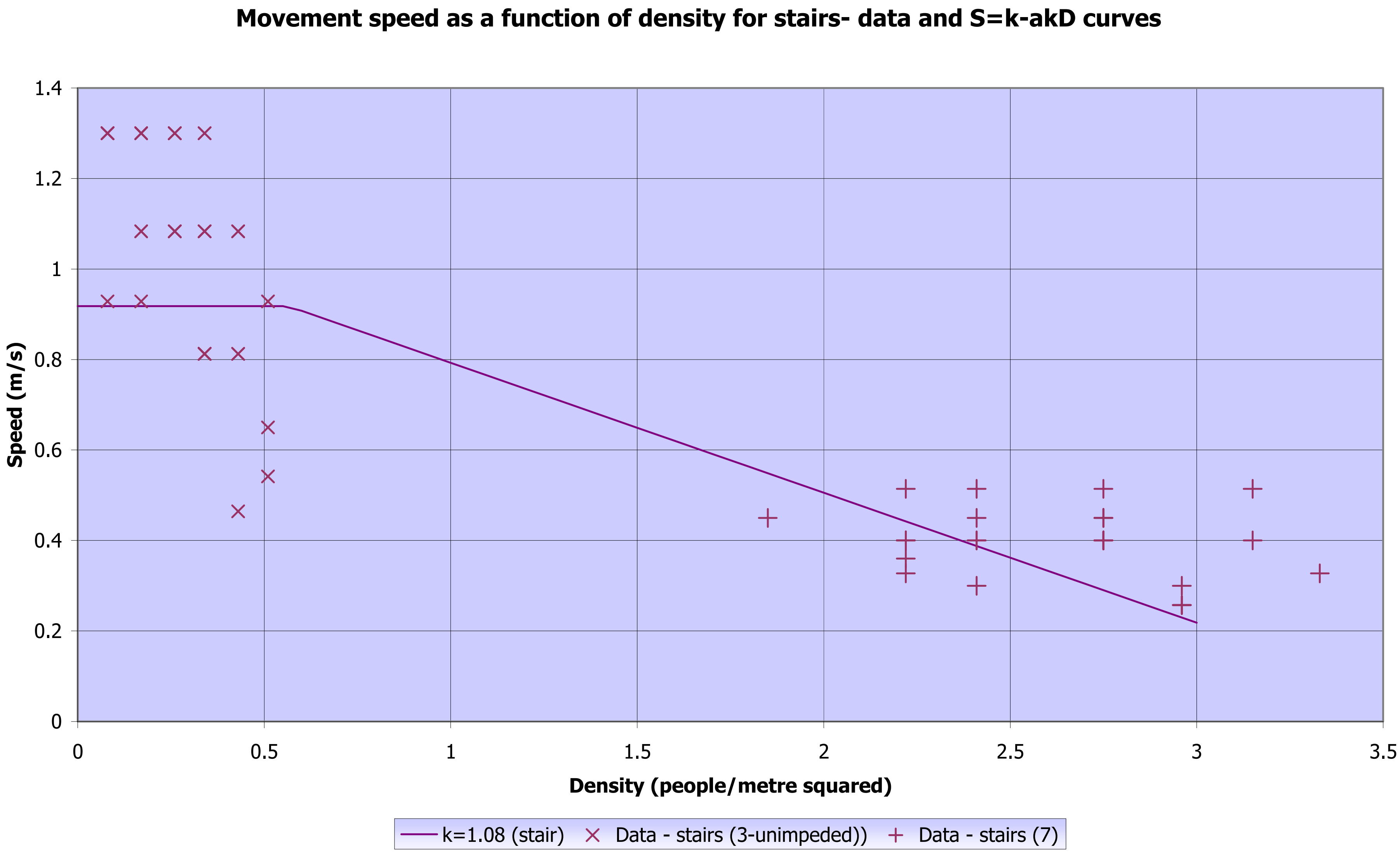


Figure 83: Movement rate as a function of density for stairs

6.3 Software limitations

Modelling human behaviour is not an easy task. Human behaviour is complex and varies with environments. The software that was used to simulate egress at stadia simplifies some of the behavioural patterns apparent in crowd movement. In less complex applications this would not be a problem but in this application it was. Consequently evacuation times obtained in using the software are dissimilar to those times observed by timing crowds. The flow profiles determined by established researchers show wide variations between each other and observations from this study. As Simulex32 is based on some of this research it makes sense that Simulex32s results also differ from that which was observed.

Problems that were encountered are not necessarily specific to Simulex32. These problems may well be encountered when trying to apply other software to occupancies on the scale of stadia. The problems encountered do serve to illustrate that a modelling program that is highly suitable for application to some occupancies is not necessarily suitable for application to all occupancies. Although many problems were encountered this should not reflect upon Simulex32s capabilities to handle other types of occupancy. Information on software limitations is only included in order to illustrate aspects of modelling that may lead to variations from observed flow movement.

In simplifying behavioural characteristics the software used did not allow for the following:

Wheelchairs and mobility impaired patrons – As found by results from egress path 3 (figure 83) mobility impaired patrons have the potential to significantly impact localised crowd flow at corners and other congestion points. Sporting events such as the Para Olympics or other events such as Papal visits or concerts that attract a predominantly elderly population will have a greater distribution of these people. Venues that intend to cater to these types of population need to be able to consider these impacts on their evacuation planning.

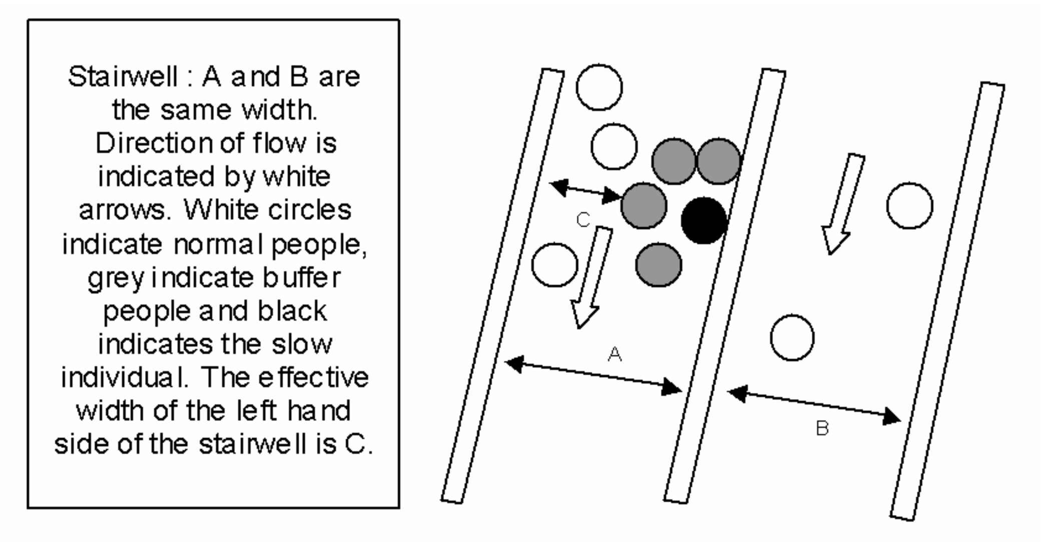

Stairwell : A and B are the same width. Direction of flow is indicated by white arrows. White circles indicate normal people, grey indicate buffer people and black indicates the slow individual. The effective width of the left hand side of the stairwell is C.

Figure 84: Altruistic behaviour decreasing effective width of egress path

Grouping of individuals within the crowd – Rugby games are typically attended by groups of people. These groups may consist of a family unit, friends or a tour party. The sizes vary from 3-4 to 10-20. Different types of group will have different levels of cohesion. In an ingress or egress situation individuals within these groups attempt to maintain contact with each other. This often results in the group moving more slowly than the rest of the crowd. The front people move slowly to enable the back people to keep up and the rest of the group constantly shuffles against the crowd in an effort to maintain group integrity. If the group becomes separated then either individuals stop to wait for the others or both factions fight the crowd in order to reunite. The prevalence of this type of movement is determined by the event. In assigned seating situations this type of action may not be as dominant as for festival seating due to the structure assigned seating provides.

Group type movement is in contradiction to “ball-bearing/cellular automata” egress models. This may make them inappropriate for modelling social venues. Social events such as rugby or concerts produce much greater internal group characteristics than other types of crowd that are modelled. To draw a greater distinction, commuter crowds (e.g. trains) attract very little grouping phenomenon. Although models such as Simulex32 may accommodate this in determining average flow rates, the behavioural pattern is not exhibited when simulations are performed.

Reverse flow – In the evacuation of a high-rise, unidirectional flow occurs in the direction of the exit. With stadia, once the concourse is reached there are often multiple exits available. Stadia occupy large spaces. Should a person exit at the wrong point they would potentially have to walk around the outside of the grounds in order to get to the place they intended. People are therefore inclined to try and leave through a predetermined exit rather than the nearest one.

Many studies of human behaviour and fires show a predisposition to leaving the way that was entered. It is hypothesised that this may account for the relatively high calculated flow exhibited by Egress path 4. As observed in Egress path 2 and 4 people will move in different directions within the concourse rather than simply radiating from the structure. Other instances of reverse flow occur when people attempt to evacuate toward the danger. Due to the size of stadia it is possible that egressing crowds may initially move toward a hazard and then attempt to reverse directions. This type of movement initiated the Ibrox disaster. Having the ability for individuals to reverse direction motion themselves based on queuing would have improved the performance of the simulations that were performed.

Sloped floors – Simulex32 allows for flat surfaces and stairs. Many stadia have ramps as well as flat surfaces and stairs. These may be for wheelchair access or for more general use. In either case the rate of movement on a ramp is not the same as for a stair or for a flat surface and the population density and speed accommodated on a ramp is greater than that of a stairwell. In the simulations run as part of this study stairs were used in place of ramps. In general, sloped pathways are treated as level surfaces rather than as stairs. This is difficult to do and increases the complexity of the model when attempted in Simulex32. It is therefore easier to treat ramps as stairs. This may not be appropriate but it reduces the incidence of the model “people” malfunctioning.

Drunken behaviour – various behavioural anomalies may be observed in sports or other social crowds distinct from offices or general places of public assembly. The most notable of these is drunken behaviour. Drunken behaviour features more predominantly for stadia than for most other structures (excluding public houses). Drunken patrons have initiated stadium stampedes through fighting and disorderly behaviour. Alcohol may potentially impact on a person’s ability to react appropriately to an evacuation signal. Behaviour of inebriated individuals during an evacuation may include slow movement, surging, falling over and moving against the crowd. Evacuating such individuals may require assistance of staff not only to initiate their movement but also to escort them to safety. Euphoric fans may exhibit similar behaviour after a victory. Video footage at Bradford in 1985 showed an apparent lack of awareness of anything other than the outcome of the game by many fans. The somewhat random behaviour of drunks during an evacuation is not considered in Simulex32. The ability to model this type of behaviour may also be suitable for modelling of sleeping accommodation occupancies when awakened people may not behave as logically as they normally would.

Conflict Avoidance - Simulex32 will allow people to bump into each other and shuffle. This action sometimes jostles individuals free of a conflict. Other times individuals repeatedly bang into each other and the model has to be rerun. In reality this behaviour is almost never observed. People will move sideways or give way to each other. This type of conflict avoidance occurs on a regular basis in the general population especially where multiple flows merge. The inability to resolve or avoid such conflicts in modelling means that simulation of vomitories is severely inhibited.

Front to back communication – Many crowd-crushing instances occur as the result of poor front-to-back communication. Front-to-back or back-to-front communication refers to communication between those at the front and the back of a crowd. If for some reason an exit is blocked, those people at the front cannot get out but those people at the back are unaware. People at the back continue to push forward resulting in increased pressure on the front people. This culminates in either the blockage giving way or people becoming asphyxiated and injured by the pressure. In Simulex32, as the density of the crowd increases people slow down and eventually stop. There is no simulation of pressure build up as movement ceases once the inter-person distance reaches approximately 30cm.

Obscured vision such as at night or in smoke – Simulex32 makes no environmental considerations in determining travelling speed. Movement is determined solely by density and terrain.

Other variables that need to be considered are:

- Obscuration to vision by smoke or poor lighting
- Factors that affect a person's respiratory function; such as smoke and distance travelled.

Most people should not be affected by the distance to traverse half a stadium but, if they are travelling through light smoke the demands on their respiratory system may impact on their speed.

Poor visibility will contribute to a slow travelling speed. Poor visibility can occur through smoke obscuration affecting the visible distance and impacting on the effective illumination from lighting, or blackout conditions. Either of these may occur during a fire. In enclosed concourses and stairwells this is a greater issue than for outdoor areas.

Logic decisions such as line of sight and alternate exit selection – In many cases it is easier to travel farther to reach a destination more quickly. In modelling stadia in Simulex32, people always seek the shortest path regardless of how many others are in their way. This means that some stairways and pathways are over utilised and others are not used at all.

Evacuation times were greatly affected by path utilisation. This highlighted the importance of decision making in evacuation models. It can be observed in many situations that people have low tolerance for queuing. When an alternate path is in line of sight people will switch. An example of this is supermarket queues. Simulex32 does not accommodate changes in path choice. Distance maps determine the shortest distance to the exit and this is the path that is taken by people in the model.

An emergency such as a fire is artificially modelled by blocking off an area. All occupants automatically "know" this and seek the next shortest distance map. Backtracking or avoiding congestion is not possible in the model.

7 Conclusions and Recommendations

New Zealand stadia are not markedly different to stadia in other parts of the world. The only major differences are that New Zealand stadia are relatively small, because of the smaller population base, and crowd management is not as comprehensively regulated as in some countries. Stadium profiles range from older type structures through to modern structures that are in line with modern stadia found in Australia. The trend towards multifunctionality of stadia is common to many stadia in New Zealand and elsewhere. This has led to greater quantities of furnishing, electronics and catering than was evident in the past. In upgrading stadia to accommodate these additions fire protection has also been upgraded. There are however areas of some stadia that have not been structurally altered but have been developed to facilitate different usage patterns than were originally intended. In these structures there is a need for greater fire protection.

In comparing observational data, recommended values, and simulation modelling for stadia, it is apparent that there is some disparity between them. As anticipated, the results obtained from comparing standard egress movement values, simulations and observed egress movement do show stadium egress movement to be unique. Standard methods of anticipating egress movement when applied to stadia appear to be more conservative than actual movement. Although this study only produced a small sample of egress values for stadia it produced sufficient results as to determine that crowd movement at stadia is a special case and as such may warrant special consideration with regards to anticipating egress requirements.

Unfortunately consistency from observational data sets was insufficient to confidently isolate specific egress movement relationships for stadia based on effective width and density. This is may be attributable to a number of variables. These variables include experimental error, time of day (lighting), outcome of the game, variation in effective widths and weather conditions. An insufficient quantity of data was collected to isolate which variables played a significant role in influencing the observed movements. Other researchers have found wide variations in density for specific flows on flat surfaces[138] so the variations observed are not uncharacteristic for densely packed crowds. Further study of densely packed, large scale entertainment crowds is needed to quantify the egress movement relationships for stadia and determine whether these relationships are common to other densely populated, large scale entertainment venues such as indoor arenas.

In most of the observed egresses in this study crowd movement was expeditious. This implies that for the most part egress is managed appropriately and safe, timely evacuations should be achievable. Stadium management with the fastest clearance times achieved this through attempting to meet the goal of an eight minute evacuation. Stadia with longer evacuation times had no such goal. The recommendation of a standard acceptable evacuation time for stadia might be helpful in encouraging all stadia to improve their egress capabilities.

The occupant profile observed in this study varied from that observed in other crowded environments by other researchers. The implication of this is that crowd movement varies with the type of crowd. This emphasises the importance of trial evacuations or profiling of crowds in anticipating actual movement rates for different types of occupancy so as to ensure that appropriate egress times can be and are achieved. In this case the standard movement profiles in the SFPE handbook and the simulation software that was used underestimate egress movement, ergo it is likely that in other instances standard movement profiles may over estimate egress movement.

Consideration of specific crowd profiles such as mobility impairment may warrant special consideration in evacuation planning. Based on the observations of the formation of temporal congestion by slow moving patrons, egress planning should include the potential impact large numbers of elderly or disabled patrons could have on evacuations. This does not apply to all stadia, but those hosting disabled sporting events or events targeting the mature generation should consider the implications of this demographic on evacuation efficacy.

There is wide variation in the understanding and implementation of evacuation requirements and application of fire protection at New Zealand’s main stadia. The role management plays is key in affecting appropriate measures to ensure the safety of patrons in the event of a significant fire. Because alerting and fire protection systems are closely linked to effective evacuation, structures that accommodate large scale populations need to consider this in developing crowd management strategies. The variation in the level of fire protection afforded to and evacuation planning between stadia indicate that greater guidance is required in order to ensure a consistent minimum acceptable level of safety is provided to patrons. Currently no such guidance is provided in New Zealand for buildings accommodating very high numbers of occupants.

Stadium management have applied an ad hoc adoption of overseas guidelines and other documents in conjunction with occupational safety inputs in order to meet the requirements of the building code and manage normal occupant usage. There is no policing of this and inconsistencies and compromises to the intent of adopted documents can be found at a number of stadia. Adoption or recommendation of a common guideline such as the Green Guide would assist in consolidating crowd management and evacuation policies in a way that provides a consistent level of protection to patrons in fire and other situations as per the intent of the Acceptable Solutions in the Approved Document for New Zealand Building Code and the Fire Safety and Evacuation of Buildings Regulations.

The suitability of modelling software must be carefully considered when applied to determining evacuation requirements or performance at large scale structures with high numbers of occupants such as stadia. It should not be assumed that modelling software that is suitable for smaller structures will deliver meaningful results for all types and sizes of occupancies. An understanding of, and appreciation for software limitations, as well as an appreciation for the types of crowd movement associated with the structure to be modelled, must be held by the modeller in order to determine the viability of simulation outputs in application to the actual structure. The software used in this study was not suitable for application to stadia but did provide an excellent learning tool in identifying pitfalls that can be encountered when attempting to model stadia.

8 Appendices

8.1 Appendix A – Glossary

Term	**Definition**
Arena	Area enclosed by stands e.g. playing field.
CIMS	Coordinated Incident Management System as used by the emergency services and others in coordinating multi agency response efforts to both emergency and non-emergency events
Concessions	Temporary or permanent retail outlets located within the grounds. These typically sell, memorabilia, food and beverages. Those selling food and beverages typically manufacture or prepare some of the food and beverages within the concession area.
Concourse	The walkways within the stadium that permit access to the various seating areas
Control Room	Room from which security, police, ambulance and sometimes other services are commanded during an event. Video surveillance and intercoms are usually based in this room. This room may contain a mimic fire panel.
Egress	The process of leaving the venue
Embankment	Sloping area for festival seating
Emergency	Abnormal situation requiring response by emergency services in order to re-establish order or preserve safety of individuals
Event	For the purpose of this document an event indicates a scheduled activity that takes place in a stadium, primarily the arena, to which patrons attend e.g. rugby game.

Festival seating	Area in which no seats are provided and people are be able to sit on the ground or stand. Permanent festival seating areas often consist of grassed or concrete terraces or embankments with crush barriers interspersed. These may have aisles but do not have vomitories or roofs. Festival seating at concerts is often provided in the area in front of the stage. Exits are either at the front and/or back and/or sides of the festival seating area.
Full time	Signal that ends a game of sport.
Grounds	The entire property within which the stadium is located
Incident	Unscheduled activity within the grounds that disrupts viewing/attendance of the event by patrons or the occurrence of the event itself e.g. a fire. An incident may lead to an emergency.
Ingress	The process if entering the venue
Lounge	Open plan room, usually fully furnished with carpet, a variety of fabrics and furniture items, containing a licensed bar. Access to these areas is usually controlled by security.
Media Suite	Area in which the media is based during an event. Usually unfurnished but will contain many power outputs. On an event day such rooms usually contain large amounts of cables, photographic equipment, catering facilities, backdrops and makeup stations. These suites contain large viewing panels facing the arena. In many stadia these viewing panels may be opened.
Patrons	Those people attending the venue for the sole purpose of viewing the event.
Private Suite	Viewing room and/or section of the stand that is either owned or leased by private individuals. These suites may be occupied outside of event hours. Private suites are typically furnished by the owner or leasee and may contain plush furnishings. Catering and bar facilities are typically included in the suite during an event.
Restaurant	Similar to a lounge but with table and chair seating and catering. This may include facilities for heating food. Food preparation may or may not occur in an adjoining area.

Stadium	Arena, surrounding stands, concourse and vomitories
Staff	Contractors, stadium employees or volunteers performing a function at the venue that contributes to the event.
Steward	Anyone whose main occupation is to direct the crowd or members of the crowd into or out of the stadium. This includes caterers but excludes concessionaries
Terraces	Sloping area for festival seating
Venue	Site on which an event occurs and attendees have access to. May or may not include the entire grounds.
Viewing panels	Windows facing the arena. Usually made of glass or plastic. Sometimes these panels can be opened. Panels typically include windows between adjoining suites so as to increase the view.
Vomitories	Access routes into and out of the stands

8.2 Appendix B – Interviews

Survey Questions – The stadium questions were asked at all stadia that were visited. The Fire service questions were asked where it was possible. More than one person may have been required to answer all the questions in either section of the survey.

8.2.1 Questionnaire

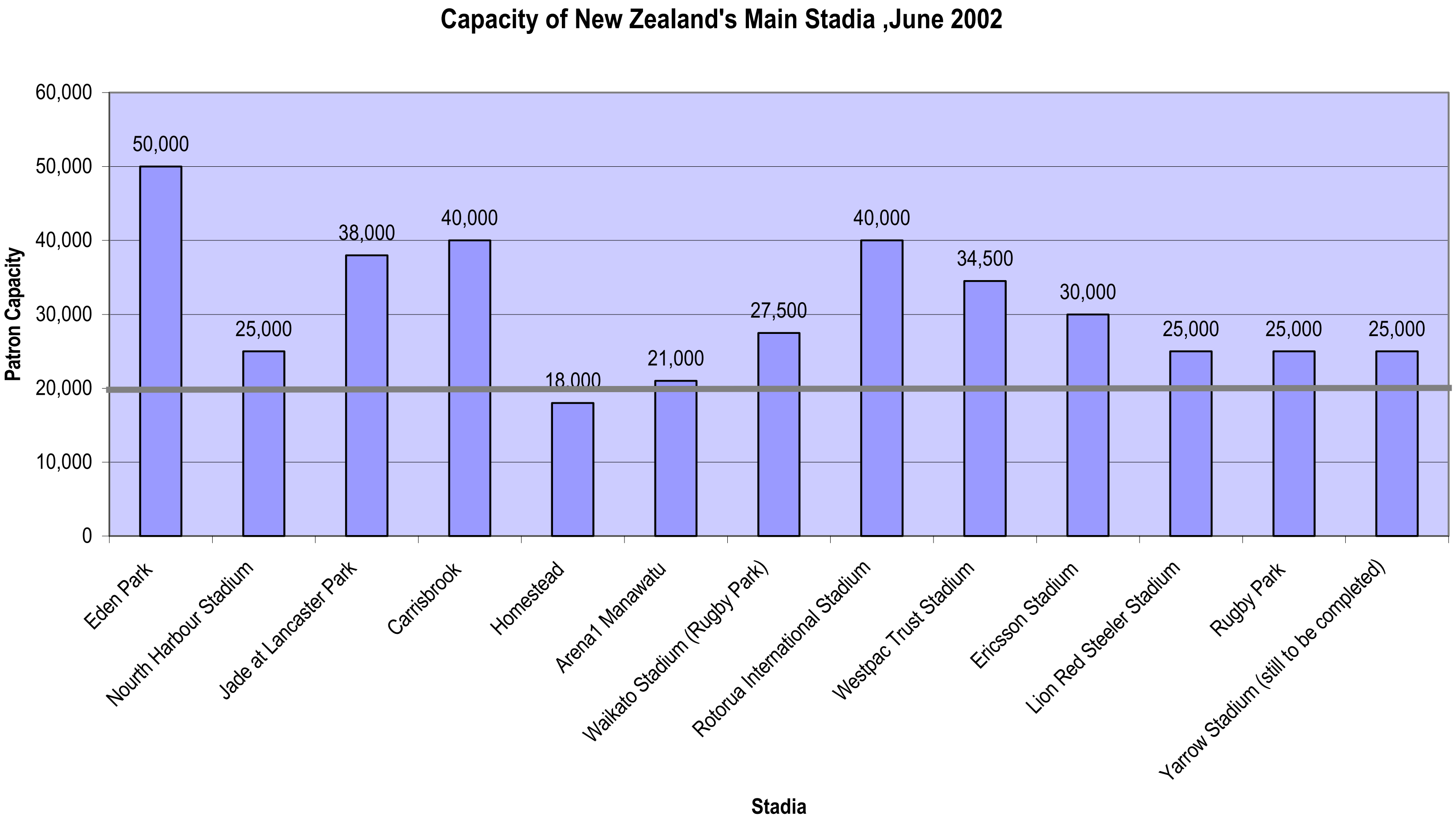
Name of Venue:
Date of Interview:
Stadium Questions
Event at Stadium:
Crowd attendance:
Reason for limited capacity attendance (if applicable):
Typical time for crowd to clear grounds following event:
Are there normally any difficulties in clearing the grounds? If so what and why?
Has your fire protection system ever been compromised by deliberate acts or otherwise? Elaborate.
Do you have an operations centre?
Who is involved in the operations centre? (Job title, experience and training)
What other roles are performed with respect to crowd safety, egress and crowd behaviour prior to /during/after the event?
Do you have any concerns about the way operations may perform in an emergency situation such as a fire?
When was your evacuation plan last evaluated?
When was your fire protection system last evaluated?
Do you believe these plans and systems are of an acceptable standard?
Describe your fire protection system: Egress Detection Structural Integrity Warning Systems Confinement

Smoke control Extinguishment Access for fire service Do you have any fire service or response teams on site during an event?
What problems do you normally face during an event?
If there is a power cut how does this affect your fire protection system?
Are you familiar with CIMS? What provision is there for using staff under emergency situations within CIMS by the lead agency?
If an aspect of your fire protection system is isolated how long does it take to bring it back on line?
Are there any aspects of your stadium that people have questioned with regards to fire safety and egress?
If so what are they and what is your answer to their questions?
What impact does live television broadcasting have on your willingness and or ability to stop a game and or evacuate the stadium?
Do you believe that your stadium can be evacuated expeditiously and safely if required?
The information gathered in this survey can remain anonymous if required.
Is it acceptable to name the stadium this data refers to in my thesis?
Is there certain data you do not want attributed specifically to this stadium?
If not, then this information shall be attributed to one (or more) stadium(s).
Fire Service Questions
What is your fire service role in relation to the stadium?
Are you familiar with the stadium?
How often do you visit the stadium during event time?
During non event time?
What do you anticipate as your response time during a scheduled event?
At the end of a scheduled event?
Are you familiar with the stadiums emergency plans as they relate to fire service attendance?
Do you have any concerns about the stadium from a fire fighting perspective?
Do you believe the stadium could be evacuated expeditiously and safely if required?

8.2.2 Interviewees

Stadium	Interviewee	Organisation	Title
Carisbrook	Mark Perham	Carisbrook Stadium	
Carisbrook	Neville Frost		OSH Contractor
Eden Park	Jayson Ryan	Red Badge Group	Operations Director
Eden Park	Murray Reade	Eden Park Stadium	
Eden Park	Trevor Sampson	Trevor Sampson	
Jade	Hamish McLennan	Holmes Fire and Safety	Director
Jade	Jayson Ryan	Red Badge Group	Operations Director
MCG	Julie McLoughlin	Melbourne Cricket Club	Manager Safety and Training
MCG	Peter Murphy	Melbourne Cricket Club	
MCG	Scott Butler	Melbourne Cricket Club	Facilities Manager
North Harbour	Murray Dick	North Harbour Stadium	Operations Manager
North Harbour	Neville Trevarton	New Zealand Fire Service	North Shore District Chief Fire Officer
Stadium Australia/Sydney Cricket Ground/ Sydney Football Stadium	Bob Russell	New South Wales Fire Brigade	Station Commander
Stadium Australia/Sydney Cricket Ground/ Sydney Football Stadium	Chris Jurgeit	NSW Fire Service	Fire Safety Officer
Sydney Superdome	Tony Edwards	Sydney Superdome	Security Manager
Waikato Stadium	Jayson Ryan	Red Badge Group	Operations Director
Waikato Stadium	Keith Parker	Waikato Stadium	Stadium Operations Manager
Waikato Stadium	Kevin Richards	New Zealand Police	Senior Seargent
Waikato Stadium	Neil Callaghan, IQP	Building Compliance Ltd	Director
Westpac Trust	Colin Clemens	New Zealand Fire Service	Fire Safety Officer
Westpac Trust	Mark Nunn	Westpac Trust Stadium	Operations Manager

8.3 Appendix C – Stadium Statistics



Yarrow Stadium is not currently functional. Upgrades are scheduled for completion in September 2002.

Figure 85: Capacities of New Zealand’s main stadia

Profile of a New Zealand Stadium

Events held in the last year: 24

Hours used for events in the last year (excluding preparation time): 241 hours

Occupancy Data for Events over a three-year period

%age of Capacity Occupancy	Estimated %age of occupied hours based on event types
>0%	100%
>1%	99%
>2%	94%
>5%	76%
>10%	66%
>15%	62%
>20%	59%
>25%	54%
>30%	53%
>40%	49%
>50%	49%
>60%	39%
>75%	27%
>80%	25%
>85%	19%
>90%	16%
>95%	14%
100%	7%

Table 11: Occupancy Data For a New Zealand Stadium

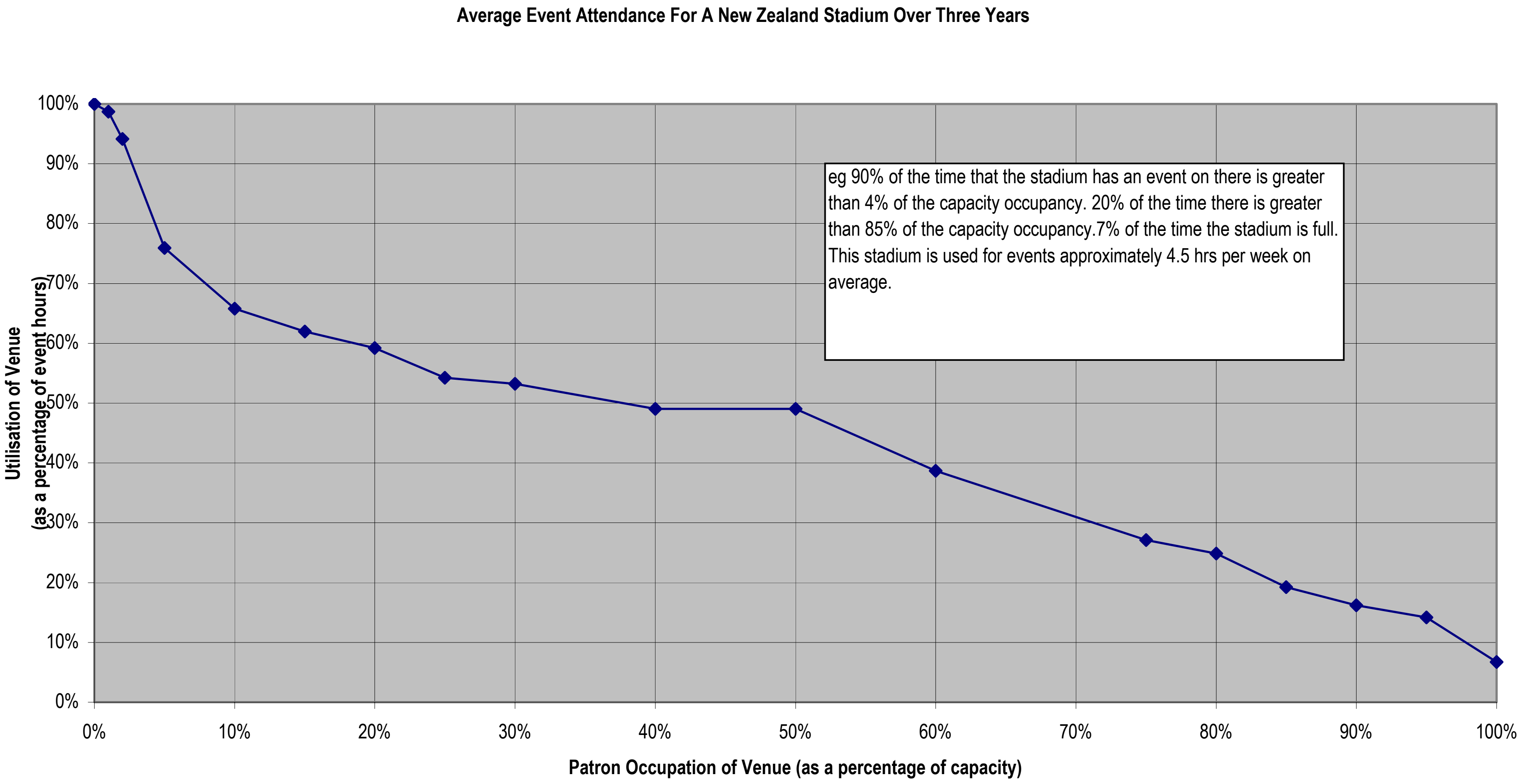


Figure 86: Average Event Attendance for a New Zealand Stadium over three years

8.4 Appendix D – Stadium Callouts

Information kindly provided by the New Zealand Fire Service (15th April 2002)

Grandstand, Stadium, Sports field

	All Fires	Hazardous Emergencies	Overpressure, Rupture, Explosives, Over Heating	Rescue, Emergency, Medical Call	Special Service Calls	Natural Disasters	False Alarms	All Incident Types
1990/91	42	2	0	3	4	0	34	85
1991/92	12	0	0	0	3	0	21	36
1992/93	43	1	1	0	6	0	38	89
1993/94	47	1	0	0	9	0	50	108
1994/95	52	1	0	4	14	3	53	127
1995/96	75	2	0	4	19	3	76	179
1996/97	92	4	0	10	28	5	73	212
1997/98	118	2	0	16	29	2	94	261
1998/99	96	5	0	18	32	3	115	269
1999/00	75	3	0	4	31	1	93	207
2000/01	132	8	1	8	33	2	31	215
2001/02	125	3	0	5	40	1	0	174
All Years	**909**	**32**	**2**	**72**	**248**	**20**	**678**	**1,962**

Table 12: Stadium Call Outs By Incident Type 1990-2002

Stadium Incidents since January 1999

	Structure Fire	Mobile Property Fire	Rescue, Emergency, Medical	Flammable Liquid, Gas Incident	Special Service	Mobil Property	False Alarms	Total
North Harbour Stadium	1	1					2	4
Jade Stadium							7	7
WestpacTrust Stadium (Wgtn)			1		1		3	5
WestpacTrust Centre (ChCh)							3	3
Carisbrook Ground				1	1	1		3
Eden Park	1						2	3
Rotorua International Stadium							3	3
Waikato Stadium		*- No data as stadium is new and not in Database*						0

Table 13: Stadium Call Outs By Stadium (1999-2002)

Details:	**Date:**	**Cause:**
North Harbour Stadium	08/16/2000	False alarm -defective
North Harbour Stadium	06/1/2000	Car/truck fire
North Harbour Stadium	05/6/2001	Structure Fire with damage
North Harbour Stadium	01/19/2001	False alarm -defective
Jade Stadium	06/3/1999	False alarm - accidental operation
Jade Stadium	09/30/2000	False alarm - excess smoke, heat
Jade Stadium	03/2/2001	False alarm - good intent - steam/dust mistaken for smoke
Jade Stadium	09/17/2000	False alarm - accidental operation
Jade Stadium	03/9/2001	False alarm -defective
Jade Stadium	03/31/2002	False alarm - malicious
Jade Stadium	04/3/2001	False alarm -defective
WestpacTrust Stadium (Wgtn)	10/11/2000	False alarm -defective
WestpacTrust Stadium (Wgtn)	10/7/2000	False alarm -defective
WestpacTrust Stadium (Wgtn)	09/7/2000	False alarm - undetermined alarm activation
WestpacTrust Stadium (Wgtn)	01/30/2001	Rescue - in or under machinery
WestpacTrust Stadium (Wgtn)	09/5/2001	Assist ambulance
WestpacTrust Centre (ChCh)	02/25/2001	False alarm - malicious
WestpacTrust Centre (ChCh)	02/11/2001	False alarm -defective
WestpacTrust Centre (ChCh)	02/3/2002	False alarm - not classified
Carisbrook Ground	02/6/2002	Mobile property accident
Carisbrook Ground	09/17/2001	Repair roof
Carisbrook Ground	04/7/2001	Liquid, gas spill no fire
Rotorua International Stadium	02/24/2002	False alarm - accidental operation
Rotorua International Stadium	03/4/2002	False alarm -defective
Rotorua International Stadium	08/18/2001	False alarm -defective
Eden Park	02/10/1999	Structure Fire with damage
Eden Park	12/13/1999	False alarm - good intent - steam/dust mistaken for smoke
Eden Park	05/25/2001	False alarm - accidental operation

Table 14: Stadium Call Out Details By Stadium (1999-2002)

8.5 Appendix E – Guide to spread sheet calculations

Egress Path	**1**		Description	Gate	
Viewed from	In front, level		Terrain	Flat	
Day or Night (D/N)	D		Wet, Cold or Dry (W/C/D)	D	
Observational Data	**Value**	Unit		**Value**	Unit
Capacity of Stadium (g)		people	Width of path (W)	4.5	metres
Attendance at event (q)		people	Boundary layer (b)	0.1	metres
Time to clear stadium (tc)	26	minutes	Effective Width (W_e)	4.3	metres
Flow Rates					
Time to clear gate/path/stair (h)	26	minutes	Specific flow		people/s/m eff. width
Total usage of gate/path/stair (y)	1982	people			
Time to reach max F_s (t)	5	minutes	Max. Specific Flow (F_s -max)	0.71	people/s/m eff. width
Total usage at max F_s (x)	541	people	Population		
Density at max F_s		people/m^2			
Time to reach sustained F_s	6	minutes	Sustained Specific Flow (F_s)	0.42	people/s/m eff. width
Duration of sustained F_s	7	minutes	Population		
Density at sustained F_s		people/m^2			
Queuing time	0	seconds	Max. Calculated Flow (F_c)	183	people/minute
Queue density	N/A	people/m^2			
Boundary layer maintained (Y/N)	Y				
Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)			**Individual Speeds**		
Fraction to leave through gate pre max F_s (A)	0.27	-	Travel distance (L)		metres
Fraction of populous to use gate (B)	0.05	-	Terrain		
Total to leave through gate post max F_s (C)	1441	people	Total no. individuals tracked		
Estimated populous to leave pre max F_s (f)	10372	people	Mean speed		m/s
Estimated populous to leave post max F_s (r)	27628	people	Maximum speed		m/s
Est. min. egress time for gate (Tg)	13	minutes	Minimum speed		m/s
Est. min. egress time for populous (Tp)	13	minutes	Density at max. speed		people/m^2
Est. min. egress time for full stadium (Tf)	13	minutes	Density at min. speed		people/m^2
Evacuation Estimates (based on established research)					
Anticipated F_s (Fruin)		k=1.40(flat), 1.16 (stair) (m/s)		1.4	people/s/m eff. width
Anticipated F_c (Fruin)				361	people/minute
Anticipated F_s (Poyner)		k=1.8 (flat) (m/s)		1.8	people/s/m eff. width
Anticipated F_c (Poyner)				464	people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)		S=1.19(flat), 1.00 (stair) (m/s)		0.6	people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)					people/m^2

Egress Path	**2**		Description	Vomitory	
Viewed from	In front, above		Terrain	Flat	
Day or Night (D/N)	N		Wet, Cold or Dry (W/C/D)	DC	
Observational Data	**Value**	Unit		**Value**	Unit
Capacity of Stadium (g)		people	Width of path (W)		metres
Attendance at event (q)		people	Boundary layer (b)		metres
Time to clear stadium (tc)	21	minutes	Effective Width (W_e)		metres
Flow Rates					
Time to clear gate/path/stair (h)	21	minutes	Specific flow		people/s/m eff. width
Total usage of gate/path/stair (y)		people			
Time to reach max F_s (t)		minutes	Max. Specific Flow (F_s -max)		people/s/m eff. width
Total usage at max F_s (x)		people	Population		
Density at max F_s		people/m^2			
Time to reach sustained F_s		minutes	Sustained Specific Flow (F_s)		people/s/m eff. width
Duration of sustained F_s		minutes			
Density at sustained F_s		people/m^2			
Queuing time	0	seconds	Max. Calculated Flow (F_c)		people/minute
Queue density	N/A	people/m^2			
Boundary layer maintained (Y/N)	N				
Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)			**Individual Speeds**		
Fraction to leave through gate pre max F_s (A)		-	Travel distance (L)	8.2	metres
Fraction of populous to use gate (B)		-	Terrain	Flat	
Total to leave through gate post max F_s (C)		people	Total no. individuals tracked	50	
Estimated populous to leave pre max F_s (f)		people	Mean speed	1.7	m/s
Estimated populous to leave post max F_s (r)		people	Max. speed	2.7	m/s
Est. min. egress time for gate (Tg)		minutes	Minimum speed	1	m/s
Est. min. egress time for populous (Tp)		minutes	Density at max. speed	0.28*	people/m^2
Est. min. egress time for full stadium (Tf)		minutes	Density at min. speed	0.34*	people/m^2
Evacuation Estimates (based on established research)					
Anticipated F_s (Fruin)		k=1.40(flat), 1.16 (stair) (m/s)		1.4	people/s/m eff. width
Anticipated F_c (Fruin)					people/minute
Anticipated F_s (Poyner)		k=1.8 (flat) (m/s)		1.8	people/s/m eff. width
Anticipated F_c (Poyner)					people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)		S=1.19(flat), 1.00 (stair) (m/s)			people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)					people/m^2
* approximate as there was no defined path width					

Egress Path	**3**	Description	Descending
Viewed from	Below, in front	Terrain	Stairs
Day or Night (D/N)	N	Wet, Cold or Dry (W/C/D)	D

Observational Data	**Value**	Unit		**Value**	Unit
Capacity of Stadium (g)		people	Width of path (W)		metres
Attendance at event (q)		people	Boundary layer (b)		metres
Time to clear stadium (tc)	18	minutes	Effective Width (W_e)		metres
Flow Rates					
Time to clear gate/path/stair (h)		minutes	Specific flow		people/s/m eff. width
Total usage of gate/path/stair (y)		people			
Time to reach max F_s (t)		minutes	Max. Specific Flow (F_s -max)		people/s/m eff. width
Total usage at max F_s (x)		people	Population		
Density at max F_s		people/m^2			
Time to reach sustained F_s		minutes	Sustained Specific Flow (F_s)		people/s/m eff. width
Duration of sustained F_s		minutes			
Density at sustained F_s		people/m^2			
Queuing time	0	seconds	Max. Calculated Flow (F_c)		people/minute
Queue density	N/A	people/m^2			
Boundary layer maintained (Y/N)	Y				
Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)			**Individual Speeds**		
Fraction to leave through gate pre max F_s (A)		-	Travel distance (L)	6.5	metres
Fraction of populous to use gate (B)		-	Terrain		
Total to leave through gate post max F_s (C)		people	Total no. individuals tracked		
Estimated populous to leave pre max F_s (f)		people	Mean speed	0.8	m/s
Estimated populous to leave post max F_s (r)		people	Max. speed	1.3	m/s
Est. min. egress time for gate (Tg)		minutes	Minimum speed	0.1	m/s
Est. min. egress time for populous (Tp)		minutes	Density at max. speed		people/m^2
Est. min. egress time for full stadium (Tf)		minutes	Density at min. speed		people/m^2
Evacuation Estimates (based on established research)					
Anticipated F_s (Fruin)		k=1.40(flat), 1.16 (stair) (m/s)		1.16	people/s/m eff. width
Anticipated F_c (Fruin)					people/minute
Anticipated F_s (Poyner)		k=1.8 (flat) (m/s)			people/s/m eff. width
Anticipated F_c (Poyner)					people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)		S=1.19(flat), 1.00 (stair) (m/s)			people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)					people/m^2

Egress Path	**4**		Description	Concourse	
Viewed from	Above		Terrain	Flat	
Day or Night (D/N)	D		Wet, Cold or Dry (W/C/D)	D	
Observational Data	**Value**	Unit		**Value**	Unit
Capacity of Stadium (g)		people	Width of path (W)	9.5	metres
Attendance at event (q)		people	Boundary layer (b)	0.46	metres
Time to clear stadium (tc)	18	minutes	Effective Width (W_e)	8.58	metres
Flow Rates					
Time to clear gate/path/stair (h)	5	minutes	Specific flow		people/s/m eff. width
Total usage of gate/path/stair (y)	2297	people			
Time to reach max F_s (t)	1.25	minutes	Max. Specific Flow (F_s -max)	1.98	people/s/m eff. width
Total usage at max F_s (x)	908	people	Population	77	
Density at max F_s	2.56	people/m^2			
Time to reach sustained F_s	1	minutes	Sustained Specific Flow (F_s)	0.34	people/s/m eff. width
Duration of sustained F_s	0.5	minutes			
Density at sustained F_s	0.24	people/m^2			
Queuing time	0	seconds	Max. Calculated Flow (F_c)	1019	people/minute
Queue density	N/A	people/m^2			
Boundary layer maintained (Y/N)	N				
Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)			**Individual Speeds**		
Fraction to leave through gate pre max F_s (A)	0.40	-	Travel distance (L)	3.5	metres
Fraction of populous to use gate (B)	0.06	-	Terrain	Flat	
Total to leave through gate post max F_s (C)	1389	people	Total no. individuals tracked	20	
Estimated populous to leave pre max F_s (f)	14824	people	Mean speed	1.5	m/s
Estimated populous to leave post max F_s (r)	22676	people	Max. speed	1.8	m/s
Est. min. egress time for gate (Tg)	3	minutes	Minimum speed	1.0	m/s
Est. min. egress time for populous (Tp)	6	minutes	Density at max. speed		people/m^2
Est. min. egress time for full stadium (Tf)	6	minutes	Density at min. speed		people/m^2

Evacuation Estimates (based on established research)			
Anticipated F_s (Fruin)	k=1.40(flat), 1.16 (stair) (m/s)	1.4	people/s/m eff. width
Anticipated F_c (Fruin)		721	people/minute
Anticipated F_s (Poyner)	k=1.8 (flat) (m/s)	1.8	people/s/m eff. width
Anticipated F_c (Poyner)		927	people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)	S=1.19(flat), 1.00 (stair) (m/s)	1.7	people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)		0.23	people/m^2

Egress Path	**7**		Description	Descending	
Viewed from	Below		Terrain	Stair	
Day or Night (D/N)	N		Wet, Cold or Dry (W/C/D)	D	
Observational Data	**Value**	Unit		**Value**	Unit
Capacity of Stadium (g)		people	Width of path (W)	1.5	metres
Attendance at event (q)		people	Boundary layer (b)	0.15	metres
Time to clear stadium (tc)	17	minutes	Effective Width (W_e)	1.2	metres
Flow Rates					
Time to clear gate/path/stair (h)	10	minutes	Specific flow		people/s/m eff. width
Total usage of gate/path/stair (y)	651	people			
Time to reach max F_s (t)	2	minutes	Max. Specific Flow (F_s -max)	1.31	people/s/m eff. width
Total usage at max F_s (x)	158	people	Population	13	
Density at max F_s	3	people/m^2			
Time to reach sustained F_s	2.5	minutes	Sustained Specific Flow (F_s)	1.1	people/s/m eff. width
Duration of sustained F_s	8	minutes			
Density at sustained F_s	2.8	people/m^2			
Queuing time	8	seconds	Max. Calculated Flow (F_c)	94	people/minute
Queue density	4.1	people/m^2			
Boundary layer maintained (Y/N)	Y				
Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)			**Individual Speeds**		
Fraction to leave through gate pre max F_s (A)	0.24	-	Travel distance (L)	3.6	metres
Fraction of populous to use gate (B)	0.03	-	Terrain	Stair	
Total to leave through gate post max F_s (C)	493	people	Total no. individuals tracked	33	
Estimated populous to leave pre max F_s (f)	4854	people	Mean speed	0.4	m/s
Estimated populous to leave post max F_s (r)	15146	people	Max. speed	0.5	m/s
Est. min. egress time for gate (Tg)	7	minutes	Minimum speed	0.2	m/s
Est. min. egress time for populous (Tp)	11	minutes	Density at max. speed		people/m^2
Est. min. egress time for full stadium (Tf)	19	minutes	Density at min. speed		people/m^2

Evacuation Estimates (based on established research)			
Anticipated F_s (Fruin)	k=1.40(flat), 1.16 (stair) (m/s)	1.16	people/s/m eff. width
Anticipated F_c (Fruin)		84	people/minute
Anticipated F_s (Poyner)	k=1.8 (flat) (m/s)		people/s/m eff. width
Anticipated F_c (Poyner)		0	people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)	S=1.19(flat), 1.00 (stair) (m/s)	1.3	people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)		2.75	people/m^2

Egress Path	**8**	Description	Concourse

Viewed from	Above		Terrain	Flat	
Day or Night (D/N)	D		Wet, Cold or Dry (W/C/D)	D	
Observational Data	**Value**	Unit		**Value**	Unit
Capacity of Stadium (g)	38,000	people	Width of path (W)	2.5	metres
Attendance at event (q)	18,000	people	Boundary layer (b)	0.2	metres
Time to clear stadium (tc)	18	minutes	Effective Width (W_e)	2.1	metres
Flow Rates					
Time to clear gate/path/stair (h)	6	minutes	Specific flow		people/s/m eff. width
Total usage of gate/path/stair (y)	551	people			
Time to reach max F_s (t)	2	minutes	Max. Specific Flow (F_s -max)	0.84	people/s/m eff. width
Total usage at max F_s (x)	178	people	Population	37	
Density at max F_s	3.8	people/m^2			
Time to reach sustained F_s	0.5	minutes	Sustained Specific Flow (F_s)	0.79	people/s/m eff. width
Duration of sustained F_s	4.5	minutes			
Density at sustained F_s	2.6	people/m^2			
Queuing time	0	seconds	Max. Calculated Flow (F_c)	106	people/minute
Queue density	N/A	people/m^2			
Boundary layer maintained (Y/N)	N				
Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)			**Individual Speeds**		
Fraction to leave through gate pre max F_s (A)	0.32	-	Travel distance (L)	4.6	metres
Fraction of populous to use gate (B)	0.03	-	Terrain	Flat	
Total to leave through gate post max F_s (C)	373	people	Total no. individuals tracked	20	
Estimated populous to leave pre max F_s (f)	5814	people	Mean speed	0.4	m/s
Estimated populous to leave post max F_s (r)	12185	people	Max. speed	0.5	m/s
Est. min. egress time for gate (Tg)	6	minutes	Minimum speed	0.3	m/s
Est. min. egress time for populous (Tp)	13	minutes	Density at max. speed		people/m^2
Est. min. egress time for full stadium (Tf)	24	minutes	Density at min. speed		people/m^2
Evacuation Estimates (based on established research)					
Anticipated F_s (Fruin)		k=1.40(flat), 1.16 (stair) (m/s)		1.4	people/s/m eff. width
Anticipated F_c (Fruin)				176	people/minute
Anticipated F_s (Poyner)		k=1.8 (flat) (m/s)		1.8	people/s/m eff. width
Anticipated F_c (Poyner)				227	people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)		S=1.19(flat), 1.00 (stair) (m/s)		0.7	people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)				1.98	people/m^2

Egress Path	**10**	Description	Concourse
Viewed from	Above, in front	Terrain	Flat
Day or Night (D/N)	N	Wet, Cold or Dry (W/C/D)	DC

Observational Data	**Value**	Unit		**Value**	Unit
Capacity of Stadium (g)		people	Width of path (W)	3	metres
Attendance at event (q)		people	Boundary layer (b)	0.2	metres
Time to clear stadium (tc)	19	minutes	Effective Width (W_e)	2.6	metres
Flow Rates					
Time to clear gate/path/stair (h)		minutes	Specific flow		people/s/m eff. width
Total usage of gate/path/stair (y)		people			
Time to reach max F_s (t)	10.75	minutes	Max. Specific Flow (F_s -max)	1.94	people/s/m eff. width
Total usage at max F_s (x)		people	Population	30	
Density at max F_s	3	people/m^2			
Time to reach sustained F_s	7.5	minutes	Sustained Specific Flow (F_s)	1.53	people/s/m eff. width
Duration of sustained F_s	2.5	minutes			
Density at sustained F_s	2.8	people/m^2			
Queuing time	0	seconds	Max. Calculated Flow (F_c)	303	people/minute
Queue density	N/A	people/m^2			
Boundary layer maintained (Y/N)	N				

Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)			**Individual Speeds**		
Fraction to leave through gate pre max F_s (A)	-		Travel distance (L)	3.9	metres
Fraction of populous to use gate (B)	-		Terrain	Flat	
Total to leave through gate post max F_s (C)		people	Total no. individuals tracked	10	
Estimated populous to leave pre max F_s (f)		people	Mean speed	0.5	m/s
Estimated populous to leave post max F_s (r)		people	Max. speed	0.7	m/s
Est. min. egress time for gate (Tg)	11	minutes	Minimum speed	0.4	m/s
Est. min. egress time for populous (Tp)		minutes	Density at max. speed		people/m^2
Est. min. egress time for full stadium (Tf)		minutes	Density at min. speed		people/m^2

Evacuation Estimates (based on established research)			
Anticipated F_s (Fruin)	k=1.40(flat), 1.16 (stair) (m/s)	1.4	people/s/m eff. width
Anticipated F_c (Fruin)		218	people/minute
Anticipated F_s (Poyner)	k=1.8 (flat) (m/s)	1.8	people/s/m eff. width
Anticipated F_c (Poyner)		281	people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)	S=1.19(flat), 1.00 (stair) (m/s)	1.6	people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)		3.06	people/m^2

Egress Path	**13**	Description	Concourse (half time)

Viewed from	Above, side on	Terrain	Flat
Day or Night (D/N)	N	Wet, Cold or Dry (W/C/D)	D

Observational Data	**Value**	Unit		**Value**	Unit
Capacity of Stadium (g)		people	Width of path (W)	5.4	metres
Attendance at event (q)		people	Boundary layer (b)	0.46	metres
Time to clear stadium (tc)	18	minutes	Effective Width (W_e)	4.48	metres
Flow Rates					
Time to clear gate/path/stair (h)		minutes	Specific flow		people/s/m eff. width
Total usage of gate/path/stair (y)		people			
Time to reach max F_s (t)	0.75	minutes	Max. Specific Flow (F_s -max)	1.87	people/s/m eff. width
Total usage at max F_s (x)		people	Population	61	
Density at max F_s	3	people/m^2			
Time to reach sustained F_s	6	minutes	Sustained Specific Flow (F_s)	1.51	people/s/m eff. width
Duration of sustained F_s	1.5	minutes			
Density at sustained F_s	1.9	people/m^2			
Queuing time	0	seconds	Max. Calculated Flow (F_c)	503	people/minute
Queue density	N/A	people/m^2			
Boundary layer maintained (Y/N)	Y				
Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)			**Individual Speeds**		
Fraction to leave through gate pre max F_s (A)		-	Travel distance (L)	4.5	metres
Fraction of populous to use gate (B)		-	Terrain	Flat	
Total to leave through gate post max F_s (C)		people	Total no. individuals tracked		
Estimated populous to leave pre max F_s (f)		people	Mean speed	0.7	m/s
Estimated populous to leave post max F_s (r)		people	Max. speed	1.1	m/s
Est. min. egress time for gate (Tg)		minutes	Minimum speed	0.4	m/s
Est. min. egress time for populous (Tp)		minutes	Density at max. speed		people/m^2
Est. min. egress time for full stadium (Tf)		minutes	Density at min. speed		people/m^2
Evacuation Estimates (based on established research)					
Anticipated F_s (Fruin)		k=1.40(flat), 1.16 (stair) (m/s)		1.4	people/s/m eff. width
Anticipated F_c (Fruin)				376	people/minute
Anticipated F_s (Poyner)		k=1.8 (flat) (m/s)		1.8	people/s/m eff. width
Anticipated F_c (Poyner)				484	people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)		S=1.19(flat), 1.00 (stair) (m/s)		1.6	people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)				2.16	people/m^2

Egress Path	**14**	Description	Concourse
Viewed from	Above, side on	Terrain	Flat

Day or Night (D/N)	N		Wet, Cold or Dry (W/C/D)	D

Observational Data	**Value**	Unit		**Value**	Unit
Capacity of Stadium (g)		people	Width of path (W)	5.4	metres
Attendance at event (q)		people	Boundary layer (b)	0.46	metres
Time to clear stadium (tc)	18	minutes	Effective Width (W_e)	4.48	metres
Flow Rates					
Time to clear gate/path/stair (h)	10	minutes	Specific flow		people/s/m eff. width
Total usage of gate/path/stair (y)	1667	people			
Time to reach max F_s (t)	2	minutes	Max. Specific Flow (F_s -max)	1.55	people/s/m eff. width
Total usage at max F_s (x)	501	people	Population	49	
Density at max F_s	2.4	people/m^2			
Time to reach sustained F_s	4.5	minutes	Sustained Specific Flow (F_s)	1.23	people/s/m eff. width
Duration of sustained F_s	1.5	minutes			
Density at sustained F_s	1.4	people/m^2			
Queuing time	0	seconds	Max. Calculated Flow (F_c)	417	people/minute
Queue density	N/A	people/m^2			
Boundary layer maintained (Y/N)	Y				

Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)			**Individual Speeds**		
Fraction to leave through gate pre max F_s (A)	0.30	-	Travel distance (L)	4.5	metres
Fraction of populous to use gate (B)	0.06	-	Terrain	Flat	
Total to leave through gate post max F_s (C)	1166	people	Total no. individuals tracked	20	
Estimated populous to leave pre max F_s (f)	8115	people	Mean speed	0.9	m/s
Estimated populous to leave post max F_s (r)	18885	people	Max. speed	1.5	m/s
Est. min. egress time for gate (Tg)	5	minutes	Minimum speed	0.6	m/s
Est. min. egress time for populous (Tp)	7	minutes	Density at max. speed		people/m^2
Est. min. egress time for full stadium (Tf)	7	minutes	Density at min. speed		people/m^2

Evacuation Estimates (based on established research)			
Anticipated F_s (Fruin)	k=1.40(flat), 1.16 (stair) (m/s)	1.4	people/s/m eff. width
Anticipated F_c (Fruin)		376	people/minute
Anticipated F_s (Poyner)	k=1.8 (flat) (m/s)	1.8	people/s/m eff. width
Anticipated F_c (Poyner)		484	people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)	S=1.19(flat), 1.00 (stair) (m/s)	1.3	people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)		1.37	people/m^2

Egress Path	**15**	Description	Aisle
Viewed from	Above, behind	Terrain	Ascending
Day or Night (D/N)	N	Wet, Cold or Dry (W/C/D)	D

Observational Data	**Value**	Unit		**Value**	Unit
Capacity of Stadium (g)		people	Width of path (W)	1.5	metres
Attendance at event (q)		people	Boundary layer (b)	0.1	metres
Time to clear stadium (tc)	18	minutes	Effective Width (W_e)	1.3	metres
Flow Rates					
Time to clear gate/path/stair (h)	4.5	minutes	Specific flow		people/s/m eff. width
Total usage of gate/path/stair (y)	274	people			
Time to reach max F_s (t)	2.5	minutes	Max. Specific Flow (F_s -max)	1.72	people/s/m eff. width
Total usage at max F_s (x)	78	people	Population		
Density at max F_s		people/m^2			
Time to reach sustained F_s		minutes	Sustained Specific Flow (F_s)	1.64	people/s/m eff. width
Duration of sustained F_s		minutes			
Density at sustained F_s		people/m^2			
Queuing time	0	seconds	Max. Calculated Flow (F_c)	134	people/minute
Queue density	N/A	people/m^2			
Boundary layer maintained (Y/N)	?				
Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)			**Individual Speeds**		
Fraction to leave through gate pre max F_s (A)	0.28	-	Travel distance (L)		metres
Fraction of populous to use gate (B)	0.01	-	Terrain	Flat	
Total to leave through gate post max F_s (C)	196	people	Total no. individuals tracked		
Estimated populous to leave pre max F_s (f)	7686	people	Mean speed		m/s
Estimated populous to leave post max F_s (r)	19313	people	Max. speed		m/s
Est. min. egress time for gate (Tg)	4	minutes	Minimum speed		m/s
Est. min. egress time for populous (Tp)	8	minutes	Density at max. speed		people/m^2
Est. min. egress time for full stadium (Tf)	8	minutes	Density at min. speed		people/m^2

Evacuation Estimates (based on established research)			
Anticipated F_s (Fruin)	k=1.40(flat), 1.16 (stair) (m/s)	1.4	people/s/m eff. width
Anticipated F_c (Fruin)		109	people/minute
Anticipated F_s (Poyner)	k=1.8 (flat) (m/s)	1.8	people/s/m eff. width
Anticipated F_c (Poyner)		140	people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)	S=1.19(flat), 1.00 (stair) (m/s)	1.4	people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)			people/m^2

Egress Path	**18**	Description	Vomitory
Viewed from	Above, in front	Terrain	Flat
Day or Night (D/N)	N	Wet, Cold or Dry (W/C/D)	D

Observational Data	**Value**	Unit		**Value**	Unit

Capacity of Stadium (g)		people	Width of path (W)	1.7	metres
Attendance at event (q)		people	Boundary layer (b)	0.15	metres
Time to clear stadium (tc)	14	minutes	Effective Width (W_e)	1.4	metres
Flow Rates					
Time to clear gate/path/stair (h)	5	minutes	Specific flow		people/s/m eff. width
Total usage of gate/path/stair (y)	441	people			
Time to reach max F_s (t)	0.75	minutes	Max. Specific Flow (F_s -max)	1.88	people/s/m eff. width
Total usage at max F_s (x)	93	people	Population		
Density at max F_s	1.2	people/m^2			
Time to reach sustained F_s		minutes	Sustained Specific Flow (F_s)		people/s/m eff. width
Duration of sustained F_s		minutes			
Density at sustained F_s		people/m^2			
Queuing time	0	seconds	Max. Calculated Flow (F_c)	158	people/minute
Queue density	N/A	people/m^2			
Boundary layer maintained (Y/N)	Y				
Estimated Evacuation Times (*if* monitored gate flow is representative of all gates)			**Individual Speeds**		
Fraction to leave through gate pre max F_s (A)	0.21	-	Travel distance (L)		metres
Fraction of populous to use gate (B)	0.01	-	Terrain		
Total to leave through gate post max F_s (C)	348	people	Total no. individuals tracked		
Estimated populous to leave pre max F_s (f)	6537	people	Mean speed		m/s
Estimated populous to leave post max F_s (r)	24462	people	Max. speed		m/s
Est. min. egress time for gate (Tg)	3	minutes	Minimum speed		m/s
Est. min. egress time for populous (Tp)	7	minutes	Density at max. speed		people/m^2
Est. min. egress time for full stadium (Tf)	8	minutes	Density at min. speed		people/m^2

Evacuation Estimates (based on established research)			
Anticipated F_s (Fruin)	k=1.40(flat), 1.16 (stair) (m/s)	1.4	people/s/m eff. width
Anticipated F_c (Fruin)		118	people/minute
Anticipated F_s (Poyner)	k=1.8 (flat) (m/s)	1.8	people/s/m eff. width
Anticipated F_c (Poyner)		151	people/minute
Anticipated density at max F_s assuming max unimpeded speed (Fruin)	S=1.19(flat), 1.00 (stair) (m/s)	1.6	people/m^2
Anticipated density at max F_s based on observed mean speed (Fruin)			people/m^2

Bibliography and References

Bibliography

- A.B.C.B. *Building Code of Australia, BCA96, Volume 1 - Building Code of Australia Class 2 to 9 Buildings*. Sydney, Australian Building Codes Board, 1996.
- Bassam, Lord. *Working Group on Football Disorder Report and Recommendations*. London, HMSO, 2001.
- Bennetts, I.D. Poh, K.W. Poon, S.L. Thomas, I.R. England, P. Kurban, N. Anderson, G. *Design of Sports Stand Buildings for Fire Safety*. Newcastle, OneSteel – Market Mills. 1998.
- *BS 5588-6: 1991 Fire Precautions in the Design, Construction and Use of Buildings. Code of Practice for Places of Assembly*. London, BSI. 72p
- Building Industry Authority, *Approved Document for New Zealand Building Code*. Wellington, Scenario Communications. 2001.
- Canter, D. Comber, M. Uzzell, D.L. In *Football in its Place An Environmental Psychology of Football Grounds*. London, Routledge. 1989. 173p.
- Department of National Heritage. *UK Guide to Safety at Sports Grounds 4th ed*. London, HMSO. 1998.
- Department of the Environment, Transport and the Regions. *Approved Document B for the UK Building Regulations 2000* London, HMSO. 151p
- Elliott, D.McGuinness, M. Public Inquiry: Panacea or Placebo?. *Journal of Contingencies and Crisis Management* 10 (1), 14-25, 2002.
- *Fire Precautions (Workplace) Regulations 1997*. London, The Stationery Office Books.
- *Fire Precautions Act 1971*. London, HMSO.
- *Fire Safety and Places of Sport Act 1987*. London, HMSO.
- Fruin, J. Pedestrian and Planning Design. *Metropolitan Association of Urban Designers and Environmental Planners*. Alabama, Elevator World Inc. 1971.
- Fruin, J.J. *The Causes and Prevention of Crowd Disasters..* 2002. Online.

Available: www.crowdsafe.com/FruinCauses.pdf. 6 April 2002.

- Greenwood, T. *Guide to Fire Precautions in Existing Places of Entertainment and Like Premises.* London, The Stationary Office Books. 1990. 200p
- Hanna, J.A. *Emergency Preparedness Guidelines for Mass, Crowd-Intensive Events*. Ottawa, Minister of Government Works and Public Services. 1994.
- Hodge, J. Managing Stadiums More Effectively. *Fire Prevention*, vol. 272, September 1994. pp31-33.
- Home Office. *Guide to Safety at Sports Grounds*. 3rd ed. London, HMSO. 1990.
- Isner, M. S. Stadium Fires Demonstrate Unique Protection Problems, *NFPA Journal* 88(4): 49-54, 1994.
- James, C.MCG scoreboard fire. *Fire Australia*, May, 2000, pp. 24-25
- KPMG Consulting Pty Ltd. *Impact Assessment of Major Reform Initiatives – 24th February 2000*. Australian Building Codes Board.
- Latane, B and Darley, J. cited in Bryan, J. Section Three Chapter 12 Behavioural Response to Fire and Smoke. *SFPE Handbook 3rd Edition*. Quincy, NFPA.2002. pp 3-315 - 3-341.
- Le Bon, G. *The Crowd: A study of the popular mind*. (Second edition). Larlin Corp. 1994. 207p.
- MacLennan, H.A., Regan, M.A., Ware, R. An Engineering Model for the Estimation of Occupant Premovement and or Response Times and the Probability of their Occurrence. *Fire and Materials* 23: 255-263. 1999.
- Mayston, B. No Restriction on Canned Beer. *Otago Daily Times*, 28 October 1998. Available: http://www.odt.co.nz/ 4 March 2002.
- Morris, D. *The Soccer Tribe*. London, Jonathan Cape. 1981. p266.
- National Fire Protection Association, *NFPA 101®:Life Safety Code®. 2003 ed*. Quincy, NFPA. 2003.
- National Fire Protection Association, *NFPA 102®: Standard for Grandstands, Folding and Telescopic Seating, Tents, and Membrane Structures ®. 1995 ed*. Quincy, NFPA. 1995.
- National Fire Protection Association, *NFPA 5000™ Building Construction*

and Safety Code™. 2003ed. Quincy, NFPA. 2003.

- Nelson, H.E.B., MacLennan, H.A., Section Three Chapter 14 Emergency Movement. *SFPE Handbook 3rd Edition*. Quincy, NFPA. 1995.pp3-286 – 3-295
- Noonan, W. Fenway Park Fire, *Boston Fire Department Journal*. Online. Available: http://www.ci.boston.ma.us/bfd/journal/fenway_fire.htm, 4 April 2002.
- Popplewell, Mr Justice O. *Committee of Inquiry into Crowd Safety and Control at Sports Grounds*. Final Report. Cmnd 9710 Jan. London, HMSO. 1986
- Popplewell, Mr Justice O., *Committee of inquiry into crowd safety and control at sports grounds: interim report.* HMSO, London. 1985. pp13-14.
- Poyner, B., Robinson, D., Hughes, N., Young, M. and Ayles, P. *Safety in Football Stadia; A Method of Assessment*, SCICON: London, Scientific Control Systems. 1972.
- Proulx, G. Section Three Chapter 13 Movement of People: The Evacuation Timing. *SFPE Handbook 3rd Edition*. Quincy*,* NFPA.2002. pp 3-342 - 3-366.
- Proulx, G., Creak, J., Kyle, B. A Field Study on Pholuminescent Signage used to guide building occupants to exit in complete darkness. *inFIRE 2000 Conference Proceedings.* Ottawa, Institute for Research in Construction. 2000.
- *Safety of Sports Grounds Act 1975*. London, HMSO.
- SFPE. Chapter 2 Occupant Characteristics. *Engineering Guide to Human Behaviour in Fire Review Draft August 2002*. Quincy, NFPA. 2002. 60p. p10-15.
- Sime, J.D. Psychological and Social Factors Influencing and Evaluation, cited in MacLennan, H.A. Towards an Integrated Egress/Evacuation Model Using an Open Systems Approach. *Fire Safety Science – Proceedings of the First International Symposium*. Washington D.C., Hemisphere Publishing Corp. 1986.
- Smith, K. Chapter 3 Risk Assessment and Disaster Management. *Environmental Hazards Assessing Risk and Reducing Disaster 3rd Edition.*

London, Routledge. 2001. pp69-74

- Smith, R.A., Dickie, J.F. *Engineering for Crowd Safety*. Amsterdam, Elsevier Science Publishers.1993.pp428
- Still, K., *Crowd Dynamics.* University of Warwick, 2000. (Thesis: PhD: Mathematics) Online. Available: http://www.crowddynamics.com/Thesis/Contents.htm. 12 May 2002.
- Tanaboriboon, Y., Guyano, J.G. Level of Service Facilities for Pedestrian Facilities in Bangkok: A Case Study. *ITE Journal*. November 1989.
- Taylor, Lord Justice. *Final Report into the Hillsborough Stadium Disaster*, CM 962. London, HMSO. 1990.
- Teo, A.P.Y. *Validation of an Evacuation Model Currently Under Development*, *Fire Engineering Research Report*. Christchurch, University of Canterbury. March 2001. p10.
- The Home Office. *Guide to Safety at Sports Grounds*. London, HMSO. 1976.
- Thompson, P.A. *Modelling Evacuation with Simulex (Simulex Help).* Edinburgh, University of Edinburgh. 1986.
- Thompson, P.A., Marchant, E.W. Modelling Techniques for Evacuation. in *Engineering for Crowd Safety*. Amsterdam, Elsevier Science Publishers.1993. pp259-269.
- Timeline to soccer stadium tragedy Available: http://www.cnn.com/2001/WORLD/africa/04/12/stampede.timeline/ April 12, 2001.
- Wheatley, Lord. *Report of the Inquiry into Crowd Safety at Sports Grounds.* CMND 4952. London, HMSO. 1972.

References

---

[1] Bennetts, I.D. Poh, K.W. Poon, S.L. Thomas, I.R. England, P. Kurban, N. Anderson, G. *Design of Sports Stand Buildings for Fire Safety*. Newcastle, OneSteel – Market Mills. 1998.

[2] Smith, K. Chapter 3 Risk Assessment and Disaster Management. *Environmental Hazards Assessing Risk and Reducing Disaster 3rd Edition*. London, Routledge. 2001. pp69-74

[3] Dickie, J.F. Crowd Disasters. *Engineering for Crowd Safety*. Amsterdam, Elsevier Science Publishers. 1993.

[4] Fruin, J.J. *The Causes and Prevention of Crowd Disasters.* 2002. Online. Available: www.crowdsafe.com/FruinCauses.pdf. 6 April 2002.

[5] Bennetts, et al. 1998. *op cit.*

[6] Isner, M. S. Stadium Fires Demonstrate Unique Protection Problems, *NFPA Journal* 88(4): 49-54, 1994.

[7] Fruin, J.J. 2002. *op cit.*

[8] Home Office. *Guide to Safety at Sports Grounds*. 3rd ed. London, HMSO. 1990.

[9] National Fire Protection Association, *NFPA 102®: Standard for Grandstands, Folding and Telescopic Seating, Tents, and Membrane Structures ®. 1995 ed.* Quincy, NFPA. 1995.

[10] Canter, D. Comber, M. Uzzell, D.L. Chapter 2 Spectators Views. In *Football in its Place An Environmental Psychology of Football Grounds*. London, Routledge. 1989. 173p. pp.22-56.

[11] Isner, M. S. 1994. *op cit.*

[12] *Ibid.*

[13] *Ibid.*

[14] Bennetts, et al. 1998. *op cit*.

[15] *Ibid.*

[16] *Ibid.*

[17] Popplewell, Mr Justice O.1985. *op cit.*

[18] Personal correspondence with Eden Park stadium management. April 19th 2002.

[19] Personal correspondence with Hamilton, MCG, Yarrow and Jade stadium management. May 10th 2002.

---

[20] Isner, M. S. *op cit.*

[21] Noonan, W. Fenway Park Fire, *Boston Fire Department Journal*. Online. Available: http://www.ci.boston.ma.us/bfd/journal/fenway_fire.htm, 4 April 2002.

[22] National Fire Protection Association, *NFPA 101®:Life Safety Code®. 2003 ed.* Quincy, NFPA. 2003.

[23] National Fire Protection Association. 1995. *op cit.*

[24] National Fire Protection Association, *NFPA 5000™ Building Construction and Safety Code™. 2003ed*. Quincy, NFPA. 2003.

[25] Building Industry Authority, *Approved Document for New Zealand Building Code*. Wellington, Scenario Communications. 2001.

[26] National Fire Protection Association, *NFPA 101®: Life Safety Code®. 2003 ed.* Quincy, NFPA. 2003. p101-86 - 101-32

[27] *Fire Safety and Places of Sport Act 1987*. London, HMSO.

[28] Department of the Environment, Transport and the Regions. *Approved Document B for the UK Building Regulations 2000* London, HMSO. 151p

[29] *BS 5588-6: 1991 Fire Precautions in the Design, Construction and Use of Buildings. Code of Practice for Places of Assembly*. London, BSI. 72p

[30] Greenwood, T. *Guide to Fire Precautions in Existing Places of Entertainment and Like Premises.* London, The Stationary Office Books. 1990. 200p

[31] *Safety of Sports Grounds Act 1975*. London, HMSO.

[32] *Fire Precautions (Workplace) Regulations 1997*. London, The Stationery Office Books.

[33] *Fire Precautions Act 1971*. London, HMSO.

[34] Department of National Heritage. *UK Guide to Safety at Sports Grounds 4th ed.* London, HMSO. 1998.

[35] Popplewell, Mr Justice O. *Committee of Inquiry into Crowd Safety and Control at Sports Grounds*. Final Report. Cmnd 9710 Jan. London, HMSO. 1986

[36] Taylor, Lord Justice. *Final Report into the Hillsborough Stadium Disaster*, CM 962. London, HMSO. 1990.

[37] Elliott, D. McGuinness, M. Public Inquiry: Panacea or Placebo?. *Journal of Contingencies and Crisis Management* 10 (1), 14-25, 2002.

[38] *Ibid.*

[39] Home Office.1990. *op cit*.

---

[40] Wheatley, Lord. *Report of the Inquiry into Crowd Safety at Sports Grounds.* CMND 4952. London, HMSO. 1972.

[41] The Home Office. *Guide to Safety at Sports Grounds*. London, HMSO. 1976.

[42] Taylor, Lord. *op. cit.*

[43] Shaw, A.C. Local Authority Experience. In Smith, R.A. Dickie, J.F. *Engineering for Crowd Safety* Amsterdam, Elsevier Science Publishers B.V. 1993. p. 43-52.

[44] Home Office. Chapter 15.1 i. *Guide to Safety at Sports Grounds*. 3rd ed. London, HMSO, 1990.

[45] Bassam, Lord. *Working Group on Football Disorder Report and Recommendations*. London, HMSO, 2001.

[46] A.B.C.B. *Building Code of Australia , BCA96, Volume 1 - Building Code of Australia Class 2 to 9 Buildings*. Sydney, Australian Building Codes Board, 1996.

[47] *Ibid.*

[48] KPMG Consulting Pty Ltd. *Impact Assessment of Major Reform Initiatives – 24th February 2000.* Australian Building Codes Board.

[49] Personal correspondence with Julie McLoughlin, Tony Edwards, Peter Murphy, and Chris Yergite. May 17th, 18th 2002.

[50] Bennetts, *et al. op cit.*

[51] James, C. MCG scoreboard fire. *Fire Australia*, May, 2000, pp. 24-25

[52] Personal correspondence with Julie McLaughlan. May 17th 2002.

[53] *Ibid.*

[54] *Fire Safety and Evacuation of Buildings Regulations 1992* Part I Regulation 5. Wellington, New Zealand Gazette 22 December 1993.

[55] Building Industry Authority. *op cit.*

[56] Correspondence between Neville Trevarton and Graham Running/Murray Dick Ref. 88-sprink. 1998.

[57] *Ibid.*

[58] *Ibid.*

[59] Personal correspondence with the North Shore Stadium Operations Manager, Murray Dick, May 10th 2002.

[60] Communications between the Chief Fire Officer of the North Shore District, Neville Trevarton and Murray Dick. 1998.

[61] Personal correspondence with Trevor Sampson. April 19th 2002.

---

[62] Personal correspondence with Neville Frost. April 5th 2002.

[63] *Ibid.*

[64] Mayston, B. No Restriction on Canned Beer. *Otago Daily Times*, 28 October 1998. Available: http://www.odt.co.nz/ 4 March 2002.

[65] Photo and caption courtesy of the Otago Daily Times. Taken from article "Supporters Do Battle" Wednesday, February 27th, 2002 reporting on crowd behaviour at the 5th match of the England vs New Zealand National Bank One Day International Series 2002 held at Carisbrook, Tuesday, February 26th, 2002.

[66] Building Industry Authority, *op. cit.*, Table 2.2 Occupant Densities. p45.

[67] *Ibid.*

[68] Building Industry Authority, *op. cit.*, Table 2.1 Purpose Groups. p43.

[69] *Ibid.*

[70] Building Industry Authority, *op. cit.*, p39.

[71] *Ibid.*

[72] Morris, D. *The Soccer Tribe*. London, Jonathan Cape. 1981. p266.

[73] Hodge, J. Managing Stadiums More Effectively. *Fire Prevention*, vol. 272, September 1994. pp31-33.

[74] Fruin, J.J. *op cit.* 2002.

[75] Sime, J.D. Psychological and Social Factors Influencing and Evaluation, cited in MacLennan, H.A. Towards an Integrated Egress/Evacuation Model Using an Open Systems Approach. *Fire Safety Science – Proceedings of the First International Symposium*. Washington D.C., Hemisphere Publishing Corp. 1986.

[76] Carey, M.S., Au, S.Y.Z., Ryan, M.C. Development of the HSE Guidance Document on the Management of Crowds in Public Venues. *Engineering for Crowd Safety*. Amsterdam, Elsevier Science Publishers. 1993. pp281-290.

[77] Mayston, B. *op cit.*

[78] Berlonghi, A.E., (1993). Understanding and Planning for different Spectator Crowds. *Engineering For Crowd Safety*. Amsterdam, Elsevier Science Publications. 1993. pp13-20.

[79] Morris, D. *op cit.*

[80] Poyner, B., Robinson, D., Hughes, N., Young, M. and Ayles, P. *Safety in Football Stadia; A Method of Assessment*, SCICON: London, Scientific Control Systems. 1972.

---

[81] *Ibid.*

[82] Cited by Smith. R.A. in Volume flow rates of densely packed crowds. *Engineering for crowd safety*. Elsevier Science Publishers. 1993. pp313-319. Original Ando, K., Ota, H., Oki, T., Forecasting the Flow of People, (in Japanese). *RRR, Railway Research Review.* 45, 8. 1988. pp8-14.

[83] Nelson, H.E.B., MacLennan, H.A., Section Three Chapter 14 Emergency Movement. *SFPE Handbook 3rd Edition*. Quincy, NFPA. 1995. pp3-286 – 3-295

[84] Proulx, G. Section Three Chapter 13 Movement of People: The Evacuation Timing. *SFPE Handbook 3rd Edition*. Quincy*,* NFPA.2002. pp 3-342 - 3-366.

[85] Cited by Still, K., *Crowd Dynamics.* University of Warwick, 2000. (Thesis: PhD: Mathematics) Online. Available: http://www.crowddynamics.com/Thesis/Contents.htm. 12 May 2002.

[86] Tanaboriboon, Y., Guyano, J.G. Level of Service Facilities for Pedestrian Facilities in Bangkok: A Case Study. *ITE Journal*. November 1989.

[87] Fruin, J. Pedestrian and Planning Design. *Metropolitan Association of Urban Designers and Environmental Planners*. Alabama, Elevator World Inc. 1971.

[88] *Ibid*

[89] Still, K. *op cit.*

[90] Nelson*, et al.*, *op cit.*

[91] Poyner, *et al. op cit.*

[92] Thompson, P.A. *Modelling Evacuation with Simulex (Simulex Help).* Edinburgh, University of Edinburgh. 1986.

[93] Poyner, *et al. op cit.*

[94] Still, K. *op. cit.*

[95] Teo, A.P.Y. *Validation of an Evacuation Model Currently Under Development*, *Fire Engineering Research Report*. Christchurch, University of Canterbury. March 2001. p10.

[96] SFPE. Chapter 2 Occupant Characteristics. *Engineering Guide to Human Behaviour in Fire Review Draft August 2002*. Quincy, NFPA. 2002. 60p. p10-15.

[97] Proulx, G., Creak, J., Kyle, B. A Field Study on Pholuminescent Signage used to guide building occupants to exit in complete darkness. *inFIRE 2000 Conference Proceedings.* Ottawa, Institute for Research in Construction. 2000.

---

[98] Latane, B and Darley, J. cited in Bryan, J. Section Three Chapter 12 Behavioral Response to Fire and Smoke. *SFPE Handbook 3rd Edition*. Quincy, NFPA.2002. pp 3-315 - 3-341.

[99] Popplewell, O. *op cit.* pp92.

[100] Still, K. *op cit.*

[101] Le Bon, G. *The Crowd: A study of the popular mind*. (Second edition). Larlin Corp. 1994. 207p.

[102] Still, K. *op cit.*

[103] Fruin, J.J. 2002. *op cit.*

[104] Fruin, J.J. 1987. *op cit.*

[105] Still, K. *op cit.*

[106] Fruin, J.J. 2002. *op cit.*

[107] Morris, D. *op cit.*

[108] Fruin, J.J. 2002. *op cit.*

[109] Still, K. *op cit.*

[110] Hanna, J.A. *Emergency Preparedness Guidelines for Mass, Crowd-Intensive Events*. Ottawa, Minister of Government Works and Public Services. 1994.

[111] *Ibid.*

[112] Nicholson, C.E., Roebuck, B. The Investigation if the Hillsborough Disaster by the Health and Safety Executive. In *Engineering For Crowd Safety*. Elsevier Science Publishers. 1993. pp145-155.

[113] Popplewell, Mr Justice O., *Committee of inquiry into crowd safety and control at sports grounds: interim report.* HMSO, London. 1985. pp13-14.

[114] Canter, D. Comber, M. Uzzell, D.L. Chapter 5 Coping with Violence. In *Football in its Place An Environmental Psychology of Football Grounds*. London, Routledge. 1989. 173p. pp103-126.

[115] Canter, D. Comber, M. Uzzell, D.L. Chapter 4 Crowds and Emergencies. In *Football in its Place An Environmental Psychology of Football Grounds*. London, Routledge. 1989. 173p. p.92.

[116] NFPA. *SFPE Handbook of Fire Protection Engineering 3rd edition*. Quincy, NFPA. 2002

[117] Nelson *et al.* 2002. *op cit.*

[118] Nelson *et al*. 2002. *op cit*

---

[119] Nelson *et al*. 2002. *op cit*. Formula (2) p3-368

[120] Canter, *et al. op cit*. p89

[121] Nelson *et al.* 2002. *op cit.* Table 3-14.1. p3-369.

[122] Nelson *et al.* 2002. *op cit.* p3-370.

[123] Nelson *et al.* 2002. *op cit*. p3-371

[124] Nelson *et al.* 2002. *op cit.* Table 3-14.2. p3-370.

[125] Nelson *et al.* 2002. *op cit*. p3-371.

[126] Sime, J,D. Crowd Psychology and Engineering: Designing for People or Ballbearings? in *Engineering for Crowd Safety*. Amsterdam, Elsevier Science Publishers. 1993. pp119-131. p128

[127] Thompson, P.A., Marchant, E.W. Modelling Techniques for Evacuation. in *Engineering for Crowd Safety*. Amsterdam, Elsevier Science Publishers. 1993. pp259-269.

[128] Nelson *et al.* 2002. *op cit*. p 3-378

[129] MacLennan, H.A., Regan, M.A., Ware, R. An Engineering Model for the Estimation of Occupant Premovement and or Response Times and the Probability of their Occurrence. *Fire and Materials* 23: 255-263. 1999.

[130] Fruin, J. (1987) *op cit.*

[131] Isner, M.S. *op cit.*

[132] Nelson *et al.* 2002. *op cit.*

[133] Home Office.1990. *op cit.*

[134] Nelson *et al.* 2002. *op cit.*

[135] *ibid.*

[136] Smith, RA. Volume flow rates of densely packed crowds. in *Engineering for Crowd Safety*. Amsterdam, Elsevier Science Publishers. 1993. pp313-319

[137] Toshiyuki, A Prediction system of passenger flow. in *Engineering for Crowd Safety*. Amsterdam, Elsevier Science Publishers. 1993. pp349-258

[138] *ibid*