Application Guidelines for the Egress Element of the Fire Protection Standard for Fixed Guideway Transit Systems

For Use with the 1997 Edition of the NFPA 130 Standard

Martin P. Schachenmayer
Parsons Brinckerhoff Quade & Douglas, Inc.
September 1998
## CONTENTS

**FOREWORD**  

**1.0 INTRODUCTION**  
1.1 Background  
1.2 Monograph Purpose and Organization  
1.3 Where Does the NFPA 130 Standard Apply?  
1.4 Relationship to Other Codes  
1.5 Enforcement  
1.6 Integration of Design Disciplines  

**2.0 EGRESS FROM STATIONS: AN OVERVIEW**  
2.1 Introduction  
2.2 Purpose  
2.3 Structure of the NFPA 130 Egress Requirements for Stations  

**3.0 EGRESS FROM STATIONS: METHODOLOGY**  
3.1 Introduction  
3.2 Egress Demand  
3.3 Egress Flow  
3.4 Egress Path  
3.5 Egress Time  
3.6 Evacuation Time Criteria  
3.7 Configuration of Egress Capacity  

**4.0 EGRESS FROM TRAINWAYS**  
4.1 Introduction  
4.2 Emergency Exits  

**5.0 APPLICATION GUIDELINES**  
5.1 Introduction  
5.2 Other Modes  

**6.0 EGRESS ELEMENT SAMPLE CALCULATIONS**  
6.1 Introduction  
6.2 Generic Subway Station  
6.3 Existing Subway Station with Mezzanine  
6.4 Deep Tunnel LRT Station  

**BIBLIOGRAPHY**  

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FOREWORD

NFPA 130, Standard for Fixed Guideway Transit Systems, establishes standards governing facility design, operating equipment, hardware, and procedures that apply to fixed guideway transit systems. Prominent among the procedures is the emergency egress element, which establishes evacuation criteria for transit stations and trainways. These criteria are important considerations in the design of fixed guideway transit systems, yet insufficient industry understanding—due in part to gaps in the existing documentation—have lead to inconsistent application, which may have resulted in some overly conservative or inadequate design solutions.

This monograph attempts to increase practitioners' understanding of egress requirements by broadening the scope of the existing literature. A review of theoretical concepts that underlie the egress requirements supports a more enlightened application of the NFPA 130 Standard, particularly in non-conventional settings. The NFPA 130 egress element is placed in a broader context in order to illustrate the overall intent of the egress requirements as well as their consistency with, and departure from, model building codes. An effort is also made to consider egress requirements with regard to general pedestrian planning principles and thereby establish linkages between related design disciplines—architecture, ventilation, fire protection, pedestrian planning—that are frequently viewed independently. Throughout these application guidelines, efforts are made to raise awareness of the interdependencies between the physical and procedural realms in the field of fire protection.

The application of the NFPA 130 egress element is frequently left to specialists and occurs at relatively late stages in the transit design process when commitments to particular design solutions have already been formed. This fragmented approach potentially leads to situations where designers find themselves engaged in the costly and frustrating process of incrementally modifying mature designs in order to comply with emergency evacuation needs introduced at a late stage. An increased understanding of the NFPA 130 egress element across a range of disciplines is intended to help better integrate fire code compliance testing into the early stages of the design process and thereby support the development of more cost-effective and elegant design solutions.

This monograph provides a general discussion of the issues in question. It is not a substitute for qualified and detailed professional advice concerning the application of any information, procedure, conclusion, or opinion contained herein.
Acknowledgments

I wish to express my gratitude to the Board of Directors of Parsons Brinckerhoff for establishing and supporting the William Barclay Parsons Fellowship. The Fellowship program provides employees an opportunity to further their technical expertise and publish their findings in a Fellowship Monograph. I am grateful to have been afforded this opportunity through the generous support provided under this program. I also wish to extend my appreciation to the Career Development Committee for its administration of the Fellowship program. I am especially grateful to Mr. Paul Gilbert for his encouragement and guidance over the course of the past year.

From its inception, this effort has been marked by the enthusiasm and active participation of my two mentors, Mr. Gregory Benz and Mr. Arthur Bendelius. Their complementary expertise in transport planning and architectural design, and mechanical engineering and ventilation, respectively, provided the foundation for this effort's cross-disciplinary character, which I believe to be its most important feature. Both mentors contributed significantly in the formative stages of the work program and remained closely involved through its completion. I remain indebted to them.

I was astonished and rewarded by the encouragement and support that this effort received throughout the past year. I am grateful for the assistance offered by Mr. Frank Cihak, Chair of the NFPA 130 Technical Committee on Fixed Guideway Transit Systems, and Mr. Richard Ortisi-Best, the NFPA staff liaison for NFPA 130. I also wish to express my gratitude to Ms. Melba Bayne of the Washington Metropolitan Area Transit Authority, Mr. Norman Danziger and Mr. William Kennedy of Parsons Brinckerhoff, and Mr. Jake Pauls, all of whom shared valuable insights and generously offered of their time to review the monograph in its various incarnations.

Finally, I wish to thank my wife, Laura Protextor, for the support and patience she has shown me over the course of a year that may at times have seemed longer to her than it did to me.

Martin Schachenmayr
New York City
January 1998
1.0 INTRODUCTION

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1.0 INTRODUCTION

1.1 Background

The National Fire Protection Association (NFPA), founded in 1896, is mandated “to reduce the burden of fire ... by advocating scientifically based consensus codes and standards, research and education for fire and related safety issues.” The association’s mission is primarily advanced through the development, maintenance, and publication of fire safety codes and standards that reflect a current understanding of technological innovations and a broad consensus among government, insurance and industry stakeholders. Today, NFPA administers 290 specific fire safety standards, addressing a broad range of facilities. Principal among these is the NFPA 101 Life Safety Code, which serves as the foundation for all NFPA standards.

The NFPA Standard for Fixed Guideway Transit Systems (NFPA 130) was adopted in 1983 to establish fire safety standards specifically tailored for transit systems. The development of the NFPA 130 Standard grew out of the recognition that model building codes and the NFPA 101 Life Safety Code do not sufficiently address the special characteristics of mass transit systems. Design activity for a number of new-start rapid transit systems in North America in the 1970s (e.g., MARTA, WMATA, BART) raised awareness of this shortcoming and resulted in the development of a fire-life safety code specifically tailored for the transit environment. The NFPA 130 Standard was developed to apply to all fixed guideway transit systems, including those that are automated, and covers at-grade, elevated, and underground systems.

The NFPA 130 Standard governs facility design as well as operating equipment, hardware, and procedures. Prominent among the NFPA 130 requirements is the emergency egress element, which establishes emergency evacuation requirements for transit stations (passengers must be able to clear station platforms within 4 minutes and reach a point of safety within 6 minutes). Unlike the generally prescriptive egress provisions of model building codes, the NFPA 130 egress element offers a performance-based approach for determining egress requirements at transit stations. Additional requirements exist for the evacuation of trainways. With increasingly widespread application of the NFPA 130 Standard, its emergency egress provisions have become an important consideration in the planning and design of fixed guideway transit systems—particularly passenger stations. The egress element, unlike other components of the NFPA 130 Standard, applies in the design of new systems as well as in the assessment of existing systems. In addition to its application for rapid transit systems, the Standard “shall be permitted to be used as a guide” to determine fire protection requirements for a broader range of transit systems, such as light rail transit, commuter rail, and busways/bus tunnels. Given the lack of alternative emergency egress performance measures for transit systems, this broader application of the Standard as a guide is widespread.
1.2 Monograph Purpose and Organization

Purpose and Scope

Application of performance-based egress requirements demands an understanding of the underlying technical concepts. These application guidelines provide technical clarification for the NFPA 130 egress requirements in order to facilitate their application and enforcement, particularly in light of the following concerns:

1. There currently exists insufficient industry understanding of the NFPA 130 emergency egress element. The definitions, instructions, and sample calculations published with the NFPA 130 Standard do not adequately guide practitioners and have led to inconsistent application of the NFPA 130 egress element, potentially leading to overly conservative design solutions or to inadequate designs that are extremely costly to remedy retroactively.

2. Although the NFPA 130 Standard technically addresses only rail rapid transit modes and “does not cover requirements for ... passenger railroad systems including those which provide commuter services” (NFPA 130, Section 1-1.2), its application as a “guide” in a broader setting is not discouraged. Indeed, transit properties are frequently applying the NFPA 130 Standard for light rail transit and commuter rail facilities. Despite this widespread practice, no guidance is offered for the application of the NFPA 130 Standard for non-rapid transit systems and facilities.1

3. The NFPA 130 Standard contains minimum design criteria with regard to emergency egress only; however, in the absence of standard specifications for transit stations, designers frequently view the NFPA 130 requirements as the principal design guidelines for transit stations. This application often occurs without sufficient understanding of the relationship between the NFPA 130 Standard and the underlying requirements of the NFPA 101 Code.

While the NFPA 130 Standard includes requirements governing virtually all transit system components, this monograph addresses only those aspects that pertain to emergency egress requirements for transit stations and trainways (Sections 2-5 and 3-2.4 of the Standard, respectively). Although these application guidelines are designed to augment the 1997 Edition of the NFPA 130 Standard for Fixed Guideway Transit Systems, it is not an official publication of NFPA nor has it received any formal endorsement from NFPA. Consequently, the recommendations and interpretations contained herein should be viewed as suggestions and in no way should be viewed as formal extensions of the Standard itself, but rather as a document that can be used in conjunction with the Standard to provide practical guidance.

1 The NFPA 130 Technical Committee is presently considering the possibility of formally broadening the scope of the Standard.
Organization

The monograph is divided into the following four sections:

1. The egress element for transit stations. Chapter 2 and Chapter 3, respectively, provide an overview and detailed technical discussion of the NFPA 130 egress requirements as they apply to transit stations. The discussion in Chapter 3 includes, where necessary, a review of the theoretical underpinnings on which the NFPA 130 requirements are based. Where appropriate, references to the NFPA 101 Code augment the discussion of the NFPA 130 requirements.

2. Evacuation requirements for trainways. Chapter 4 addresses the trainway egress requirements. Trainway requirements are considerably more prescriptive than the station egress element and therefore require relatively little elaboration. Reference to the NFPA 101 Code is not necessary, as its requirements do not apply to trainways.

3. Application guidelines. Chapter 5 contains recommendations and general guidelines for the application of the NFPA 130 egress element for a broader range of transit systems and modes, including commuter rail and light rail transit stations.

4. Sample calculations. A number of sample calculations are provided to guide designers in the application of the NFPA egress element for transit stations. Sample calculations range from relatively straightforward applications in conventional stations to more complex station configurations that involve considerable interpretation of the NFPA 130 literature.

1.3 Where Does the NFPA 130 Standard Apply?

NFPA codes and standards are advisory, as the NFPA has no enforcement or monitoring authority. Given the association’s high regard and standing, however, many of its codes and standards have been adopted by all levels of government, giving them the force of law in many jurisdictions. Many jurisdictions where recent-generation fixed guideway transit systems were constructed have incorporated the NFPA 130 Standard into their local ordinances. Where this is the case, the Standard applies as law, governing all new and, in the case of the egress element, existing transit facilities. Given its origin in conjunction with modern-era transit systems, the NFPA 130 Standard sets performance measures that may not be realistically achievable in existing facilities of some of the nation’s oldest transit systems. In such instances, the Standard is being applied only in the construction of new facilities. Frequently, these agencies will also use the Standard to support capital programming for the modernization and rehabilitation of existing facilities. Finally, it is common for transit agencies to apply the Standard as a design guide for a broad range of facilities—even if not required to do so under local building codes. The table on the following page provides an overview of the current application of the Standard in North America.
### Table 1.1 USE OF NFPA 130 STANDARD IN NORTH AMERICA

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The NFPA 130 Standard is finding increasing application outside of North America. In Singapore, for instance, the Standard has been formally adopted as part of the building code. Cities where the NFPA 130 Standard was used as a guide in the design of transit systems include Hong Kong, China; Izmir, Turkey; Caracas, Venezuela; London, England; and Taipei, Taiwan.
1.4 Relationship to Other Codes

Transit stations are characterized by dynamic occupancy patterns that differ drastically from those in conventional places of assembly. This is due to the fact that the station occupant load is subject to frequent, yet predictable, fluctuations, includes persons arriving by way of street entrances as well as trains, and is concentrated at predictable locations. Transit stations are distinguished physically from conventional areas of assembly in that they are configured as areas of transition rather than places of long-term assembly. As a result, the difference between emergency evacuation demand patterns and circulation patterns that prevail during normal use are less pronounced at transit stations than in most buildings. In contrast to most buildings, transit stations typically rely on emergency exits only to augment, rather than duplicate, the carrying capacity of the egress facilities used during normal operations. In the event of an emergency, a significant portion of the occupant load typically evacuates the station by way of the facilities that they use under normal operating conditions. As a result, many emergency egress routes in transit stations are familiar to passengers. Transit stations further differ from conventional places of assembly in that their occupancy level is not a function of building capacity as, for instance, in theaters, but rather is determined by quantifiable patronage demand volumes. Unlike in conventional buildings, the occupancy level in transit stations may alter as a result of the emergency itself. For instance, service disruptions caused by the emergency may result in station occupancy levels that significantly exceed normal levels. In addition to the above-mentioned differences, transit stations differ from most conventional buildings in that they are generally constructed of and contain materials with relatively low combustibility.

Model Building Codes

Acknowledging the unique conditions at transit stations, the NFPA 130 Standard puts forth performance-based means of egress requirements that differ considerably from the means of egress criteria in most model building codes, such as the BOCA National Building Code (BOCA) and the Uniform Building Code (UBC), which offer a more prescriptive approach for determining minimum egress capacities and do not rely on time-based egress criteria. Exit capacity requirements under BOCA and UBC are a function of occupant loads that are directly proportional to the size of the area to be evacuated. This strictly linear approach does not adequately address the dynamic occupancy patterns in transit stations. Under BOCA and UBC, the number of persons occupying transit station platforms would be assumed to be equal to the maximum number of persons who could simultaneously occupy a given platform, as dictated by a specified crowding level. Empirical or projected station entry demand as well as passengers onboard trains inside the station would not be considered. The NFPA 130 Standard, in contrast, offers a demand-driven approach for computing station occupancy that is based on station patronage and train ridership, as determined by empirical data or from demand forecasts and system operating parameters.

A departure from the conventional method of defining occupant loads strictly as a function of available floor area is appropriate in the context of transit stations, since there does not necessarily exist a direct correlation between station demand volumes and platform dimensions. For instance, a platform’s length is generally determined by the length of the longest trains to be accommodated while its width is often determined by structural requirements and the configuration of vertical circulation facilities.
Neither the model building code nor the NFPA 130 methodology for determining station occupant loads consistently leads to more or less conservative egress requirements. In most high-volume urban transit systems, occupant loads determined according to NFPA 130 often substantially exceed those determined under BOCA and UBC. This is particularly true for underground or elevated stations where platform dimensions are constrained and therefore reduce occupant loads as would be computed under BOCA and UBC. On the other hand, it is possible that, at suburban stations, the confluence of low ridership, infrequent train service, and generous platform dimensions create a situation where the BOCA and UBC would result in larger occupant loads and more stringent egress requirements.

**NFPA 101 Life Safety Code**

Transit stations are considered areas of public assembly and are therefore subject to the requirements of the NFPA 101 Life Safety Code. Consequently, the NFPA 130 Standard serves only to augment the relevant provisions of NFPA 101, as made clear by the introduction to Chapter 2 of the NFPA 130 Standard, which states that “a station shall comply with the provisions of NFPA 101, Life Safety Code, Chapter 5, Means of Egress, and Chapter 8, New Assembly Occupancies” (2-5.1), except as modified in the NFPA 130 Standard. Since there exist few redundancies among NFPA documents, NFPA 130 contains only requirements and definitions that modify or augment the requirements in the NFPA 101 reference code. This is not the case for trainways, which are not addressed in NFPA 101 and are therefore subject only to the requirements put forth in Chapter 3 of the NFPA 130 Standard. The absence of a reference code for trainways explains the inclusion of some detail in Chapter 3 that is absent from Chapter 2 (e.g., door specifications), as inclusion of such detail for transit stations would be redundant with the provisions in NFPA 101.

The NFPA 130 egress element for stations (Chapter 2) primarily offers requirements regarding the minimum amount of egress capacity required inside transit stations under a given demand load. Since the NFPA 130 Standard departs significantly from NFPA 101 in the computation of egress capacity requirements (the NFPA 101 Means of Egress approach closely resembles the methodology of model building codes), designers will find that, for purposes of measuring station compliance with the time-based egress criteria of NFPA 130, the NFPA 130 Standard generally functions as an independent document, offering a sufficient level of guidance for its application.

However, where NFPA 130 does not offer modifications to the NFPA 101 criteria, reference to the NFPA 101 Chapters on Means of Egress and New Assembly Occupancy is essential, as provisions in NFPA 101 that are not modified in the context of transit facilities are not reprinted in the NFPA 130 Standard. This is particularly important with regard to the arrangement of egress facilities (as opposed to their capacity), materials and hardware specifications, as well as accessibility guidelines. The NFPA 101 Means of Egress criteria apply to both existing and new stations while the New Assembly Occupancy criteria apply to new stations only. Significant expansions to existing stations are generally subject to the design criteria for new stations.
Accessibility Guidelines

The NFPA 130 Standard does not specifically mention egress needs for disabled passengers. Consequently, the NFPA 101 requirements for accessible means of egress (5-5.4) as well as all other accessibility criteria apply without modification to transit stations, particularly for new construction (a number of exceptions exist for existing stations). In addition, the Americans with Disabilities Act (ADA), American National Standard for Accessible and Usable Buildings and Facilities (ANSI A117.1), and several similar standards set guidelines for facilitating access by disabled persons. Such guidelines have been adopted in many jurisdictions and may apply to transit stations, particularly for new construction. It is therefore recommended that designers performing egress analyses consult local building codes with regard to applicable accessibility requirements.

1.5 Enforcement

NFPA does not have enforcement powers and responsibilities. Compliance with the NFPA 130 egress element is determined solely by the “authority having jurisdiction” (AHJ)—typically a role played by the local fire department in the United States. NFPA’s role is limited to updating the Standard and responding to requests for “formal interpretations” regarding specific language contained in the NFPA 130 Standard. Given the time required for formal responses, the “formal interpretations” process is not readily integrated into the design process. NFPA should therefore not be relied on to offer timely opinions or rulings on issues arising during the development of a particular design.

In communities where transit systems are relatively new or play only a minor role, it is possible for local enforcement authorities to not be fully aware of their unique occupancy characteristics and egress needs. It is therefore likely that the performance-based approach in the NFPA 130 Standard—given its significant departure from model building codes—is unfamiliar to local enforcement authorities. This creates situations where enforcement authorities need to become familiar with the requirements of the Standard that they are charged to enforce. Under these circumstances, given the absence of an active expert body charged with settling technical disputes, the process of measuring compliance with NFPA 130 egress requirements often takes the form of an extended technical exchange between designers and fire enforcement officials (AHJs). This process is based as much on consensus building as on appeal to definitive rulings.

1.6 Integration of Design Disciplines

Emergency evacuation requirements are only one of the many design considerations that affect the design of transit stations. Consideration of emergency evacuation requirements in conjunction with related design efforts generally provides opportunities for more flexible solutions and ultimately encourages more elegant design solutions. Although
not explicitly recommended in the NFPA 130 Standard, the egress element should be applied in conjunction with a broad range of design concerns in order to raise early awareness of potential conflicts and efficiencies (see Figure 1.1).

Coordination among different disciplines is frequently inadequate. For instance, pedestrian circulation studies are typically performed in the early conceptual design stages, while emergency egress requirements are often addressed independently at a much later stage when strong allegiances to particular design solutions may already have been formed. This sequential organization potentially leads to a situation where designers find themselves incrementally modifying mature designs to comply with emergency evacuation needs introduced at a relatively late stage. Similarly, egress computations are typically associated with the physical design process and therefore not sufficiently integrated with facility operations. Emergency response procedures, which govern the operation of ventilation and public information systems, are often not developed until after the station geometry is finalized. As a result, there exists little integration between the procedural and design realms. This represents a missed opportunity, as consideration of emergency and other operational procedures as part of the egress analyses could identify procedural solutions in lieu of capital improvements as a means for meeting requirements.
Emergency egress should be viewed in a broader context than the range of design disciplines typically associated with the field of fire-life safety.

The incorporation of emergency egress and ventilation requirements into a common standard acknowledges the interrelationship between these two fields. During a fire emergency, the capability to protect station occupants from contaminated air clearly has an effect on emergency egress needs. As a result, the ability to meet egress requirements is not necessarily a function only of exit capacity but may also depend on the availability of areas inside the station that offer adequate protection for passengers during an emergency. While NFPA 130 permits consideration of such areas of safe refuge as part of the egress analysis, the time-based egress criteria put forth in the Standard are in most applications considered to be fixed. That is, there does not exist an explicit mechanism for adjusting egress requirements to reflect varying levels of ventilation capabilities, or vice versa. Thus, in these applications, it may be said that the Standard’s “performance-based” approach is limited to the realm of the egress element and does not extend to ventilation.
The Standard does offer a framework for developing an exception to the fixed time-based egress criteria (i.e., the 4- and 6-minute tests). An engineering analysis may be performed to consider special factors affecting emergency egress, such as the combustibility of station and vehicle materials and special emergency response procedures. If the engineering analysis demonstrates, to the satisfaction of the authority having jurisdiction, that the special circumstances at a given station warrant a departure from the default egress time requirements, station-specific egress time criteria may be used in lieu of those defined in the Standard. Thus, the engineering analysis exception offers a means for expanding the egress analysis across disciplines. The engineering analysis exception was added to the Standard quite recently. The extent to which review authorities are willing to embrace a departure from fixed egress time criteria remains to be seen; to date, use of the default time criteria is the norm.
2.0 EGRESS FROM STATIONS: AN OVERVIEW
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2.0 EGRESS FROM STATIONS: AN OVERVIEW

2.1 Introduction

This chapter provides an overview of the NFPA 130 egress element by describing its purpose and structure and identifying key parameters. This overview serves as the foundation for the detailed technical discussion in the following chapter.

2.2 Purpose

The NFPA 130 Standard establishes minimum requirements “that will provide a reasonable degree of safety from fire and its related hazards.” Although the egress element specifically addresses evacuation needs in the event of a fire emergency, its provisions aid life safety for a broad range of emergencies, including structural failure, natural disasters such as earthquakes, and terrorist incidents. Interestingly, certain non-fire related emergencies, such as the sudden onset of extreme hail in an uncovered station, may have a broader simultaneous impact than many fire hazards.

2.3 Structure of the NFPA 130 Egress Requirements for Stations

The NFPA 130 egress element evaluates transit station configurations according to a time-based egress analysis that simulates the movement of passengers through the transit station. Evacuation time measurements begin with passengers on station platform(s) and follow their passage through a series of egress elements on their route to safety. Compliance is measured by comparing measured evacuation times with explicit egress time criteria.

Evacuation times are essentially a function of the evacuation demand; the capacity and configuration of egress facilities; and the distance to be traversed. The NFPA 130 egress element is structured accordingly:

1. **Egress Demand**: The Standard provides explicit direction for determining the number of passengers (station occupant load) who need to be evacuated from platforms and reach a point of safety.

2. **Egress Capacity**: The Standard defines the carrying capacity for egress elements, such as walkways, ramps, stairs, escalators, and turnstiles through which evacuating passengers pass. For each egress element, the capacity and demand to be accommodated are used to estimate the time passengers spend waiting to be processed. Where egress paths diverge, the relative capacity of the alternate routes determine the distribution of evacuating passengers.
3. **Travel Speed and Distance**: Average walking speeds are used to calculate the time required to traverse the egress route. Limits are set on the maximum permissible travel distance for egress routes.

4. **Egress Time Calculations**: Using calculated queuing and walking times, a methodology is provided for measuring compliance with the time-based egress criteria.

**Egress Demand**

The number of persons who need to be evacuated from the station is determined through consideration of a hypothetical emergency event ("emergency incident"). The Standard offers explicit direction regarding the series of events leading up to the moment when the station needs to be evacuated. Definition of the "emergency condition requiring evacuation" (NFPA 130, Section 2-5.2.1) is an important first step in the application of the egress element, as it is the principal determinant of the number of passengers to be evacuated. Although the Standard provides a clear framework for developing a scenario of emergency events, it is important to understand that the emergency condition considered must reflect the physical and operational realities at the station in question. If, for instance, physical constraints preclude occurrence of the emergency condition as specified in the Standard, then a site-specific worst-case scenario needs to be developed. Similarly, designers should confirm that the emergency condition developed under NFPA 130 indeed represents the worst-case scenario for a given station.

**Egress Capacity and Waiting Times**

Depending on the distribution of the egress demand and the relative capacity of the successive egress elements encountered by evacuating passengers, queues will form at the foot of the most restrictive egress elements. The location of such bottlenecks and the wait times encountered there are a function of the specific capacities of individual egress elements and the arrival rate of the passenger flow. Depending on its width, each egress element is assigned a capacity that yields the time required for a given demand load to be “processed” by the egress element. This “flow time” represents the time required for the entire passenger demand to move through the facility, which is beyond the time required to actually traverse the distance of a facility. For instance, where a broad corridor leads to a more narrow one, the flow time computed for the narrow corridor represents the time required for passengers to enter the narrow corridor but does not include the time required for passengers to walk the length of the corridor (this “walk time” is computed separately). Flow time, which is computed only as a function of egress element capacity and the overall magnitude of the demand, does not consider the rate at which passengers arrive. Therefore, in order to account for the “metered” arrival of passengers, flow times at each egress element are reduced to yield wait times that consider the effect of previously encountered egress elements on the passenger arrival rate.
Distribution Among Egress Paths

When faced with two or more possible egress paths, passenger behavior is governed by a “hydraulic model,” which assigns passengers among competing routes in ratios that are directly proportional to the carrying capacity of the next egress element encountered. Following this model, passenger flow loads decrease in locations where egress paths diverge and increase where paths converge, as on mezzanine or concourse levels fed by stairs leading up from several platforms.

The hydraulic model optimizes the use of all available egress capacity. This approach is reasonable in a transit station environment, where the following conditions typically prevail: (1) the evacuation demand is sufficiently large that queues form at all egress elements and wait times at egress elements are sufficiently long to encourage passengers to distribute themselves across queues; and (2) there exist no obstacles, such as localized congestion due to contra-flow movements, which depress the capacity of a given egress path below its theoretical level. In the hydraulic model, alternate egress paths are distinguished only by the magnitude of their capacity and are otherwise assumed to be equally attractive. The overall length of the path or the location of the fire source are not considered in the distribution of passengers. This too is a generally reasonable assumption, as the fire source is typically assumed to be on the train or track where it would not block egress paths (although station fires have originated in locations—such as in mechanical equipment—that were remote from tracks).

Egress Time

The time required for a passenger load to reach a given location is calculated by summing the time spent traversing the length of the egress path and the time spent waiting at queues encountered along the way. Waiting times are determined by simulating the flow of passengers through successive bottlenecks. The metering effect of previously encountered queues is considered by identifying for each egress route the limiting egress element where the combination of passenger load and egress element capacity yields the longest wait time. For each egress route the total wait time is assumed to be equal to that encountered at this limiting egress element.

It is important to recognize that the methodology offered for calculating egress times and thus the NFPA 130 egress time criteria represent the minimum time required for all passengers to evacuate the station. The computed egress times do not consider behavioral factors such as decision-making and orientation time and therefore do not constitute a measure of the time required for the station to be emptied.

Experience has shown that behavioral factors generally retard evacuation times. It has been observed, for instance, that persons faced with a hazard are surprisingly reluctant to commence evacuation. False diagnoses, such as mistaking smoke as evidence of a past rather than an ongoing hazard, may also cause tangible delays in evacuation. Interestingly, the passengers’ familiarity with egress routes—a frequently cited justification for assuming superior egress performance in transit stations—may actually have a negative effect, as insistence on using regular egress routes can prove

---

2 See Section 3.5 for clarification of this concept.
In large station facilities, persons in some areas may not be aware of a hazard and may not begin evacuating until some time after evacuation has begun elsewhere in the station. These uncertainties preclude development of reliable predictions of actual evacuation times. Consequently, the egress times computed under the NFPA 130 Standard should be viewed as performance measures—to evaluate station designs and allow comparisons among alternative design solutions—rather than predictions of the actual time required to clear a station of its occupants.

### Egress Time Criteria

The NFPA 130 egress element requires that transit stations are configured such that, in the event of a fire emergency, all passengers assembled in the station are able to:

1. Clear each station platform in 4 minutes or less; and
2. Reach a point of safety in 6 minutes or less.

---

4 Passengers’ familiarity with station egress facilities is often exaggerated, considering that passengers evacuating from trains (i.e., the calculated train load) may be evacuating from a station that they do not typically use.
3.0 EGRESS FROM STATIONS: METHODOLOGY
3.0 EGRESS FROM STATIONS: METHODOLOGY

3.1 Introduction

The egress element’s time-based evacuation criteria, combined with defined processing capacities for station facilities and a prescribed methodology for egress time calculations, form a performance-based approach for evaluating the adequacy of egress facilities at existing and future transit stations. Reliance on a rather complex, performance-based methodology for the determination of egress requirements demands a thorough understanding of the Standard’s theoretical underpinnings, particularly given the potentially substantial cost implications associated with egress requirements. This chapter documents the NFPA 130 egress element and provides a technical foundation to support the application of the egress element.

3.2 Egress Demand

Emergency Condition

When determining evacuation demand, it is useful to carefully consider a combination of events to define an emergency condition requiring evacuation of the station. The emergency condition to be considered could generically be summarized as follows:

At a time when there are no trains inside the station, a temporary service disruption (i.e., “failure period”), the duration of which is a function of train frequency, prevents peak direction trains from entering the station. During the failure period passengers continue to enter the station according to their peak-period entry rate and accumulate on the platform to which they are destined under normal conditions. Peak direction passengers linger on the platforms while passengers traveling in the off-peak direction are able to board trains arriving at regular headways. After the duration of the failure period, trains are assumed to enter the station simultaneously “on all tracks in normal traffic direction.” Due to a missed headway, trains operating in the peak direction are either filled to “crush capacity” or are carrying twice their normal peak loads to account for the missed train. Trains operating in the off-peak direction are assumed to carry their average peak 15-minute passenger volumes. The fire source is located onboard one (and only one)

5 Where a platform abuts a single track, or where trains arrive on two tracks from only one direction, all trains are defined as peak direction trains, regardless of system demand patterns.

6 “Crush capacity” is based on the maximum passenger load for train cars observed for the system under consideration. Generally, this value significantly exceeds the manufacturer-specified “nominal” car capacity. “Crush capacity” should be used as the train capacity value for all emergency egress calculations.
of the trains entering the station (i.e., “incident train”). The number of passengers to be evacuated includes those who have accumulated on all platforms as well as those on board all trains.

No emergency incidents need to be considered beyond those that are implied in the NFPA 130 methodology for determining the occupant load. It is therefore not necessary to consider the compounding effect of additional service disruptions, and demand volumes should be adjusted only as discussed above. The above definition of the emergency condition should be considered in the context of the physical and operational realities of the transit station and system under investigation, as they may place limits on the emergency condition.

**Operational Constraints**

For most on-line stations, interpretation of the requirement of simultaneous train arrival on all tracks is straightforward, as it is generally possible for trains to arrive simultaneously on each platform track. At more complex stations, however, simultaneous arrival of trains on every track should be considered only when it is operationally feasible. In instances where track geometry (e.g., single track sections) or switch configurations limit the number of trains that can arrive simultaneously, the emergency condition should reflect the simultaneous arrival of only as many trains as operationally feasible. For instance, at terminal stations where many platform tracks may be served by relatively fewer approach tracks, it is possible that the number of trains that can simultaneously arrive at the station is limited by the approach tracks, particularly since the Standard states explicitly that “not more than one train will unload at any one track during an emergency.”

**Complex Station Configurations**

In complex stations, careful distinctions need to be made between station platforms and non-platform areas. Station platforms are defined as “the area of a station used primarily for loading and unloading transit vehicle passenger” (NFPA 130, 1-5) and should be thought of as those areas that abut tracks and to which the train doors open. Pedestrian circulation areas, such as passageways, mezzanines, as well as remote ticket vending and waiting areas, do not constitute station platforms (see Figure 3.1). At the commencement of the station evacuation, the evacuation load is located entirely on the platforms and no passengers are assumed to occupy non-platform areas anywhere in the station.

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7 It is generally not necessary to designate which platform serves the train carrying the fire source—or the incident train—as all platforms are treated identically. Only in instances where one or more station platforms are defined as a refuge area, does the incident platform need to be designated. In these circumstances, the platform with the largest occupant load should be designated as the incident platform.
At multi-level stations, where the egress path from some platforms may traverse platforms on another level, it is important to distinguish between platform occupant load and additional “through demand” originating from another platform (see Figure 3.2). The time-based egress requirements for each platform are based only on the platform occupant load for the platform under consideration. In other words, each person in the station is considered only once in the 4- and 6-minute tests.

Note that when measuring compliance with time-based egress criteria, only the last person clearing the most remote platform—from where the overall egress time is the longest—needs to be considered. Care must be given, however, to account for the impact persons originating from other platforms (i.e., “Second Platform” in Figure 3.2) may have on the egress time of the person originating on the most remote platform (see Section 3.3).
Patronage Volumes

Depending on the demand characteristics of the station under investigation, the egress calculations should reflect either AM or PM peak-hour conditions, whichever result in the higher overall station occupant load. The choice of AM and PM peak period depends on the demand characteristics of the particular station. Care must be given to consider the contribution of both those passengers arriving during the failure period (i.e., entraining load) and those arriving on the train(s) (i.e., calculated train load). For instance, in transit systems with pronounced commuter-oriented demand patterns, stations near the periphery of the system, typically serving residential districts and park-and-ride locations, may in the morning attract very high entraining loads but relatively low train loads. Conversely, central business district (CBD) stations in such transit systems are likely to be characterized by very high train loads but low entraining loads in the morning.

In the design of new systems, demand volumes are determined from patronage forecasts. In Appendix C of the Standard, it is recommended that 2 years past the commencement of service, actual ridership volumes be used to confirm the demand assumptions used in the egress calculations. Furthermore, the Appendix recommends that compliance with the NFPA 130 egress requirements be verified at least every 5 years or anytime operating plans are substantially modified, station configurations are altered, or system characteristics change. The construction of system extensions, for instance, may well result in increased train loads throughout the system and thereby affect station occupant loads at pre-existing stations.

In the analysis of existing systems, actual ridership data—typically adjusted to reflect a future design year—should be used as the basis for the NFPA 130 egress analysis. Where ridership volumes are not recorded in 15-minute increments, they are computed as a function of the peak AM or PM hourly patronage volumes. The 15-minute volumes are inflated by a “peaking factor” to account for non-uniform arrival patterns during the peak hour. The NFPA 130 Standard prescribes a default 15-minute peaking factor of 1.5.

\[
\text{Peak 15-Minute Demand Volumes} = \frac{\text{Peak Hour Demand (AM or PM)}}{4} \times \text{Peaking Factor}
\]

where \(\text{Peaking Factor} = 1.5\) (default value) or observed value

Peaking characteristics vary widely among transit systems, with the higher demand systems typically exhibiting more pronounced peaking during the peak hour. Furthermore, peaking can be more or less pronounced at different stations of the same system, ranging from relatively uniform arrival patterns at some stations to extremely peaked patterns at stations which, for instance, are directly linked to employment centers or which are integrated into intermodal facilities. Therefore, in instances where empirical data is available to measure the degree of peaking that occurs at a given station, it should be used in lieu of the default value of 1.5.
Station Occupant Load

The station occupant load represents the total number of passengers who need to clear each platform and reach a point of safety. Two components contribute to the station occupant load: (1) the entraining load, or the total number of persons accumulated on each platform during the course of the failure period; and (2) the calculated train load, or the number of persons on board all trains in the station.

\[
\text{Station Occupant Load} = \text{Entraining Load} + \text{Calculated Train Load}
\]

At multi-platform stations, it is necessary to distribute the station occupant load among individual platforms, since (1) the 4-minute test is performed separately for each platform; and (2) the relative contribution of each platform to the overall station egress demand needs to be known to simulate demand flows through the station in the 6-minute test. Occupant loads for individual platforms (“platform occupant load”) are computed as in the above equation. Thus, entraining loads and calculated train loads need to be determined for each individual platform.

The Entraining Load

Passengers entering the station during the failure period arrive according to their normal peak arrival rate. For each platform, the entraining load consists of passengers who are destined to that platform under normal operating conditions. The failure period is defined as follows:

\[
\text{Failure Period} =
\begin{cases}
  12 \text{ minutes} & \text{for headway } \leq 6 \text{ minutes} \\
  \text{headway (min)} \times 2 & \text{for headway } > 6 \text{ minutes}
\end{cases}
\]

On side platforms (and center platforms where trains arrive from only one direction) no trains arrive for the duration of the failure period and passengers continue to accumulate on platforms. The magnitude of the entraining load is directly proportional to the duration of the failure period.

On center platforms where trains arrive from two directions, the entraining load consists of (1) peak direction passengers accumulated during the entire failure period, as defined above; and (2) off-peak direction passengers arriving during one headway in the peak 15 minutes (i.e., 15-minute boarding volume divided by the number of off-peak trains arriving at the platform in 15 minutes).
Calculated Train Load

The calculated train load represents the number of passengers who are on board the train(s) that arrive in the station at the end of the failure period. Prior to the arrival of the train(s), one headway has been missed in the peak direction. To account for the increased demand due to the missed headway, the number of passengers on board peak direction trains arriving at the station, as predicted by 15-minute demand volumes on the link immediately before the station and the train frequency, is doubled. In high demand systems where the doubling of the peak 15-minute train load results in a calculated train load that exceeds the nominal train capacity, the calculated train load is set equal to the “crush” train capacity.

### Calculated Train Load

1. Platforms where trains arrive from one direction:

   \[
   \text{Calculated Train Load} = \frac{\text{peak 15 - minute link load}}{\# \text{of trains per 15 minutes}} \times 2
   \]

   where: Calculated Train Load ≤ Maximum Train Capacity

2. Platforms where trains arrive from two directions:

   (a) Peak direction train load computed as above

   (b) Calculated Train Load (Off-peak direction) \[
   \frac{\text{peak 15 - minute link load}}{\# \text{of trains per 15 minutes}}
   \]

All trains operate in the direction of normal traffic and arrive on the track on which they would arrive under normal operating conditions. For each train, the calculated train load will be discharged to the platform serving its track. In instances where a single track abuts more than one platform, it is possible to assume that doors open on both sides, provided that this is operationally feasible. Such an operational adjustment may be desirable as it distributes the calculated train load among two platforms. Where trains of varying consist lengths make use of a single track, the calculated train load should reflect the demand (or capacity) that corresponds to the longest trains in service on that track.
3.3 Egress Flow

Station circulation facilities, such as platforms, corridors, and stairways, place constraints on the ability to evacuate the station’s occupant load. The physical characteristics of facilities through which evacuating passengers pass (i.e., egress elements) affect the rate at which passenger streams move through the station, and are thus the principal determinants of evacuation time. The extent to which the passenger flow is retarded by a given station facility is expressed as a function of the facility’s capacity. These capacities form the basis for distributing the egress demand among alternate exit paths and for estimating the time passengers spend waiting in queues at various locations along the egress path. The time required to evacuate transit stations is further influenced by assumptions made about the rate at which evacuating persons are able to walk in the various station environments (e.g., on stairs, along corridors).

Capacity and Speed

Passengers evacuating the station move through a series of egress elements (e.g., corridors, stairs, doors, fare collection gates). Two performance parameters define the extent to which each type of egress element will retard the flow of evacuating passengers. An explicit capacity describes the rate at which an arriving stream of passengers is absorbed by the facility. Capacities are expressed in terms of flow rates (persons per minute) per unit width. For egress elements that extend over a distance, such as platforms, corridors and stairs, assigned speeds define the walking speed of persons inside a stream that passes through that egress element. Speeds are expressed in units of feet (meters) per minute.8 Elements such as doors and gates, which are essentially without depth and require negligible time to traverse, are not assigned walking speeds. Table 3.1 contains the capacities and speeds assigned by NFPA to various egress elements (see NFPA 130, Sections 2-5.3.4.1 - 2-5.3.4.4).

---

8 The measure of distance contained in the walking speeds defined for stairs, stopped escalators, and ramps with slopes of more than 4 percent refers to the change in elevation that is bridged by these facilities.
### Table 3.1 Egress Element Capacity and Speed

<table>
<thead>
<tr>
<th>Egress Elements</th>
<th>Capacity (Flow Rate) (ppm)</th>
<th>Speed (fpm)</th>
<th>Speed (m/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platforms, Corridors, &amp; Ramps under 4%</td>
<td>50 (per 22-inch/.559m lane)</td>
<td>200</td>
<td>61.00</td>
</tr>
<tr>
<td>Stairs, Escalators, &amp; Ramps over 4% (up)</td>
<td>35 (per 22-inch/.559m lane)</td>
<td>50</td>
<td>15.24</td>
</tr>
<tr>
<td>Stairs, Escalators, &amp; Ramps over 4% (down)</td>
<td>40 (per 22-inch/559m lane)</td>
<td>60</td>
<td>18.30</td>
</tr>
<tr>
<td>Doors and Gates</td>
<td>50 (per 22-inch/.559m lane)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Fare Collection Gates</td>
<td>50 (per 22-inch/.559m lane)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

The NFPA 130 Standard departs from general pedestrian flow principles in that the capacities and walking speeds defined for egress elements are not linked to density levels. In reality, congestion levels inside the station have a significant effect on the rate at which persons inside the station are able to move. Introduction of a mechanism for adjusting egress element performance characteristics in order to reflect varying congestion levels in station areas would be rather cumbersome. Instead, the NFPA 130 egress element capacity and speed parameters were defined to apply in all situations. The NFPA 130 approach notwithstanding, application of the egress element should be informed by an understanding of the relationship between flow rates, walking speeds, and density conditions.

**Implicit Densities**

Implicit in the egress element capacity and speed parameters assigned in NFPA 130 are underlying assumptions about the level of crowding that persists in station areas during the emergency evacuation. An appreciation of these assumptions helps place the NFPA 130 pedestrian flow parameters within the context of general pedestrian principles and is useful for interpreting the egress times computed under the NFPA 130 methodology.

The relationship between flow rates, walking speeds, and crowd densities is governed by fundamental pedestrian flow principles, as expressed in the following equation, where flow represents the number of people passing a reference point, speed reflects the speed of persons inside the pedestrian stream, and density, measured in terms of persons per square foot, is indicative of the level of congestion inside the stream:

\[
\text{flow} \times \text{speed} = \text{density} \times \text{flow rate}
\]

9 ppm = passengers per minute; fpm = feet per minute; m/m = meters per minute.
Where the magnitude of a stream of persons is physically constrained, as by the width of a corridor, the flow of persons through the corridor is fixed and, under the NFPA 130 terminology, represents the capacity for individual egress elements. When flow is held constant, an increase in the pedestrian volume (and therefore density) necessarily causes a decrease in the average walking speed of persons in the stream. This reflects the fact that persons with less space available to them will be constrained by those around them and will therefore not be able to necessarily choose their own speed. Figure 3.3 helps visualize these interdependencies by illustrating pedestrian densities under varying egress flow rates down stairs with a nominal width of 65 inches (i.e., 2.5 exit lanes, see the equation for exit lane calculations on page 34). Stair descent speeds range from about 2.0 stair treads per second in the least crowded condition (left stair) to 1.3 stair treads per second in the most crowded condition.10

**Figure 3.3  Pedestrian Densities on Stairs**

The pedestrian density level on the center stair generally corresponds to the flow rates assigned for stairways in NFPA 130. In contrast, densities on the stair shown on the left correspond to the egress capacity for stairways in general buildings as required under NFPA 101. On the right hand stair, density levels correspond to high-capacity flow rates used at large stadia.

Based on the pedestrian flow relationship (see previous equation), the theoretical density levels that underlie the NFPA 130 capacities and speeds for corridors and stairways are determined as follows:

\[
\text{Density (pers/sf (m²))} = \frac{\text{Capacity (pers/min per 22" (0.559m))}}{200 \text{ fpm}} \times \frac{1}{22" (0.559m)}
\]

\[
\text{Speed (ft/min)} = \frac{0.0 (1.0m)}{22" (0.559m)}
\]

Given the awkwardness of expressing crowding in terms of small fractions of persons occupying a square foot, designers frequently express crowding levels in terms of the inverse of density, or the area available per person (sometimes referred to as “module”). The NFPA 130 capacity and speed parameters imply an average availability of 7.3 square feet (0.68 m²) per person for platforms, corridors, and ramps under 4 percent, and 2.6 square feet (0.24 m²) per person for stairways, stopped escalators and ramps over 4 percent. For stairways, the density implicit in the NFPA 130 capacity and speed parameters is consistent with observed values (see Figure 3.4). Indeed, it appears that the maximum flow conditions observed by Fruin served as the basis for NFPA 130 stair capacities.

For walkways, however, the NFPA 130 parameters depart from empirical observations. As illustrated in Figure 3.5, the NFPA 130 walkway capacity and implicit density fall outside the range of observed values. This is due to the unusually fast walking speeds assigned in NFPA 130. The NFPA 130 walking speed of 200 feet per minute exceeds most values observed in high-capacity passenger flows. Observations by J. Pauls and J. Fruin confirm that high-capacity flows depend in large part on high pedestrian densities which, in turn, cause walking speeds to decline (to levels below those assigned in NFPA 130). The empirical data suggest that the NFPA 130 walking speed for level conditions is overly optimistic in light of the density levels required to achieve the flow volumes (i.e., capacities) defined in the Standard. The discrepancy between the NFPA 130 speed parameter and empirical observation and the apparent internal inconsistencies between the NFPA 130 capacity and speed parameters suggest that egress times computed using the NFPA 130 capacity and speed values should serve as performance measures rather than actual predictions of station egress times. Furthermore, the high speed values would imply that they refer to the speed of the first person in the stream rather than the constrained speed of persons inside, or near the end of, the stream.

Figure 3.5 illustrates that flow rates drop drastically when pedestrians are afforded less than 5 square feet (0.47 m²)/person on walkways. Crowding levels where less than 5
square feet (0.47m²) are available per person on platforms should therefore be avoided, even if not required under NFPA 130 (see Figure 3.6). Designers should measure crowding levels on platforms to confirm that the assumptions about flow rates and speeds contained in NFPA 130 apply. When calculating station platform density levels, only the entraining load should be considered, as the calculated train load will not occupy the platform until the evacuation has commenced and portions of the entraining load have cleared the platform.
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Figure 3.4 Pedestrian Flows on Stairways

Figure 3.5 Pedestrian Flows on Walkways
Platform density levels affect the time required for persons to clear the platform. In addition to the size of the platform occupant load, platform dimensions need to be considered when assessing the pedestrian environment on platforms. Where platform widths are severely restricted (see top), only small entraining loads are capable of creating crowding conditions sufficient to retard egress flows. In many modern stations (see below), platforms are sufficiently wide that the NFPA parameters offer a good estimate of walking speeds during emergency egress conditions.
Egress Width

Exit Lanes

The width of egress elements is defined in terms of the number of travel lanes accommodated. The width of an exit lane (22 inches/0.559 m) is based on shoulder breadth and is consistent with values traditionally used in the design of pedestrian facilities. The exit lane concept is based on the notion that not every incremental increase in the width of an egress element necessarily produces an increase in the facility’s overall carrying capacity. Width increases are therefore only considered when they result in the addition of at least one-half additional exit lane. This method for determining the carrying capacity presents a departure from the strictly linear convention used in most model building codes, including the NFPA 101 Life Safety Code.

For each egress element, the width actually available for passengers—effective width—is computed according to specified width reductions for areas abutting walls and platform edges (see Table 3.2). The following equation illustrates how the number of exit lanes provided by an egress element is determined as a function of the effective width.

\[
\text{Exit Lanes} = \text{INT} \left( \frac{\text{Width}}{22" (0.559m)} \right) + 0.5 \text{ INT} \left( \frac{\text{Width} - 12" (0.305m)}{22" (0.559m)} \right) + \text{INT} \left( \frac{\text{Width} - 22" (0.559m)}{12" (0.305m)} \right)
\]

Where: (1) fractions inside the function \( \text{INT} / \) are rounded down to the nearest integer; and (2) \( \text{Width} \) represents the effective width of the egress element.

For each type of egress element, the minimum width as well as deductions made to convert actual clearance into effective widths are summarized in Table 3.2.
Table 3.2 NFPA 130 Exit Lane Equivalency

<table>
<thead>
<tr>
<th>Egress Element</th>
<th>Minimum Clear Width</th>
<th>Deduction for Effective Width</th>
<th>Exit Lane Equivalency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platforms</td>
<td>5' 8&quot; (1.73m)</td>
<td>- 18&quot; (.457m) at track edge</td>
<td>as per exit lane calculation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- 12&quot; (.305m) at walls</td>
<td></td>
</tr>
<tr>
<td>Corridors and Ramps &lt; 4%</td>
<td>5' 8&quot; (1.73m)</td>
<td>- 12&quot; (.305m) at walls</td>
<td>as per exit lane calculation</td>
</tr>
<tr>
<td>Stairs</td>
<td>44&quot; (1.12m)</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td>Ramps &gt; 4%</td>
<td>6' 0&quot; (1.83m)</td>
<td>none</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Stopped Escalators</td>
<td>48&quot; (1.22m)</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td></td>
<td>32&quot; (0.813m)</td>
<td>none</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>&lt; 32&quot; (0.813m)</td>
<td>none</td>
<td>1.5</td>
</tr>
<tr>
<td>Doors and Gates</td>
<td>36&quot; (0.914m)</td>
<td></td>
<td>as per exit lane calculation</td>
</tr>
</tbody>
</table>

Platforms are assigned an egress capacity under NFPA 130, Section 2-5.3.4.1, for instances where passengers who have cleared their origin platform need to traverse additional platforms on their egress path (as in the case of stations with platforms on multiple levels). In this case, the additional platforms essentially function as corridors and are therefore included in Table 3.2. (Movement of passengers on their origin platform is addressed as part of the 4-minute test, involving only the platform occupant load and the sum of the capacity of all vertical circulation elements serving the platform (see Section 3.6)).

For each egress element, the product of the number of exit units provided and the capacity flow rates shown in Table 3.1 yields the total capacity, expressed in persons per minute.

Alternate Measure of Width

Based on the observation that persons rarely move in regular files or lanes, NFPA 130 is presently considering calculating egress capacities as a function of incremental changes in exit width rather than according to exit lanes. The transition from one approach to the other is only a matter of unit conversion and essentially maintains existing egress element capacities. Adoption of the linear model eliminates the need to convert egress element widths to exit lanes and brings the NFPA 130 methodology in line with that of the NFPA 101 Code, where the exit lane concept was abandoned in the 1988 edition. Since the linear method for computing egress widths is likely to be incorporated into the 1999 Edition of the NFPA 101 Standard, the method is described here for informational purposes and possible future reference.

Adoption of the linear width measure while maintaining existing capacity levels would involve revising NFPA 130, Section 2-5.3.4.1 to assign a unit capacity of .44 inches per person per minute (ipm) to platforms, corridors and ramps of 4 percent slope or less. Section 2-5.3.4.1 would be revised to assign a unit capacity of .63 ipm to platforms, corridors and ramps of over 4 percent slope. With the adoption of the ipm units, the capacity (flow rate) for a given element would be computed as follows (minimum widths and side wall and platform edge deductions would still apply):

14 Stairway handrails shall project no further than 3.5 inches (NFPA 130, 2-5.3.1). Further stair details are provided in NFPA 101, 5-2.2.3.
Capacity (persons per minute) = \frac{\text{Element Width (inches)}}{\text{Unit Capacity (ipm)}}

Under this method, small increments of width result in capacity increase. Figures 3.7 and 3.8 compare the computed capacity values for egress elements under the proposed unit capacity and existing exit lane methodologies. These figures illustrate how adoption of the proposed capacity values (i.e., .44 and .63 ipm) results in egress element capacities that are exactly equal to the existing capacities for exit widths accommodating full or one-half exit lanes. For exit widths that fall between the 12-inch increments considered in the exit lane approach, the linear unit capacity approach results in slightly increased capacities.
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**Figure 3.7** Linear Capacities for Platforms and Corridors

![Diagram showing flow rates versus effective width for existing and proposed capacities.]

**Figure 3.8** Linear Capacities for Stairs and Stopped Escalators

![Diagram showing flow rates versus effective width for existing and proposed capacities.]
Capacity Reductions

Doors

With regard to the regulation of doors as an egress component from transit stations, NFPA 130 offers few modifications to the requirements put forth in the NFPA 101 Code. Indeed, the NFPA 130 discussion of doors (Chapter 2) is limited to establishing the minimum clearance width of 36 inches (.914m) (2-5.3.4.3). No additional specifications are required in NFPA 130, as the requirements of NFPA 101 (Chapters 5 and 8) apply to transit stations. Although the treatment of doors in NFPA 101 is rather exhaustive (and certainly worth review), two key requirements essentially define the only type of door considered to be credited with exit capacity:

• 5-2.1.4.1: Any door in a means of egress shall be of the side-hinged or pivoted-swinging type. The door shall be designed and installed so that it is capable of swinging from any position to the full use of the opening in which it is installed.

• 5-2.1.4.2: Doors required to be [of the] side-hinged or pivot swinging type shall swing in the direction of egress travel where serving a room or area with an occupant load of 50 or more.

These requirements aim to avoid situations where evacuating passengers find themselves pulling open a door against the force of a surge of persons. Although there exist a number of exceptions to the above requirements that govern, for instance, the use of sliding doors, the NFPA 101 essentially requires that doors designed to be in the closed position at any time during system operation must be of the conventional swing door type if they are to be assigned egress capacity. Other door designs, such as revolving doors, although acceptable for normal operations, may not be credited with egress capacity for purposes of the NFPA 130 egress calculations. Specifications for such doors are defined in NFPA 101.

Elevators

Elevators are not credited with egress capacity under NFPA 130 and therefore do not constitute a permissible means of egress in the context of the time-based egress analysis. Many modern elevators are designed to be automatically disabled under high temperatures. While it is common for one or two selected elevators to be equipped with an emergency generator, their primary purpose in the event of an emergency is often to transport emergency personnel and equipment.

Although not acceptable as a vehicle for transporting persons to a point of safety under the NFPA 130 6-minute test, specially equipped elevators frequently serve an important role in the evacuation of refuge areas in deep tunnels (see Section 3.4). Under such circumstances, elevators transport the occupants of an area, offering temporary safety to permanent safety. In the event that the area of temporary safety meets the NFPA 130 and NFPA 101 requirements for an area of safe refuge, such an elevator movement falls outside the NFPA 130 egress time criteria. Designers should, however, confirm that the elevator capacity is sufficient to evacuate the area of safety occupant load within the time during which the area is considered safe. Elevator capacity is measured as a function of the capacity of the available elevator car(s) and the combined

15 The NFPA 130 Technical Committee has recently considered expanding the range of acceptable doors for egress calculations to include “butterfly doors.” Presently these models may not be credited with egress capacity.
elevator cycle time. Care must be given to not assign elevators for egress that are dedicated to the transport of emergency personnel.

Escalators

Escalators are permissible as a means of emergency egress. Escalators operating in the direction opposite to the direction of egress are assumed to be stopped and function as stairs (albeit with variable and higher step height). Although the Standard indicates that escalators operating in the direction of the egress stream may be permitted to be left in the operating mode, no additional capacity is considered under such circumstances. Consequently, for purposes of the egress analysis, all escalators should simply be assumed to be stopped. The operating speed of escalators is not considered and their egress capacity is determined solely as a function of their width. Due to escalators’ high maintenance requirements, adding uncertainty about their availability as a means of egress during an emergency, the NFPA 130 Standard strictly regulates the use of escalators for emergency egress purposes. The following restrictions apply:

• “[O]ne escalator at each station shall be considered as being out of service in calculating egress requirements. The escalator chosen shall be that one having the most adverse effect upon exiting capacities” (2-5.4.1.1). This requirement addresses the fact that escalators undergoing maintenance may have their treads removed, leaving them without any egress capacity at all.

• “Escalators shall not account for more than half of the units of exit at any one level” (2-5.3.4.2). This requirement (i.e., 50 percent escalator rule) effectively dictates that significant stair capacity needs to be provided between all station levels and to the street level (Figure 3.9). Although individual vertical circulation locations equipped exclusively with escalators are technically acceptable under this section as long as there exist other locations serving the same two levels that offer sufficient stair capacity, the intent of the requirement would dictate that, whenever possible, all escalators should be augmented by adjacent stairs. At individual locations, however, it is not necessary that the 2-to-1 stair-to-escalator capacity ratio be met.
The 50-percent escalator rule raises a number of concerns, affecting the validity of the hydraulic distribution of passengers. Although stairways must serve the same level as the escalators that they augment, they need not necessarily connect the same station areas. Therefore, one means of compliance is the provision of emergency stairs that lead directly to the street, rather than to the interim station area served by the escalators. In many instances, these stairways are rarely used during normal
operations, since (1) they may be remote from the escalators that they augment; (2) the climb is too long to attract passengers under normal operating conditions; and (3) for security and maintenance purposes, they may be made available only for emergency egress.

Given peoples’ reluctance to evacuate stations by way of unfamiliar egress routes, the stairways mandated under the 50-percent escalator rule are likely to attract disproportionately low demand levels (relative to their capacity), since persons, if at all possible, will choose to evacuate by way of escalators. This causes a failure of the “hydraulic” distribution model, where passengers are assumed to be distributed among alternate egress routes according to their capacities, since escalators not credited with any capacity would, in reality, attract evacuating passengers while emergency stairs would attract demand at levels below their capacity. Thus, the hydraulic distribution of passengers among facilities credited with capacity underestimates the occupancy of areas served primarily by escalators. Designers therefore need to anticipate the emergency facilities required in areas served primarily by escalators (see Figure 3.10), even when the NFPA 130 demand distribution predicts significantly lower levels of occupancy.

**Figure 3.10 Areas Served by Escalators Only**

Given that “escalators shall not account for more than half of the units of exit at any one level,” station areas that are served exclusively by escalators—such as the station mezzanine on the left—are not credited with egress capacity. In reality, passengers would nonetheless evacuate by way of these areas.
Demand Distribution

Passengers are distributed in a manner that optimizes the use of the available egress capacity. At each decision-making point, the number of passengers are divided proportionally to the carrying capacity of the egress paths that are available to them. Figure 3.11 illustrates the distribution of passenger flows in a schematic representation of a two-level subway station.

**FIGURE 3.11 DEMAND DISTRIBUTION**

Arrows in Figure 3.11 represent stairs leading from one station level to another. Numbers inside the arrows identify the relative capacity of elements. On the platform level, for instance, evacuating passengers have a choice of four stairs of equal capacity leading to the concourse level. In addition, two emergency stairs, each with a capacity equal to one-half of one of the concourse stairs, provide a direct route to the street level. Under the hydraulic model, 80 percent of a given platform occupant load would evacuate by way of the stairs leading to the concourse and 20 percent would exit the station via the two emergency stairs. Passengers evacuating by way of the concourse would be distributed equally among the eight turnstiles and the two exits leading to the street.

Where the concourse level serves more than one platform, the contribution from each platform needs to be considered when determining the passenger demand at the concourse turnstiles and the stairs to the street. Thus, the concourse platform load is equal to the sum of passengers from all platforms who exit the station by way of the concourse. This demand is assumed to arrive simultaneously on the concourse and at all subsequent egress elements.
3.4 Egress Path

Paths chosen by evacuating passengers need to be defined to measure:

1. The time required to evacuate the station along the longest egress path (in connection with measuring compliance with NFPA 130, Section 2-5.3.3, or the 6-minute test); and

2. Compliance with the requirement that “[t]he maximum travel distance to an exit from any point on the platform shall not exceed 300 feet” (NFPA 130, Section 2-5.3.2, or the 4-minute test).

In both instances, the egress path originates on the station platform. Yet the acceptable destinations for the paths defined in connection with the above requirements—an “exit” versus a “point of safety”—can differ substantially. Once the appropriate path is defined, however, the same method is used for computing its length. Both horizontal and vertical distances are computed. For egress elements with vertical components (e.g., stairs, stopped escalators, ramps with slopes greater than 5 percent), the travel distance is computed along the slope of the egress element, as illustrated in Figure 3.12:

![Figure 3.12 Travel Distance on Stairs and Escalators](image)

Longest Egress Path

The longest egress path, defined for purposes of measuring egress time, originates on the most remote point on any station platform and terminates at a point of safety. The longest egress path should be defined along the route that requires the longest amount of time to traverse, without considering detours made, for instance, to avoid hazards. Although the longest egress path is defined as a measure of time, it is generally only necessary to identify the origin platform where platform clearance times are longest and then trace the longest distance to a point of safety. This is the case since, under most station configurations, wait times encountered subsequent to the initial merging of platform occupant loads are the same along all routes, as each route will attract demand proportional to its capacity and thus involve the same wait times.

In complex stations, the above approach for defining the longest egress route may not suffice. For instance, in stations containing egress routes along which capacities decline, the hydraulic distribution among competing routes according to the capacity of the first constraint encountered on each route may result in downstream delays on some

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16 Note that conventions for the distance and speed computations on vertical circulation elements differ.
routes that are different from those for others\textsuperscript{17} (see Figure 3.13). Similarly, multi-level platform stations need to be considered carefully, as it is conceivable that passengers originating from a platform with relatively short platform clearance time evacuate the station by way of another platform (see Figure 3.14), where they encounter wait times different from those encountered along other egress routes. In such instances, it is necessary to sum the wait times encountered at each egress element along alternate exit paths in order to determine the longest egress path.

\textsuperscript{17} NFPA 130 recommends that evacuating passengers be distributed among alternate routes “in proportion to the exit capacity provided by the various paths at the decision point” (Appendix C-1.1).
The capacity of downstream elements, such as the width of passageways, can result in significantly different egress flow rates for alternate paths that share a common capacity at the decision making point. It is generally desirable that, in the direction of egress, successive egress elements are no more limiting than the previously encountered elements.
In instances where egress from one platform involves traversing a second platform, the occupancy level of one platform needs to be considered when determining the egress demand from the other.

Each egress route terminates at a point of safety, which is defined in NFPA 130 as “[a]n enclosed fire exit that leads to a public way or safe location outside the structure, or at-grade point beyond any enclosing structure, or other area that affords adequate protection for passengers (1-5).” In most stations, a point of safety is defined as a location outside of the transit station structure, such as a sidewalk or parking lot. Only areas under control of the authority or areas without use restrictions during transit operating hours are acceptable as destinations for emergency egress paths. This is a particularly important consideration for transit stations that are integrated into joint development or multi-use building structures. In such developments, transit stations are frequently connected to “quasi-public” areas (e.g., shopping concourses, sports stadia) by way of passageways that are not open during all transit operating times. In such circumstances, only areas outside the station that are accessible during all operating hours are suitable emergency egress destinations.\footnote{18}

\footnote{18 In some instances, operating/maintenance agreements between transit operators and joint development partners may offer means for increasing egress capacity. For instance, extension of the operating hours of joint development areas (e.g., through installation of surveillance equipment) may be more attractive than the construction of a new station entrance (which may not find much use during normal operations).}
Refuge Area as a Point of Safety

Since elevators are not a permissible means of emergency egress, it is common that in stations that rely exclusively on elevators for vertical circulation (e.g., deep tunnel stations), passengers require longer than 6 minutes to reach the station exterior by way of emergency stairs. In such instances, an area of refuge inside the station offering sufficient smoke and fire protection is typically designated as a point of safety and serves as an acceptable egress destination in the context of the NFPA 130 egress criteria. Once inside a refuge area, passengers may require assistance to reach permanent safety. Evacuation of refuge areas, however, is not subject to the NFPA 130 time criteria.

A definition of and design criteria for a refuge area are provided in the NFPA 101 Code (Chapter 5), which requires that “area[s] of refuge shall be accessible from the space they serve by an accessible means of egress” (NFPA 101, 5-2.12.2.1). This essentially dictates that areas of refuge be located on the same level as the platform they serve so as to permit access by persons with severe mobility impairment, including those using wheelchairs. In addition, NFPA 101 states that “an area of refuge shall have access to a public way, without requiring return to the building spaces through which travel to the area of refuge occurred ...” (NFPA 101, 5-2.12.2.2). This exit leading from the area of safe refuge to the station exterior need not be “accessible” and could therefore be an emergency stair or elevator.

Areas of refuge frequently serve as intermediary egress destinations in deep tunnel transit stations, when the elevator lobby is located on the platform level and is configured such that it can be separated from the station platform(s) by way of fire doors. Evacuating passengers reaching the elevator lobby are considered to be at a point of safety from where they reach permanent safety by way of emergency stairs or elevators. Care must be given to ensure that the area of refuge is sufficiently large to accommodate the anticipated passenger load.

In stations with completely separate trainrooms, where the environments are independently controllable, one or more non-incident platforms may also be defined as an area of refuge, from where passengers continue to permanent safety by way of one or a combination of the following routes: (1) on-board rescue trains operating on non-incident tracks; (2) assisted use of elevators; (3) walkways in non-incident trainways; or (4) emergency stairways. In instances where a station platform is designated as an area of refuge, it is necessary to define the incident platform to which persons on board the train assumed to carry the fire source discharge. Egress calculations, measuring the time required for all persons to reach the platform(s) designated as refuge areas, should be based on the assumption that the incident trains arrived on that platform for which the total occupant load (entRAINing load and calculated train load) is highest. Station platforms that function as refuge areas and that do not service the incident train are not subject to the 4- and 6-minute tests since, in the context of the NFPA 130 egress criteria, passengers occupying these platforms are by definition at a point of safety.
Egress for the Mobility Impaired

The egress needs of disabled persons are not specifically addressed in NFPA 130 and are therefore governed by the relevant provisions in the NFPA 101 Life Safety Code (Chapters 5 and 8). The NFPA 101 Code requires that in new construction transit stations, all areas that are accessible to persons with severe mobility impairment (this typically includes all station areas, as they are accessible by way of elevators under normal operating conditions) shall be connected to the street level or a refuge area by way of at least one accessible means of egress. Thus, in all locations where—without reliance on elevators—the street level cannot be reached by the mobility impaired, accessible refuge areas need to be provided to offer temporary fire and smoke protection for passengers unable to evacuate by way of stairs or stopped escalators. Refuge areas are enclosed rooms, accessible to persons in wheelchairs and equipped with two-way communication devices, that serve as staging areas from where passengers reach permanent safety with the assistance of emergency response personnel. Design criteria for an accessible area of refuge are defined in the NFPA 101 Code (5-1.1) by reference to the ANSI A117.1 criteria for Accessible and Usable Buildings. The provision of refuge areas for the staging of disabled persons during emergency egress is not required in existing stations.

Maximum Travel Distance

The maximum travel distance is defined as the route leading from the most remote position on any of the station’s platforms to a station exit that leads directly to the station exterior. From the most remote position, the egress route should proceed directly to the nearest exit. It is not necessary to consider detours made, for instance, to avoid hazards when defining the route. Definition of the egress path for purposes of measuring the maximum travel distance is unrelated to the time-based egress test. For instance, a refuge area inside the station, although an acceptable destination for the time-based egress analysis, does not constitute an exit, as it does not provide “a protected way of travel” to a “public way” (NFPA 101, 5-1.2). Thus, the path defined to measure the maximum travel distance must terminate at a vertical circulation element, door, or passageway leading to the station exterior. Unlike the case of the longest egress path, the distance for the maximum travel distance is measured only to the location of the exit leading to the station exterior (e.g., the foot of a stairway) and does not include the vertical distance that needs to be traversed to reach the station exterior.

3.5 Egress Time

Compliance with the 6-minute test is measured by computing the time required for passengers to move along the entire length of the longest egress path, originating on a station platform and terminating at a point of safety. The egress time for the longest egress path is computed by summing (1) the time spent by the last person waiting to be processed by the successive egress elements; and (2) the time required to traverse the length of the egress path. In the context of transit stations, queuing times encountered along an exit route constitute by far the largest component of the total egress time. It is important to note that the total egress time computed under the NFPA 130 methodology does not include any mobilization, communication, or decision making time and therefore does not present an estimate of the actual time required for persons to reach a point of safety.
Flow Time

For each egress element, flow time represents the time required for a given number of passengers to be processed by the element. Flow time is a function of the size of the incoming passenger flow and the element capacity, as determined by the egress element’s unit capacity and the number of exit lanes provided (see Tables 3.1 and 3.2).

\[
\text{Flow Time (min)} = \frac{\text{Passenger Load (p)}}{\text{Capacity (ppm) \times no. exit lanes}}
\]

The above equation considers only the absolute number of passengers seeking to pass through a given egress element—rather than the rate at which persons arrive—and therefore should be thought of as the hypothetical time required for all passengers (i.e., the last passenger) to be processed by the element in the event that they arrive simultaneously. Flow times represent the basis for computing queuing delay that need to be adjusted in order to consider the fact that passenger arrivals are “metered” by varying walking distances and speeds as well as by previously encountered obstacles.

Wait Time

When computing the time passengers spend waiting in queues as they evacuate the station, it is necessary to compare the arrival rates of passenger flows with the processing rate (i.e., flow rate or “capacity”) of the egress elements that they encounter. Typically, the surge of evacuating passengers will face relatively long wait times as they commence their evacuation (e.g., at platform stairs). As the evacuation stream passes through the early egress elements, its flow rate is retarded. With the metering of the passenger stream, the arrival rate and wait times at successive egress elements are usually reduced. When computing the total egress time along a route, the wait times encountered at each egress element are summed to yield the total wait time for the last person evacuating by way of that route. Either of the following two methodologies for calculating the total wait time are acceptable.

Appendix C Method

In the sample calculations in Appendix C of the Standard, the total wait time for an egress route is determined by summing the wait times computed successively for each egress element through which the egress flow passes. At each egress element, the wait time is determined by first computing the flow time and then deducting the longest previously encountered flow time. In the case of the first egress element (i.e., platform exits), the wait time is computed by subtracting the flow time from the walk time on the platform. Thus, at each egress element, the fact that passenger arrivals are metered is considered by initially computing the time required to process the entire demand simultaneously and then subtracting any previously encountered flow times (or platform walk times, in the case of the first element). Using the terminology of Appendix C, total wait time along an egress path with “N” egress elements is defined as follows:
**Total Wait Time (Appendix C Method)**

\[
\text{Total Wait Time} = (W_1 - T_1) + \sum_{n=2}^{N} W_n - \max(W_1, ..., W_{n-1})
\]

Where:
- \( W_1 \) = flow time at egress element 1 (i.e., “time to clear platform”)
- \( T_1 \) = walk time on platform
- \( W_{n-1} - T_1 \) = wait time at platform exits
- \( W_n \) = flow time at egress element \( n \)
- \( W_n - \max(W_1, ..., W_{n-1}) \) = wait time at egress element \( n \), adjusted for metering

Using the values from the example for the Inbound Platform in Section C-1.3 of the NFPA 130 Standard, the steps involved in the **Appendix C Method** for computing the total wait time are illustrated below:

1. **Compute time to clear platform (i.e., platform exit flow time)**
   - \( W_1 \) (time to clear platform) = \( \frac{\text{Platform Occupant Load}}{\text{Platform Exit Capacity}} \)
   - \( W_1 = 3.267 \text{ min} \)

2. **Compute wait time at platform exits (i.e., platform exit wait time)**
   - \( W_P \) (wait time at platform exits) = \( W_1 - T_1 \) (walking travel time on the platform)
   - \( W_P = 3.267 - 0.825 = 2.442 \text{ min} \)

3. **Compute the flow time at each subsequent egress element**
   - \( W_n \) (flow time at element \( n \)) = \( \frac{\text{Occupant Load}}{\text{Element Capacity}} \)
   - \( W_2 \) (fare barrier flow time) = \( \frac{534}{400} = 1.335 \text{ min} \)
   - \( W_3 \) (concourse exit flow time) = \( \frac{534}{105} = 5.086 \text{ min} \)

4. **Adjust each flow time to account for the metering effect of previous elements**
   - \( W_1 \) (“metered” wait time at element \( n \)) = \( W_n - \max(W_1, W_2, ..., W_{n-1}) \)
   - At a given egress element (e.g., element \( n \)), if a previous egress element had a longer flow time than \( W_n \) (the flow time at element \( n \)) then \( W_n \) (the “metered” wait time at element \( n \)) is set to zero, since there will be no additional wait encountered at element \( n \).
   - \( W_F \) (fare barrier wait time) = \( 1.335 - 3.267 = 0.000 \text{ min} \)
   - \( W_C \) (concourse exit wait time) = \( 5.086 - \max(3.267 \text{ or } 1.335) = 1.819 \text{ min} \)

5. **Sum the platform wait time and all subsequent wait times (considering metering)**
   - **Total Wait Time** = \( W_P + \sum \text{ egress element “metered” wait times} \)
   - Total Wait Time = \( 2.442 + 0.000 + 1.819 = 4.261 \text{ min} \)

**NOTE:** The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
Simplified Method

The total wait time along a given route can alternatively be defined to be equal to the time required for the entire passenger flow to be processed by the most restrictive egress element along that path. This approach yields the same result as the Appendix C Method. Under the simplified method, the total wait time along a route is said to be equal to the flow time at that egress element where the capacity and the demand volume combine to yield the maximum flow time value. Thus, the total wait time (reflects metering) is said to be equal to the flow time (does not reflect metering) at that egress element along the route where capacity and demand combine to yield the maximum flow time value. When determining which element produces the maximum flow time, all elements—including the platform exits—need to be considered. Under this method, the total exit time along a given egress route is defined as:

\[ \text{TOTAL WAIT TIME (SIMPLIFIED METHOD)} \]

\[ \text{Total Wait Time} = \text{Maximum Flow Time} \]

Where the “flow time” at any element along the route is calculated as:

\[ \text{Flow Time (min)} = \frac{\text{Passenger Load (p)}}{\text{Capacity (ppm)} \times \text{no. exit lanes}} \]

This method for determining the wait time for the entire egress path seems deceptively straightforward and deserves some amplification. The following example from queuing theory validates the approach of using the time required to process the entire demand at the most restrictive egress element. This example illustrates the concepts that underlie both the Simplified Method and the NFPA 130 methodology (given that the two approaches yield the same outcome).

The following four equations illustrate the computation of the total wait time encountered by the last passenger in a given demand flow that passes through a series of two egress elements. Passengers are assumed to arrive simultaneously at the first egress element and then proceed at a “metered” rate. In the context of evacuation from transit stations, the assumption of simultaneous arrival at the first egress element is reasonable, considering that platform-level exit demand generally significantly outweighs the available platform exiting capacity. With the simultaneous arrival of passengers at the first egress element (i.e., Element A), the following equation represents the wait time encountered there:

\[ \text{WAIT TIME AT ELEMENT A} \]

\[ \text{Wait at Element A (min)} = \frac{\text{total passenger load (p)}}{\text{capacity of Element A (ppm)}} = \frac{N}{C_A} \]

Passengers passing through Element A are metered by its capacity and continue at a flow rate equal to the processing rate of that egress element (i.e., \( C_A \)). The length of time for which this flow persists is given by the wait time computed for Element A (i.e., \( N/C_A \)). Thus, ignoring random variation during the transition from Element A to the following egress element, passengers will arrive at Element B at a rate of \( C_A \) persons per
minute for a duration of N/C\(_A\) minutes (the last persons to arrive at Element B waited N/C\(_A\) minutes at Element A and will thus arrive at Element B N/C\(_A\) minutes after the first person arrives there). In instances where Element A is the most restrictive egress element along the exit route, the capacity of Element B and all subsequent egress elements exceeds the passenger arrival rate and no additional wait times are encountered. Therefore, the wait time computed for Element A (i.e., N/C\(_A\)) represents the total wait time along the entire egress route. This, in the NFPA 130 terminology, is equal to the maximum flow time along the path.

Where a subsequent egress element (i.e., Element B) is more restrictive than Element A, a queue will form at Element B. General queuing principles dictate that, where the arrival flow exceeds a given facility's processing rate (i.e., capacity), the length of the resulting queue (measured here in terms of persons) is equal to the difference between the arrival flow and the processing rate (i.e., the “deficiency rate”) multiplied by the duration for which the demand flow persists:

### General Queue Formula

Queue Length (p) = \([\text{arrival rate (ppm)} - \text{capacity (ppm)}] \times \text{demand duration (m)}\)

Thus, at Element B, the length of the queue (in persons) and the time for it to be cleared (in minutes) are as follows:

### Queue Length and Wait Time at Element B

\[
\text{Queue Length at Element B} = \left[ C_A - C_B \right] \times \frac{N}{C_A}
\]

\[
\text{Queue Wait Time} = \frac{\text{Queue Length (p)}}{\text{Capacity of Element B (ppm)}} = \frac{\left[ C_A - C_B \right] \times \frac{N}{C_A}}{C_B} = \frac{C_A(N)}{C_A C_B} - \frac{C_B(N)}{C_A C_B} = \frac{N}{C_B} - \frac{N}{C_A}
\]

The total wait time for an egress path involving the two elements in a series is equal to the sum of the wait times at each:

### Total Wait for Elements in Series

Total Wait Time = Wait at Element A + Wait Time for Queue at Element B

\[
\text{Total Wait Time} = \frac{N}{C_A} + \left( \frac{N}{C_B} - \frac{N}{C_A} \right) = \frac{N}{C_B}
\]
Thus, the total wait time for the two elements in a series, as calculated above, is equal to the time required for the most restrictive egress element to process the entire passenger load under simultaneous arrival conditions (as calculated under the NFPA 130 methodology for computing flow times at individual egress elements). The example validates the simplified method for computing wait times by illustrating that the equation for the Wait Time at Element A (see page 50), when applied to the most restrictive element, yields the combined wait time for elements in a series. Since the longest waiting time is based on the entire demand faced by that element, the egress time represents the time required for the last person (i.e., all persons) to pass through the series of elements.

The Simplified Method for computing the total wait time produces the same outcome as the Appendix C Method, as illustrated using the example for the Inbound Platform in Section C-1.3 (compare with sample calculation on page 49):

\[
\text{Total Wait Time} = \text{Maximum Flow Time} \\
\text{Total Wait Time} = \max(W_1, W_2, W_3) \\
\text{Total Wait Time} = \max(3.267, 1.335, 5.086) = 5.086
\]

Since the Appendix C methodology defines the waiting time at platform exits by subtracting from the time to clear the platform (i.e., platform exit flow time or \(W_1\)) the walking time on the platform (\(T_1\)), for purposes of comparison, the value of \(T_1\) needs to be subtracted from the total wait time computed per the Simplified Method.

\[
\text{Total Wait Time} = \text{Total Wait Time} - \text{Walking Time on Platform (}T_1)\]
\[
\text{Total Wait Time} = 5.086 - 0.825 = 4.261 \text{ min}
\]

*This step is included here only to demonstrate that the simplified method yields the same result—the step is not necessary when the simplified method for computing wait times is used in conjunction with the simplified method for computing the total egress time (see page 56).

The fact that the simplified method yields the same outcome as the Appendix C method confirms that the NFPA 130 methodology too is based on the assumption that passengers arrive simultaneously at the first element. As indicated earlier, this assumption is appropriate in the context of emergency evacuation from transit stations, where the first element is typically a stair or doorway on a crowded origin platform (see underlying assumptions listed in the discussion of the 4-minute test in Section 3.6).
Walk Time

For a given egress element, the time required to traverse its depth is based on walking speeds specified for egress elements and is computed as follows:

\[
\text{Walk Time (min)} = \frac{\text{Distance (feet)/(m)}}{\text{Speed (fpm)/(m/min)}}
\]

For egress elements with vertical components (e.g., stairs, stopped escalators, ramps with slopes greater than 4 percent), speed and distance are defined in terms of the vertical change in elevation bridged by the facility (see Figure 3.15):

![Figure 3.15 Distance Measure for Walk Time on Stairs and Escalators](image)

Computation of the total walk time is based only on the travel distance of the longest egress path—including both horizontal distances and the distance along the slope of stairs and escalators—and walking speeds corresponding to the various facilities (see Table 3.1).

Computing Total Exit Time

Total exit time is defined as the sum of the wait times and walk times computed along the longest egress path. As in the case of the computation of wait times, both the method outlined in Appendix C of the Standard as well as a simplified method are described for the computation of total egress time.

Appendix C Method

As the first step in computing the total exit time (for measuring compliance with the 6-minute test), Appendix C recommends determining the waiting time at the platform exits (Wₚ) by subtracting the walking travel time on the platform (T₁) from the platform exits flow time (i.e., time to clear platform, Wᵢ):
WAITING TIME AT PLATFORM EXITS

Waiting Time at Platform Exits (WP) =
Time to Clear Platform (W1) - Walking Time on Platform (T1)

Under the Appendix C method, the total exit time is then computed by adding to the waiting time at the platform exits (WP), the total walking time encountered along the egress path (T) and any additional wait times encountered at subsequent egress elements (see Appendix C method for computing wait times at individual egress elements):

TOTAL EXIT TIME (APPENDIX C METHOD)

Exit Time = T + WP + W_F + W_C

Where:
T = total walk time
WP = wait time at platform exits
W_F = wait time at subsequent egress element (e.g., fare barriers)
W_C = wait time at subsequent egress element (e.g., concourse exits)

The Appendix C method for computing total exit times deserves further scrutiny. In the computation of the waiting time at the platform exits (WP), platform walk times are considered in order to account for the fact that the flow of persons arriving at the platform exits is metered by previous events (use of the platform exits flow time (W1) as a measure of wait time at the exits would imply simultaneous arrival of passengers at the exits). The following discussion illustrates that the introduction of the waiting time at the platform exits (WP) as a component of the total wait time is superfluous and needlessly raises a number of logical concerns regarding the methodology for computing the total exit time.

The NFPA 130 method for computing the waiting time at the platform exits suggests that the time to clear platform (or platform exits flow time, W_I) is equal to the sum of the walk time on the platform and the wait time at the platform exits. Although this makes sense conceptually, it is logically flawed in the context of the established parameters. Since the time to clear platform (W_I) is computed only as a function of the exit capacity of the platform exits (and not the platform length and walking distances on the platforms), it does not contain a mathematical component that represents the walk time on the platform. Consequently, subtracting from W_I an independently calculated platform walk time (based on measured walking distance and walk speed) yields a value for the waiting time at the platform exits that is only arbitrarily lower than the platform exits flow time (W_I) in order to account for a metered arrival flow.¹⁹

¹⁹ There is no basis for using platform walk time as a measure of the metering of the arrival flow at the platform exits; indeed, other factors, such as the flow capacity of the train doors, have a much greater effect on the distribution of the egress flow than does the walking distance on the platform. Furthermore, computation of separate values for the walking time on the platform and the wait time at the platform exits is complicated by the fact that persons traverse a portion of their platform travel distance while already absorbed in the queue.
Introduction of the waiting time at the platform exits ($W_p$) as a component of the total wait time causes confusion. If $W_1$ is computed to represent the time required to clear the platform, then it is needlessly complicated and counterintuitive to subtract from the platform clearance time the walking time on the platform ($T_1$) only to add it again when computing the total walk time ($T = T_1 + T_2 + T_3 + \ldots + T_N$). Inclusion of the walking time on the platform ($T_1$) in the overall exit time effectively cancels the step introduced previously to account for the metering of persons on the platform (i.e., the subtraction of $T_1$ from $W_1$ to yield $W_p$)\textsuperscript{20}. Thus, the Appendix C method for computing the total exit time adds unnecessary variables and computation steps.

**Simplified Method**

Adoption of a slightly revised method (i.e., the “partially simplified” method) for computing the total exit time eliminates the above-mentioned confusion while yielding the same results as the Appendix C Method. Under this method, the total exit time is said to be equal to the sum of:

1. The time to clear platform ($W_1$, as computed in Test No. 1);
2. The wait times encountered at subsequent egress elements; and
3. The walk time required to traverse the egress route once the platform has been cleared (time measure begins after the clearing of the platform and therefore includes neither the walk time on the platform nor the walk time required to traverse the platform exits):

\[
\text{TOTAL EXIT TIME (PARTIALLY SIMPLIFIED METHOD)}
\]

\[
\text{Exit Time} = T_{NP} + W_1 + W_F + W_C
\]

Where:

- $T_{NP}$ = walk time on all “non-platform” areas, such as the concourse and all stairs
- $W_1$ = flow time at egress element 1 (i.e., “time to clear platform”)
- $W_F$ = wait time at subsequent egress element (e.g., fare barriers)
- $W_C$ = wait time at subsequent egress element (e.g., concourse exits)

As illustrated with the values from the sample calculation in Section C-1.3, Appendix C and the partially simplified method yield the same result:

**Appendix C Method**

\[
\text{Exit Time} = T + W_0 + W_F + W_C
\]

\[
= (T_1 + T_2 + T_3 + T_4 + T_5) + (W_1 - T_1) + (W_F - W_1) + [W_C - \max(W_1, W_F)]
\]

\[
= 2.330 + (3.267 - 0.825) + (1.335 - 3.267) + [5.086 - \max(3.267, 1.335)]
\]

\[
= 2.330 + 2.442 + 0.000 + 1.819 = 6.591 \text{ min}
\]

**Partially Simplified Method**

\[
\text{Exit Time} = T_{NP} + W_1 + W_F + W_C
\]

\[
= (T_2 + T_3 + T_4 + T_5) + W_1 + (W_F - W_1) + [W_C - \max(W_1, W_F)]
\]

\[
= 1.505 + 3.267 + (1.335 - 3.267) + [5.086 - \max(3.267, 1.335)]
\]

\[
= 1.505 + 3.267 + 0.000 + 1.819 = 6.591 \text{ min}
\]

\textsuperscript{20} The calculations on page 52 confirmed that the NFPA 130 methodology ultimately yields a result that considers simultaneous arrival at the first egress element.
With the partially simplified method, the transition from Test No. 1 (4-minute test) to Test No. 2 (6-minute test) is sequential; that is, the wait and walk times computed as part of Test No. 2 are simply added to the outcome of Test No. 1 (e.g., \( W_i \)) to yield the total exit time. Incorporating the simplified computation of the total wait time (see page 50) into the above equation for total exit time yields the following simplified expression:

\[
\text{TOTAL EXIT TIME (SIMPLIFIED METHOD)}
\]

\[\text{Total Exit Time} = T_{NP} + \text{Maximum Flow Time} \]

or

\[\text{Exit Time} = T_{NP} + \max (W_1, W_2, ..., W_N)\]

As illustrated using the values from the sample calculation in NFPA 130 Section C-1.3, the above formula yields the same value for the total exit time as is computed under the Appendix C method (compare with Appendix C Method in the box on previous page).

**Appendix C Method**

Exit Time: 
\[= T + W_P + WF + WC \]
\[= (T_1+T_2+T_3+T_4+T_5) + (W_1-T_1) + (W_2-W_1) + \max(W_1,W_2) \]
\[= 2.330 + (3.267 - 0.825) + (1.335 - 3.267) + \max(3.267, 1.335) \]
\[= 2.330 + 2.442 + 0.000 + 1.819 = 6.591 \text{ min} \]

**Simplified Method**

Exit Time: 
\[= T_{NP} + \text{Maximum Flow Time} \]
\[= (T_2+T_3+T_4+T_5) + \max(W_1,W_2,...,W_N) \]
\[= 1.505 + \max(3.267, 1.335, 5.086) \]
\[= 1.505 + 5.086 = 6.591 \text{ min} \]

### 3.6 Evacuation Time Criteria

#### 4-Minute Test

2-5.3.2 “There shall be sufficient exit lanes to evacuate the station occupant load ... from the station platforms in 4 minutes or less.”

The 4-minute test is applied independently for each station platform but does not consider non-platform areas in the station. The 4-minute test measures the time required for the platform occupant load to clear the station platform(s) and reach areas in the station that are not defined as station platforms. These “non-platform” areas may be on the same level as the platforms or may be on a concourse level at a higher or lower elevation. For each station platform, the time to clear platform is a function only of the number of passengers to be evacuated from that platform and the total exit capacity.
available from that platform. All egress elements serving a given platform are considered to be equally attractive and their location on the platform is not considered.

\[
\text{TIME TO CLEAR PLATFORM}
\]

\[
\text{Time to Clear Platform (m)} = \frac{\text{Platform Occupant Load (p)}}{\text{Platform Exit Capacity (ppm)}}
\]

The time to clear platform represents the total time required for all passengers to clear the platform and is computed similar to the "processing" times for individual egress elements. Thus, in essence, in the 4-minute test, the capacities of all egress elements serving a platform are combined and treated as a single egress element. Although not disaggregated here, in reality the time to clear the platform includes, depending on the station configuration, varying combinations of both walking time and time spent waiting in queues. The absence of this distinction as part of the 4-minute test points to a number of underlying assumptions about platform conditions that are similar to those implicit in the "hydraulic" distribution of demand throughout the station:

1. The platform occupant load is distributed across the platform in a manner that permits a relatively uniform distribution of the egress demand among all available egress facilities (e.g., turnstiles, stairs, escalators, walkways).

2. The platform occupant load is sufficiently large (relative to the available platform egress capacity) to cause queues to form at the foot of all egress facilities. Even passengers reaching a given vertical circulation element from the most remote point on the platform are expected to encounter a queue.

3. Since all egress facilities attract portions of the platform occupant load that are proportional to their egress capacity, wait times encountered at each facility are similar.

These assumptions generally hold for rapid transit systems; however, their validity should be confirmed in applications of the NFPA 130 Standard for other modes.

**6-Minute Test**

2-5.3.3 “The station also shall be designed to permit evacuation from the most remote point on the platform to a point of safety in 6 minutes or less.”

Compliance with the 6-minute test is measured by simulating the flow of passengers along the longest (in terms of time) egress route, originating on a platform and terminating at a point of safety. Once the longest egress route is defined, the 6-minute test is applied only for that route. Determining the longest route, however, requires not only definition of the longest walking path but also an examination of wait times encountered at various locations in the station.

Once the longest exit route is defined, the egress time is calculated as the sum of the total time spent walking along the path and the longest wait time encountered. Thus, in contrast to the 4-minute test, the 6-minute test distinguishes between time spent walking and time spent in queues. Comparison of wait times at the various egress elements, for purposes of defining the longest wait time, requires consideration of
capacities of various elements as well as the combined demand encountered there. Thus, while the 6-minute test measures egress time for a specific path, originating on one particular platform, the determination of the longest wait time encountered along the path typically involves consideration of demand originating from multiple platforms.

Figure 3.16 schematically represents demand flows and egress elements encountered for egress paths originating from two platforms with varying occupant loads. At each egress element, the wait time is computed as a function of the combined flow demand present at that location and the available capacity.

**FIGURE 3.16 EXIT ROUTE WAIT TIME**

Under NFPA 130, the egress demand at any location is expressed in terms of total persons rather than arrival rates. Per the Simplified Method for computing the total wait time along a given route (see page 50), the total wait time encountered by passengers evacuating the station from Platform 1 or Platform 2 above is equal to the maximum flow time (simultaneous arrival of all passengers without consideration of metering) at any element along the egress route (i.e., 3 minutes for Platform 1 and 2.5 minutes for Platform 2). Thus, in the above example—assuming walking distances along routes are similar—Platform 1 constitutes the critical 6-minute test.

Given the unit capacity and unit demand figures shown above, the time required to reach the street level from Platform 1 is equal to the sum of the walking time for the total path length and a waiting time of 3 minutes, the longest wait encountered along the route. For Platform 2, on the other hand, the waiting time component of the total egress time would be equal to 2.5 minutes.
3.7 Configuration of Egress Capacity

Introduction

In addition to egress capacity requirements, a number of NFPA 130 criteria govern the relative location of egress elements. With regard to the location of exits, however, the NFPA 130 Standard offers relatively limited guidance. NFPA 130 requirements that govern the configuration of exits should therefore be viewed as minimum design standards. Designers may find it useful to consider some principles in Chapters 5 and 8 of the NFPA 101 Code, even in instances where they do not apply explicitly to transit stations.

NFPA 130 Requirements

The NFPA 130 requirements governing the location of exits in transit stations are essentially limited to the following two criteria:

1. The Standard requires that the “maximum travel distance to an exit from any point on the platform shall not exceed 300 feet” (91.4m) (2-5.3.3).

2. “A second means of egress at least two lanes wide shall be provided from each station platform and shall be remote from the major egress route” (NFPA 130, 2-5.3.6). This requirement essentially stipulates that all station platforms need to be served by a minimum of two exit routes, each offering a minimum of two 22-inch exit lanes. In instances where normal operations require only one access route (i.e., stairway) to a platform, the secondary exit required under this provision may be an emergency exit that is activated only for purposes of emergency evacuation. NFPA 101 offers hardware specifications for doors leading to emergency exits. Emergency exits need not necessarily lead to the mezzanine or street level but could, for instance, lead to a trainway meeting the requirements of a point of safety or refuge area.

Other Considerations

One of the principal concerns in most fire codes and model building codes is the elimination or reduction of dead-end corridors. Dead-end corridors offer only one route of egress and thus present a significant hazard, since a localized fire source or obstruction can potentially entrap the entire corridor's occupant load. To reduce the risk of passengers being trapped by an emergency in a “dead-end” corridor, NFPA 101 requires that in areas of public assembly “[e]xits shall be located remotely from each other and shall be arranged to minimize the possibility that they might be blocked by any emergency” (101, 8-2.5.1). This criteria is augmented by the provision that several exit routes may share a “common path of travel” of 20 feet (6.1m) (“maximum common path” requirement). Thus, from any point in the station, passengers commencing their evacuation must encounter the choice of an alternate, discrete exit route within 20 feet (6.1m) of their original position. Although the requirements in Chapter 2 of the NFPA 130
Standard technically constitute an exception to the NFPA 101 common path requirement, it is nonetheless worth consideration as a good design practice.\textsuperscript{21}

The maximum common path requirement is particularly relevant on transit station platforms, where the danger exists that an obstruction (i.e., fire source) could block access to the remainder of the platform and strand passengers at the end of the platform. Figure 3.17 illustrates the maximum common path criteria in the context of several schematic platform configurations. Example 1 in this figure illustrates that, with an endloading stair at either end of a platform, passengers occupying any position on the platform are able to reach one or the other stairway, regardless of the location of an emergency incident. At any point on the platform, the approach path to one exit does not overlap the approach path to the other; therefore, the two exits are said to not share a common path. This condition generally prevails in all passageways and on station mezzanines. In Examples 2 through 4, passengers located in platform areas that are shaded could be stranded by an obstruction spanning the width of the platform. In contrast, the non-shaded areas offer a minimum of one exit route, regardless of the location of the obstruction.

**Figure 3.17 Common Path to Exits**

Example 1: no common paths

Example 3: two common paths with length $x$ and $y$

Example 2: one common path with length $x$

Example 4: one common path with length $x$

Persons located in non-shaded areas have a choice of two completely discrete egress routes (i.e., routes that have no horizontal distance in common). Thus, a hazard spanning the width of the platform could not block persons located in non-shaded areas from reaching a stair (see Example 3). Persons in shaded areas, however, could be blocked from an exit by such a hazard (see Example 4).

\textsuperscript{21} The fact that the NFPA 130 requirements under Chapter 2 constitute an exception to the common path of travel requirement under the NFPA 101 Code was confirmed by the Technical Committee on Fixed Guideway Systems’ response to a formal interpretation request in October of 1997.
The maximum common path requirement restricts the portion of the platform that could be blocked by an incident (dimensions x and y in Figure 3.17). Essentially, this results in the provision that, where platform egress elements are further than 20 feet (6.1m) from the end of the platform (i.e., “y” in Example 3), an endloading emergency exit is required (see difference between Example 3 and Example 4). This emergency exit does not need to lead to the same level to which the other platform stairs lead but instead could lead down to the trainroom, provided it meets the requirements for a refuge area or offers a means of egress to a point of safety.
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4.0 EGRESS FROM TRAINWAYS
4.0 EGRESS FROM TRAINWAYS

4.1 Introduction

Chapter 3 of the NFPA 130 Standard addresses egress requirements for all trainways (e.g., at-grade, elevated and tunnel alignment sections). In contrast to transit stations, trainways are not considered areas of public assembly and are not subject to the requirements of the NFPA 101 Code. NFPA 130 means of egress requirements for trainways are, therefore, not augmented by NFPA 101 criteria (except in instances where explicit reference is made, as in the case of hardware requirements). Unlike the egress provisions for transit stations, NFPA 130 egress requirements for trainways are not performance-based but instead follow a more prescriptive model. Egress requirements for trainways do not involve time-based criteria and are expressed only in terms of maximum distances between exits. The carrying capacity of egress elements and the demand that needs to be accommodated are not considered.
4.2 Emergency Exits

Emergency exit stairways shall be "spaced so that the distance to an emergency exit shall not be greater than 1,250 feet (381m)..." (NFPA 130, Section 3-2.4.2). Distance—as opposed to egress path—refers to the maximum linear distance to an exit without considering obstructions. The above requirement is met when exits are located no further than 2,500 feet (762m) from each other or from stations. Tunnels less than 2,500 feet (762m) long, or where the distance between portals and stations is less than 2,500 feet (762m), do not require exit stairs. The requirement that exit doors "shall open in the direction of exit travel" (NFPA 130, Section 3-2.4.4) essentially limits exit doors to swing hinge doors.22

Where trainways in tunnels are separated by a fire wall or are in twin bores, the non-contaminated trainway is able to function as a point of safety and exit stairs are not required, provided that passengers are able to access the non-contaminated tunnel by way of cross-passageways. Cross-passageways are to be equipped with fire doors and "shall be no further than 800 feet (244m) apart" (NFPA 130, Section 3-2.4.3). Such doors are not required to open in the direction of exit travel.

Egress Way in Trainways

The NFPA 130 requirements for pedestrian facilities inside trainways are somewhat vague, stating only that "[a] suitable method shall be provided for evacuating passengers in the uncontaminated trainway, for protecting passengers from oncoming traffic, and for evacuating the passengers to a nearby station or other emergency exit" (3-2.4.3). This provision is generally satisfied by installing a walkway alongside the trackway. Where two tracks abut each other without separation, a single walkway is sufficient to accommodate passengers discharging from trains on either track. Where tracks are separated, walkways need to be provided for each track. Accessibility guidelines are generally not applied to walkways inside trainways, as the cost associated with construction of walkways offering clearance sufficient to accommodate a wheelchair would be prohibitive. A minimum width of 2.0 feet (0.61m) is recommended for walkways inside trainways.

Evacuation Time: A Hypothetical Example

Although measurement of egress times from locations in trainways is not required under NFPA 130, it is nonetheless illustrative to simulate the evacuation of passengers inside a trainway by way of narrow walkways. Using the egress element capacities and walking speeds prescribed for the time-based egress criteria for transit stations (NFPA 130, Section 2-5.3.4.1), the following calculations estimate the time required for 400 passengers on board a train inside a tunnel to reach the foot of the emergency stairway that is located 800 feet (244m) from the end of the train by way of a 2-foot-wide (0.61m) tunnel walkway.

The walkway accommodates single-file egress only and is assumed to offer a passenger flow capacity approximately equal to that of a corridor with an effective width

22 Although the same restriction applies to doors in transit stations that are credited with exit capacity, the "swing in the direction of exit travel" requirement is not explicitly included in Chapter 2 since it would be redundant with the NFPA 101 criteria invoked in Chapter 2.
of one 22-inch (.559m) exit lane. Although the curvature of the tunnel wall creates a somewhat larger shoulder-level clearance than the 2-foot (0.61m) floor width, it should be noted that the assignment of a full exit lane for the walkway is nonetheless optimistic since full wall deductions and minimum corridor widths per NFPA 130, Section 2-5.3.4.1 were not considered for the purpose of this exercise. A corridor of 4 percent slope or less offers a capacity of 50 persons per minute (ppm) per 22-inch (.559m) exit lane and permits passengers to walk at speeds of 200 feet (61m) per minute (fpm).

The total egress time for the last passenger aboard the train is computed as the sum of the time required for that passenger to be processed by the walkway (i.e., wait time) and the time required to walk from the head of the train to the egress location (i.e., walk time). For purposes of these calculations, the walkway is treated as a single egress element as prescribed in the NFPA 130 station egress computations. The wait time for the last passenger to be processed by the egress flow on the walkway is a function only of the total train load and the carrying capacity of the walkway.

**Trainway Egress Wait Time Example**

\[
\text{Wait Time (min)} = \frac{\text{Egress Demand (p)}}{\text{Capacity (ppm)}} \approx \frac{400 \text{ p}}{50 \text{ ppm}} = 8 \text{ min}
\]

It is assumed that during the 8-minute wait period, the last passenger is able to traverse the length of the train (500 feet) (152m) in the direction of egress. Consequently, a distance of 800 feet (244m) remains to be traversed by the last person after the wait period (see Figures 4.1 and 4.2).

**Figure 4.1  Egress from Trainway**

**Trainway Egress Walk Time Example**

\[
\text{Walk Time (min)} = \frac{\text{Distance (f)}}{\text{Walk Speed (fpm)}} = \frac{800 \text{ f}}{200 \text{ fpm}} = 4 \text{ min}
\]

\[
\text{Exit Time (min)} = \text{Wait Time} + \text{Walk Time} = 8 \text{ min} + 4 \text{ min} = 12 \text{ min}
\]
A total of 12 minutes is required for the last person to reach the foot of the exit stair. The hypothetical example illustrates that, due to the limited capacity of a typical walkway, the waiting time by far constitutes the biggest component of the total evacuation time. The range of passenger egress times for this hypothetical example is depicted in Figure 4.2.

**Figure 4.2 Tunnel Evacuation Time**

The substantial wait time and the long overall duration of the egress time underscore the general observation that the evacuation of passengers inside trainways is only desirable in circumstances where the trainways are uncontaminated and that, when at all feasible, trains requiring evacuation should proceed to the nearest station to discharge passengers.
5.0 APPLICATION GUIDELINES
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5.0 APPLICATION GUIDELINES

5.1 Introduction

The NFPA 130 egress element provides a methodology for quantifying evacuation performance. Egress times computed according to this methodology should be viewed as performance measures rather than accurate predictions of the actual time required to evacuate the station, as suggested by the following observations.

The egress times computed under NFPA 130 do not consider human factors such as panic or initial disorientation and decision-making time:

1. Distribution of passengers throughout the station according to the hydraulic model, although generally appropriate for transit settings, does not account for the tendency of passengers to evacuate the station by way of routes with which they are familiar or which are most recognizable (because they were chosen by others). Passengers are more likely to attempt to evacuate via the routes with which they have become familiar as part of their regular use of the station as compared to emergency stairs and corridors that are only made available during emergencies. Thus, in reality, alternate paths differ not only in terms of their available capacity, as suggested by the methodology. Designers may acknowledge this by providing, to the extent that is practical, the majority of the required exit capacity to facilities that are available during normal operations.

2. The walking speeds and egress element capacities used in NFPA 130 apply generally and are not modified to reflect different pedestrian density levels. It is, however, well established that pedestrian flow rates, and thus walking speeds, vary considerably according to density levels (see Figure 3.4 and pedestrian flow relationship equation on page 29). Under extremely crowded conditions, the assumptions about flow rates through egress elements and horizontal as well as vertical walking speeds that underlie the NFPA 130 computations may be overly optimistic. Designers may chose to independently confirm that the walking speeds are appropriate.

The above factors notwithstanding, the NFPA 130 methodology offers an acceptable measure of station emergency performance, which is particularly useful in a comparison of alternate station configurations.
5.2 Other Modes

Aside from the NFPA 130 Standard, there do not exist any guidelines or standards that adequately address the unique demand characteristics of passenger transportation facilities. Thus, designers are increasingly employing the NFPA 130 egress element as a guide in the design of a broad range of transportation facilities. While application of the egress element as a guide for facilities beyond those for which it was developed (rapid transit fixed guideway systems) is not inappropriate, it should be informed by consideration of conditions unique to each mode. The following section provides an overview of such issues for a range of modes for which the NFPA 130 egress element has found application. Sample calculations included in the next section help illustrate the application of the egress element for these modes.

Light Rail Transit

Most LRT systems, regardless of whether they are employing low-floor vehicles, generally have low-level station platforms (Long Beach, Downtown San Francisco, and Pittsburgh are the exceptions). Generally, platform height is sufficiently low that passengers, under some circumstances, may be directed to clear platforms by stepping down onto the track level, which may be suitable for egress, particularly in alignment sections with embedded or direct-fixation trackbeds. Due to the absence of the third rail power supply, LRT trainways offer a relatively safe egress route.

The choice of vehicle technology significantly affects egress time computations. Egress times for LRT systems with high-floor vehicles are likely to be significantly longer than for those that offer level alighting (most rapid transit systems and low-floor LRT systems).
Commuter and Intercity Rail

In many large metropolitan areas, commuter rail systems make use of mature urban rail terminals designed for intercity rail. Several factors need to be considered in such settings:

1. Constrained approach track capacity often limits the number of trains that can simultaneously arrive at the station (this is true for all terminal station configurations but most frequently associated with heavy rail systems). Therefore, rather than define the station occupant load by considering the simultaneous arrival of as many trains as is operationally feasible, it may be more appropriate to consider passenger loads on board trains inside the station that are about to depart. Since it is not unusual for passengers to begin boarding commuter rail and intercity trains significantly prior to their scheduled departure (as opposed to waiting for a train to arrive at the platform), the combined occupant load of several platforms may reach its maximum when a number of trains are scheduled to depart within a relatively short time period.

2. At large stub-end terminals where all platform exits are located at one extreme end of very long platforms, it is possible that, under low demand conditions with relatively little queuing, the computation of the platform clearance time under the 4-minute test is inappropriate as it does not consider walking time on the platform \( W_1 \) = platform occupant load/egress capacity).

3. The NFPA 130 assumption that, at the commencement of the evacuation, all passengers are located on station platforms does not typically apply in complex rail terminals where passengers are often not aware of their train location until immediately prior to boarding. Passenger accumulation in waiting areas or rooms needs to be considered. Where passengers do not wait for trains on station platforms, only those platforms where trains are receiving passengers will have an entraining load.
4. Commuter rail cars are typically longer than rapid transit trains and are in some instances served by only two doors per car. Given the large number of passengers seeking to pass through a given door, a significant amount of time may be required for passengers to alight from trains. Effectively, the doors could be one of the more restrictive egress elements, metering the passenger flow. Note that the difference between “crush” capacity and nominal capacity is usually more pronounced for commuter rail cars than it is for rapid transit vehicles.

AGT/People Movers

People mover or AGT stations are frequently integrated into “joint use” structures that house transportation as well as non-transportation activities, such as those generated by commercial, retail, or entertainment uses. Integration of transit-related pedestrian flows with general pedestrian traffic in a common facility raises a number of issues with regard to the NFPA 130 egress computations.

Since the boundaries between the transit environment and the building in which it is housed (“host building”) may not always be readily defined, the egress analysis for the transit station may require consideration of the occupant load of surrounding spaces. The NFPA 130 assumption for rapid transit stations that the entire occupant load is located on platforms ignores the impact of nearby pedestrian activity on station egress and is therefore not suitable for many AGT stations. Depending on the extent to which station areas are separated from surrounding uses (i.e., through fare collection systems—see Figure 5.1), non-platform areas in AGT stations may contain sizable occupant loads as a result of the pedestrian activity in the host building. Where this load occupies areas that are traversed by egress routes from platforms, it could significantly slow station egress times and therefore should be quantified. The occupant load defined in NFPA 101 for “assembly areas of concentrated use without fixed seats” as one person per 7 square feet (0.651 m²) of floor space (see Section 101 8-1.7) may be suitable for calculating occupancies in non-platform areas at AGT stations that are fully integrated into surrounding uses.
Figure 5.1 Fare Collection

Fare collection gates significantly retard egress flows. Proof-of-payment fare collection systems, as shown in the bottom example, eliminate egress bottlenecks and thereby reduce egress times.
Since it is possible that the emergency requiring evacuation from an AGT station would simultaneously trigger evacuation from the host building, the entire occupant load of the host buildings may need to be considered in connection with the station egress analysis. Areas where the egress routes from the two uses converge should be sized according to a combination of the NFPA 130 and the NFPA 101 approaches.

Where there are no physical barriers between the transportation environment and the other uses, essentially resulting in full integration of the two facilities, the occupant load for any given area may be composed of AGT passengers as well as general building users, resulting in a broader population base than characteristic of most transit settings. A large share of elderly and young persons in the occupant load is likely to adversely affect egress times.

AGT systems frequently find application in large airports. This environment presents a number of special considerations:

• In order to accommodate travelers carrying baggage, vertical circulation at airport AGT stations typically relies extensively on escalators and elevators. Consequently, compliance with the NFPA 130 requirement that at least one-half of the egress capacity from a given level must be provided by stairs requires provision of extensive emergency stair capacity at each level.

• "Moving sidewalks" are often used to facilitate movement by passengers carrying baggage. Since moving sidewalks are rarely found in conventional rapid transit stations, NFPA 130 does not assign capacity values to them. NFPA 101, however, requires that “… moving walks shall not constitute a part of the required means of egress” (NFPA 101, Section 5-2.7).

• Although airport AGT systems frequently do not include fare collection barriers (as they do not require a fare or rely on the “honor system”), security barriers separate passenger facilities into “secured” and “unsecured” areas. Evacuation routes need to reflect these zones. Passenger egress routes should not require passengers to move from unsecured to secured zones.

• AGT systems frequently serve facilities that are not necessarily characterized by temporal demand distributions typically found in transit stations. Airports, for instance, are prone to pronounced seasonal fluctuations. Demand calculations at airport AGT systems, therefore, need to account for demand peaks during the principal travel months and around holidays.

• AGT systems usually rely on low-capacity vehicles operating at very high frequencies (e.g., 90-second headways). Very high service frequencies, such as those in many AGT systems, are often offered to minimize passenger wait times and do not necessarily relate directly to station entrance demand. The NFPA 130 methodology addresses this by assigning the default “failure period” of 12 minutes for stations where headways are below 6 minutes.
6.0 EGRESS ELEMENT SAMPLE CALCULATIONS
6.0 EGRESS ELEMENT SAMPLE CALCULATIONS

6.1 Introduction

The following sample calculations reflect methodologies used in actual applications of the NFPA 130 egress element. Volumes and capacities may have been adjusted in order to illustrate points. Moreover, in some cases, station configurations and dimensions do not reflect actual conditions. As a result, the outcomes do not necessarily reflect the actual condition at these stations.

6.2 Generic Subway Station

Introduction

This example illustrates the application of the egress element for a single-level subway station. Given the rather simple station configuration, the distribution of passenger flows through the station and the determination of minimum egress capacities is relatively straightforward. As part of the computation of the total egress time, this sample calculation introduces a simplified method for computing the total wait time along the longest egress route (as discussed in Section 3.5).

The same station geometry is evaluated as: (1) an existing station; and (2) a design for a new station. The two scenarios illustrate the different requirements for existing and new stations, particularly as they pertain to the configuration of exits (as opposed to their capacity) and egress provisions for disabled persons.

Existing Station

The following calculations outline the application of the NFPA 130 egress element for an existing subway station. For existing stations, the NFPA 130 requirements focus primarily on the computation of the egress demand and an assessment of whether the existing (or proposed) exits are sufficient to meet the 4- and 6-minute egress criteria. Requirements regarding the arrangement of exits (e.g., maximum common path requirement) and the egress of disabled persons (e.g., provision of refuge areas) generally do not apply to existing stations.

Overview

The cut-and-cover subway station is located one level beneath the street level and does not contain a mezzanine (see Figure 6.1). Two side platforms serve one track each. Each platform is accessed by way of a row of turnstiles from a station lobby located at the center of the platform. Each station lobby contains a token booth and is connected to the street level by way of two stairways and one elevator, which is used for ADA access only.
Stations and facilities are generally arranged symmetrically along the centerline of the trackway. Trains operate at 5-minute headways in both directions.

**Emergency Condition**

The station is characterized by heavy commuter-oriented demand patterns. The AM peak period is the critical analysis period, as (1) CBD-bound trains (southbound) are already carrying heavy loads when they arrive at the station located just outside the core; and (2) the station serves a sizable residential district and consequently experiences significant peak-direction boardings in the mornings. After a “failure period” of 12 minutes, two trains enter the station simultaneously (the 12-minute default time is used since the headways are less than 6 minutes—see failure period computation on page 25). The southbound train arriving at Platform A is carrying a peak-direction load. Ridership on off-peak direction trains and station entries to the off-peak platform (Platform B) are relatively low.
FIGURE 6.1 EXISTING GENERIC SUBWAY STATION

NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
**Platform Occupant Loads**

Reliable ridership data is available from recent field inspections. Since egress flows from platforms remain discrete, the entraining and train occupant loads computed for each platform are not combined to yield an overall station occupant load.

**Entraining Load.** Field observations indicate that 320 persons typically enter the station during the peak AM hour to board southbound trains by way of Platform A. Only 40 persons board northbound trains from Platform B during the peak AM hour. A system-specific peaking factor to account for the demand distribution within the peak hour is not available.

\[
\text{Platform A Entraining Load} = 320 \text{ p/hr} \times \frac{15 \text{ min}}{60 \text{ min}} \times 1.5 \times \frac{12 \text{ min}}{15 \text{ min}} = 96 \text{ p}
\]

\[
\text{Platform B Entraining Load} = 40 \text{ p/hr} \times \frac{15 \text{ min}}{60 \text{ min}} \times 1.5 \times \frac{12 \text{ min}}{15 \text{ min}} = 12 \text{ p}
\]

**Calculated Train Load.** The observed peak hour line demand in the peak and off-peak directions is 2,600 and 400 persons per hour, respectively. The observed “crush” capacity of a subway car is 120 persons (p). All trains operate in six-car consists, yielding a “crush” capacity of 720 persons per train. Trains operate at 5-minute headways in both directions.

**Platform A**

1. \[
\frac{\text{Peak 15- min link load}}{\text{#trains in 15 min}} \times \frac{2,600 \text{ p}}{60 \text{ min}} \times 1.5 \times \frac{2}{3 \text{ trains/15 min}} = 650 \text{ p}
\]

2. \(650 \text{ p} < 720 \text{ ("crush capacity"), thus Calculated Train Load} = 650 \text{ p}\)

**Platform B**

1. \[
\frac{\text{Peak 15- min link load}}{\text{#trains in 15 min}} \times \frac{400 \text{ p}}{60 \text{ min}} \times 1.5 \times \frac{2}{3 \text{ trains/15 min}} = 100 \text{ p}
\]

2. \(100 \text{ p} < 720 \text{ ("crush capacity"), thus Calculated Train Load} = 100 \text{ p}\)
Platform Occupant Load

\[
\text{Platform Occupant Load} = \text{Calculated Train Load} + \text{Entraining Load}
\]

Platform A: Platform Occupant Load = 650 + 96 = 746 p

Platform B: Platform Occupant Load = 100 + 12 = 112 p

Given that the two station platforms and their exit configurations are identical, it is only necessary to consider the egress flow from the platform with the larger occupant load.

Exit Lanes and Capacity Provided

The capacity associated with the egress elements contained in the station are summarized in the table below. Turnstiles have a fixed capacity of 25 persons per minute (ppm). For both platforms, the placement of the elevator restricts the width of the North Stair, causing it to be slightly more narrow than the South Stair. The North Stairs are exactly 10 feet wide, affording five exit lanes (see exit lane calculation on page 34). The South Stairs are 10 feet 6 inches wide and afford six exit lanes.

<table>
<thead>
<tr>
<th>Egress Element</th>
<th>No. of Units</th>
<th>Lanes each</th>
<th>Capacity per Lane</th>
<th>= PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform to Lobby</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turnstiles</td>
<td>8</td>
<td>1.0</td>
<td>25</td>
<td>200</td>
</tr>
<tr>
<td>Lobby to Street</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Stair</td>
<td>1</td>
<td>5.0</td>
<td>35</td>
<td>175</td>
</tr>
<tr>
<td>South Stair</td>
<td>1</td>
<td>6.0</td>
<td>35</td>
<td>210</td>
</tr>
</tbody>
</table>

Walking times for the longest exit route are based on the station dimensions and the fixed walking times stipulated by NFPA 130 for the various trip components. The walk speed provided for stairs refers to the vertical distance to be traversed (at this station, the change in elevation between the platform and street level is 30 feet).

<table>
<thead>
<tr>
<th>Walking Time For Longest Exit Route</th>
<th>Feet</th>
<th>/fpm</th>
<th>Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Platform</td>
<td>T1</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td>In Lobby</td>
<td>T2</td>
<td>90</td>
<td>200</td>
</tr>
<tr>
<td>Lobby to Street Level</td>
<td>T3</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Total Walking Time (T=T1+T2+T3)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Test 1: Evacuate Platform Occupant Loads from Platforms in 4 Minutes or Less

The 4-minute test computes the time required to clear the platform (Platform A). Since all persons exit the platform by way of the eight turnstiles leading to the fare collection lobby, the sum of the individual turnstile capacities represents the total platform exit capacity. As no alternative exit paths exist, the entire platform occupant load must pass through the turnstiles in less than 4 minutes. As discussed, this load is assumed to arrive simultaneously.

\[
W_1 = \frac{\text{Platform Occupant Load (p)}}{\text{Platform Exit Capacity (ppm)}} = \frac{746 \text{ p}}{200 \text{ ppm}} = 3.73 \text{ min} < 4.00 \text{ min}
\]

\(W_1\) represents the time required for the last persons on Platform A to be processed by the turnstiles. Since the 4-minute test is based on the assumption that even persons arriving at the turnstiles from the most remote location on the platform will encounter a queue there (see Section 3.6), \(W_1\) represents the sum of the last person's walk time to reach the turnstiles and the wait time encountered there (these times are disaggregated as part of the 6-minute test).

Test 2: Evacuate Platform Occupant Loads from Most Remote Point on Platforms to a Point of Safety in 6 Minutes or Less

The longest exit route originates at the most remote point on either platform, traverses the lobby, and reaches the street level by way of the nearest stairway (see Figure 6.1). The 6-minute test calculates the total time required to exit the station by way of this route. This time is equal to the sum of the wait times at all elements—accounting for the metering effect of previous obstacles—and the total walk time.

Waiting Time at Platform Exits (i.e., Turnstiles). The waiting time at the turnstiles is equal to the total time required to clear the platform (\(W_1\), as computed in Test 1) minus the time spent walking from the most remote point on the platform (\(T_1\)), as computed from the platform walking distance and speed.

\[\text{Waiting Time at Platform Exit (i.e., Turnstiles), } WT = W_1 - T_1\]
\[WT = 3.73 \text{ min} - 1.50 \text{ min} = 2.23 \text{ min}\]

Waiting Time at Stairways. Under the hydraulic model, passengers facing multiple egress options distribute proportionally to the capacity of the alternate routes. Thus, the wait time encountered at the foot of the two stairways is the same for both and is a function of (1) the portion of the platform occupant load attracted to each stair; (2) the capacity of the stair; and (3) the metering effect of the turnstiles. Dividing the egress demand at each stairway by the stairway capacity yields the “gross” wait time for the stair. The passenger flow arriving at the stairways is metered as a result of having passed through the turnstiles. This metering effect is accounted for by subtracting from the “gross” wait time the wait time at the turnstiles (i.e., \(WT\)).

Gross Wait Time at Stairs (not adjusted for metering)
Gross Wait (m) = \frac{\text{Platform Occupant Load (p)}}{\text{Total Stair Capacity}} \times \text{Stair Capacity}

Stair 1 = 746 \text{ p} \times \left[\frac{175 \text{ ppm}}{175 \text{ ppm} + 210 \text{ ppm}}\right] / 175 = 2.34 \text{ min}

Stair 2 = 746 \text{ p} \times \left[\frac{210 \text{ ppm}}{210 \text{ ppm} + 175 \text{ ppm}}\right] / 210 = 2.34 \text{ min}

Again, under the hydraulic model, it is expected that where a passenger flow diverges, the wait time encountered at two alternate routes is the same.

Wait Time at Stairs (adjusted for metering at turnstiles)

\[
\text{Wait} = \text{Gross Wait} - \text{Turnstile Wait Time (WT)}
\]
Stair 1 or 2 = 2.34 min - 2.23 min = 0.11 min

Thus, the last person emerging from the turnstiles will encounter a wait of 0.11 minutes at the foot of the stairway to the street level.

Total Exit Time. The total exit time is the sum of (1) the total walk time for the exit route; and (2) the total wait time. The total wait time reflects the metering effect of prior obstacles. Either of the following two methodologies accomplishes this:

1. **Appendix C Method**: Under the sample calculations contained in Appendix C of the NFPA 130 Standard, the total wait time for the egress route is computed by adding to the platform wait time (i.e., the WT) the wait times computed for each subsequent egress element, where the wait times at subsequent elements are adjusted for the metering effect of previous elements.

\[
\text{Total Wait Time} = \text{WT} + \text{Egress Element Wait Times (adj. for metering)}
\]
Total Wait Time (min) = 2.23 min + 0.11 min = 2.34 min

2. **Alternate Method**: As illustrated in Section 3.5, the total wait time along a given egress route is equal to the wait time at that egress element along the route where capacity and demand combine to yield the longest wait time (without consideration of metered arrival rates).

\[
\text{Total Wait Time} = \text{MAX [Gross Wait Time]}
\]
Total Wait Time = MAX [2.23 min, 2.34 min] = 2.34 min
Total Exit Time = Total Walk Time (T) + Total Wait Time
Total = 2.55 min + 2.34 min = 4.89 min < 6.00 min

Thus, the existing station shown in Figure 6.1 meets the 4- and 6-minute test and is therefore in compliance with the NFPA 130 egress requirements.
New Station

Although the station geometry depicted in Figure 6.1 satisfies the time-based egress criteria, it is not an acceptable station design for a new facility since the station does not offer disabled persons an accessible path to a point of safety (see Section 3.4). It is also worth noting that platform exit configurations result in “common” egress paths to separate exits that exceed 20 feet (6.1 m) (see Section 3.7) and thus create the possibility that persons near the end of the platform could be trapped there by an obstruction on the platform. Although not explicitly required under NFPA 130, good design practice would aim to avoid such “common path” configurations. Both of these concerns would be met with the improvements illustrated in Figure 6.2.

The installation of the fire doors separates the platforms from the fare collection lobby, thereby allowing the lobbies to function as areas of refuge from which disabled persons could reach the street level by way of the elevators. Elevators would be operated manually by emergency personnel. The addition of emergency stairways at the end of the platforms would offer two discrete exit routes from any location on the platform. Since the platform exits do not share a “common path” (common path length is equal to zero), passengers positioned anywhere on the platform are able to reach an exit regardless of the location of an obstruction. The emergency exits must meet the minimum stair width requirement of 3 feet 6 inches (see Table 3.2). Emergency stairs need not connect to the street level, but could instead lead to a walkway in the trainway, which may be defined as an area of refuge and offer a route to the street level by way of stairs located along the trainway (e.g., as part of a ventilation shaft).

The addition of platform emergency exits significantly affects station egress times. For each platform, a portion of the occupant load will now evacuate by way of the emergency exits, thereby reducing the egress demand through the turnstiles and at the North and South Stairs to the street. The share of the platform occupant load exiting by way of the emergency stairways is directly proportional to their capacity as compared to the overall platform exit capacity. As a result of this demand diversion, the wait times encountered at the turnstiles and the North and South Stairs will be reduced. Consequently, the platform clearance and total station egress times for the station shown in Figure 6.2 will be less than those calculated for the existing station scenario.
FIGURE 6.2  DESIGN FOR NEW SUBWAY STATION

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6.3 Existing Subway Station with Mezzanine

Introduction

This example illustrates application of the egress element in a relatively complex existing subway station. Interesting features of the egress analysis include (1) simulation of egress flows through an asymmetrical station configuration; (2) use of operational modifications to optimize the distribution of train loads among station platforms; (3) use of peak train load volumes in both directions; and (4) application of a 15-minute peak factor based on actual ridership data in lieu of the NFPA 130 default factor.

Overview

The system under consideration is a third-rail powered rapid transit system that connects several urban centers with a regional CBD. The construction of a new light rail transit (LRT) system included the provision of a new entrance to a subway station (i.e., “East Entrance” in Figure 6.3) in order to facilitate transfers between the two systems. The following NFPA 130 analysis reflects these planned physical station improvements, anticipated demand increases due to LRT-to-subway transfers, and operational adjustments made to better distribute train loads.

The subway station is a two-level subway station with two tracks that are served by one center platform and one side platform (see Figure 6.3). Passengers entering the station through the future East Entrance access both platforms by way of the mezzanine. An underground corridor (South Passageway) connects the mezzanine with the existing West Entrance. A second corridor, the North Passageway, leads from the existing West Entrance to the foot of both platforms. Both passageways are equipped with fire doors near their west end. With the doors in the closed position, the passageways constitute a point of safety from which passengers are able to proceed to the West Entrance without assistance.

Southbound trains operate on the western track (Track 1) and discharge onto the center platform. Northbound trains on the eastern track (Track 2) can discharge onto either platform. Prior to the introduction of the LRT transfer activity, the side platform was not in service and all passengers boarded and alighted from trains on both tracks via the center platform. With the increased activity, however, it became desirable to reactivate the side platform to permit distribution of passengers alighting from trains among both platforms. The NFPA 130 analysis reflects this operational change and trains on Track 2 are assumed to be discharged onto the side platform.
NOTE: The author is no longer employed with Parsons Brinckerhoff. This monograph is for reference/research purposes only and not for distribution.
Emergency Condition

Given that the station is located near the central urban core and is a commuting destination in its own right, trains arriving at the station already carry high passenger volumes. With the implementation of LRT service, a significant number of commuters are forecast to transfer from the LRT to the subway at this station. Consequently, the morning rush hour is the critical analysis period, as large station entry volumes due to transfer activity and high train volumes combine for maximum station occupant loads. The default “failure period” duration of 12 minutes applies since subway service is sufficiently frequent that twice the headway is less than 12 minutes. After the failure period, trains are assumed to arrive simultaneously on both tracks.

Platform Occupant Loads

Entraining Load

Based on empirical peak 15-minute demand volumes, a calculated peak factor of 1.28 is used in lieu of the default factor of 1.5. The total entraining load, as calculated below, reflects all station entries and is used to determine entraining loads for individual platforms. The entraining load is computed according to the peak direction methodology, as each station track could be occupied by peak direction trains (see table below).

\[
\text{Total Entraining Load} = \frac{4,479 \text{ p/hr} \times 15 \text{ min}}{60 \text{ min}} \times 1.28 \times \frac{12 \text{ min}}{15 \text{ min}} = 1,147 \text{ p}
\]

Passengers are distributed among platforms according to their destination. The center platform and side platform serve all south- and northbound trains, respectively. Each track accommodates two services. Based on available empirical data, the table below illustrates the relative distribution of passengers among the four services during the AM peak 15 minutes.

<table>
<thead>
<tr>
<th>Service (direction)</th>
<th>Platform</th>
<th>Distribution</th>
<th>15-Minute Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service #1 (peak)</td>
<td>Center</td>
<td>23%</td>
<td>264</td>
</tr>
<tr>
<td>Service #2 (peak)</td>
<td>Side</td>
<td>5%</td>
<td>57</td>
</tr>
<tr>
<td>Service #3 (off-peak)</td>
<td>Side</td>
<td>60%</td>
<td>688</td>
</tr>
<tr>
<td>Service #4 (off-peak)</td>
<td>Center</td>
<td>12%</td>
<td>138</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100%</td>
<td>1,147</td>
</tr>
</tbody>
</table>

Platform Entraining Load = \( \frac{15\text{-Minute Boarding Volumes}}{} \)
Center Platform: Entraining Load = 264 + 138 = 402 p
Side Platform: Entraining Load = 57 + 688 = 745 p

### Calculated Train Load

Under the station and track configuration, each track serves peak-direction service: Service #1 on the west track and Service #2 on the east track, each operating with seven-car trains (each car having a “crush” capacity of 130 persons). Therefore, for both tracks, the calculated train load is computed as described for trains arriving in the “peak direction.” Since peak direction trains are generally fully occupied by the time they arrive at the station, the following applies:

\[
\text{Peak 15-min link load} = \frac{\text{# trains in 15 minutes} \times 2}{\text{Train Capacity}} > 1
\]

Therefore, per the stipulation that the maximum calculated train load should not exceed the train “crush” capacity, the calculated train load for each platform is computed as:

\[
\text{Calculated Train Load} = \frac{130 \text{ persons(p)}}{\text{car}} \times \frac{7 \text{ cars}}{\text{train}} = 910 \text{ p}
\]

Platform Occupant Load = Calculated Train Load + Entraining Load

Center Platform: Platform Occupant Load = 910 + 402 = **1,312 p**

Side Platform: Platform Occupant Load = 910 + 745 = **1,655 p**

---

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## Exit Lanes and Capacity Provided

<table>
<thead>
<tr>
<th>Egress Element</th>
<th>No. of Units</th>
<th>Lanes each</th>
<th>Capacity per Lane</th>
<th>= PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform To Mezzanine</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center Platform</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Stairs to Mezzanine</td>
<td>3</td>
<td>2.0</td>
<td>35</td>
<td>210</td>
</tr>
<tr>
<td>Side Platform</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Stairs to Mezzanine</td>
<td>2</td>
<td>2.0</td>
<td>35</td>
<td>140</td>
</tr>
<tr>
<td>New Stair to Mezzanine</td>
<td>1</td>
<td>2.5</td>
<td>35</td>
<td>88</td>
</tr>
<tr>
<td>Platform To Passageway</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center Platform</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endloading Stair</td>
<td>1</td>
<td>6.0</td>
<td>35</td>
<td>210</td>
</tr>
<tr>
<td>Side Platform</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endloading Stair</td>
<td>1</td>
<td>6.0</td>
<td>35</td>
<td>210</td>
</tr>
<tr>
<td>Mezzanine To Safe Area</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Street Via New Entrance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mezz.-Level Turnstiles</td>
<td>8</td>
<td>1.0</td>
<td>25</td>
<td>200</td>
</tr>
<tr>
<td>Escalators to Street(^1)</td>
<td>2(-1)</td>
<td>1.5</td>
<td>35</td>
<td>53</td>
</tr>
<tr>
<td>Stairs to Street</td>
<td>1</td>
<td>3.0</td>
<td>35</td>
<td>105</td>
</tr>
<tr>
<td>Past Fire Doors</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passageway Fire Doors</td>
<td>2</td>
<td>3.0</td>
<td>50</td>
<td>300</td>
</tr>
</tbody>
</table>

**Note 1:** One escalator not credited per 2-5.4.1.1. Escalator test: 53 ≤ 50% x (105 + 53)

---

### Walking Time For Longest Exit Route

<table>
<thead>
<tr>
<th>Walking Time For Longest Exit Route</th>
<th>Feet</th>
<th>/fpm</th>
<th>Minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>On Side Platform(^1)</td>
<td>60</td>
<td>200</td>
<td>0.30</td>
</tr>
<tr>
<td>Platform to Mezzanine Level</td>
<td>14</td>
<td>50</td>
<td>0.28</td>
</tr>
<tr>
<td>On Mezzanine Level</td>
<td>200</td>
<td>200</td>
<td>1.00</td>
</tr>
<tr>
<td>Mezzanine to Street Level</td>
<td>30</td>
<td>50</td>
<td>0.60</td>
</tr>
<tr>
<td>Total Walking Time (T=T1+T2+T3+T4)</td>
<td></td>
<td></td>
<td>2.18</td>
</tr>
</tbody>
</table>

**Note 1:** The longest exit route originates on the side platform, since platform wait time (see Test 1) is longer on the side platform than on the center platform.
Test 1: Evacuate Platform Occupant Loads from Platforms in 4 Minutes or Less

\[
W_1 \text{ (time to clear platform, in minutes)} = \frac{\text{Platform Occupant Load (p)}}{\text{Platform Exit Capacity (ppm)}}
\]

Center Platform: \(W_1 = 1,312 \text{ p}/420 \text{ ppm} = 3.12 \text{ min} < 4.00 \text{ min}\)

Side Platform: \(W_1 = 1,655 \text{ p}/438 \text{ ppm} = 3.78 \text{ min} < 4.00 \text{ min}\)

Test 2: Evacuate Platform Occupant Loads from Most Remote Point on Platforms to a Point of Safety in 6 Minutes or Less

The longest exit route originates at the most remote point on the side platform, traverses the mezzanine, and reaches the street level by way of the new entrance. (Egress routes along either passageway to the street level via the existing entrance are not considered, as passengers have reached a point of safety, as defined for purposes of the NFPA 130 egress analysis, once they pass through the fire doors at the west end of the passageways.) Wait times are computed as per the method outlined in Appendix C of the NFPA 130 Standard.

Waiting Time at Platform Exits

The waiting time at the platform exits for the last person to arrive there is equal to the total time required to clear the platform (\(W_1\)), as computed in Test 1, minus the time spent walking from the most remote point on the platform to reach the stair (\(T_1\)), as computed from the platform walking distance and speed.

\[
\text{Waiting Time at Platform Exits, } W_P = W_1 - T_1
\]

Side Platform: \(W_P = 3.78 \text{ min} - 0.30 \text{ min} = 3.48 \text{ min}\)

Mezzanine Occupant Load

The mezzanine occupant load represents the total number of persons who traverse the mezzanine on their egress route from either platform to a point of safety. For each platform, the contribution to the mezzanine occupant load is computed by subtracting from the total platform occupant load those persons who cleared the platform by way of exits that do not lead to the mezzanine (i.e., via the endloading stairs).
Mezzanine Occupant Load = 
Platform Occupant Load - (W1 x Endloading Stair Capacity)

Center Platform: = 1,312 p - (3.12 min x 210 ppm) = 657 p
Side Platform: = 1,655 p - (3.78 min x 210 ppm) = 861 p
Total:  = 1,518 p

Waiting Time at Fare Barriers

The wait time at the mezzanine-level fare barriers (WF) is a function of the number of persons passing through the turnstiles (“turnstile demand”), the capacity of the turnstiles, and the metering effect of previously encountered obstacles.

Passengers facing multiple egress options distribute proportionally to the capacity of the first egress element for each alternate route. The “turnstile demand” is determined according to the ratio of the turnstile capacity to the total available capacity (i.e., sum of turnstile capacity and south passageway fire door capacity). The wait time encountered at the fare barriers is computed by dividing the “turnstile demand” volume by the total turnstile capacity and then subtracting the platform wait time (W1) in order to account for the metering effect of the queue encountered during the clearing of the platform (a negative number for WF means that, due to metering, there is no additional wait time encountered at the fare barriers and WF = 0).

\[
W_2 = \left( \frac{\text{Mezz. Occupant Load (p)}}{\text{Turnstile Capacity}} \right) \times \frac{\text{Turnstile Capacity}}{\text{Turnstile Capacity + Psgwy. Cap.}} \times \frac{\text{Turnstile Capacity (ppm)}}{
\]

\[
W_2 = \left( \frac{1,518 \text{ p} \times (200 \text{ ppm} / (200 \text{ ppm} + 300 \text{ ppm}))}{200 \text{ ppm}} \right) = 3.04 \text{ min}
\]

Waiting Time at Fare Barriers, WF = W2 - W1

WF = 3.04 min - 3.78 min = 0 min

Waiting Time at Concourse Exits (New Entrance to Street)

The wait time at the foot of the new entrance (WC) is a function of the total number of passengers exiting the station by way of this facility, the total capacity of the stairs and escalators (one escalator is assumed to be out of service), and the metering effect of previously encountered obstacles. The number of passengers exiting by way of the new entrance (“new entrance demand”) is determined according to the ratio of the new entrance capacity to the overall mezzanine exit capacity (as above). The wait time at the new entrance (WC) is computed by dividing the “new entrance demand” by the total exit capacity and subtracting the longest previously encountered wait time to account for the metering effect of previous queues (again, a negative number for WC means that there is no additional wait time encountered at the new entrance and WC = 0).
\[
W_3 \text{ (min)} = \frac{\text{Mezz. Occupant Load (p)}}{\text{New Entrance Cap.}} + \text{Psqwy. Cap.} \quad \text{New Entrance Capacity (ppm)}
\]

\[W_3 = \{1,518 \times (158 \text{ ppm} / (158 \text{ ppm} + 300 \text{ ppm})]\} / 158 \text{ ppm} = 3.31 \text{ m}\]

Waiting Time at Concourse Exits, \(W_C = W_3 - \text{MAX}(W_2 \text{ or } W_1)\)

\[W_C = 3.31 \text{ min} - \text{MAX}(3.04 \text{ min or } 3.78 \text{ min}) = 0 \text{ min}\]

**Total Exit Time from Side Platform to Safe Area by Way of New Entrance**

The total exit time is the sum of (1) the total walk time for the exit route via the new entrance; (2) the wait time at the platform exits (WP); and (3) any additional wait times encountered.

\[
\text{Total Exit Time, Total} = T + WP + WF + WC
\]

\[\text{Total} = 2.18 \text{ min} + 3.48 \text{ min} + 0 \text{ min} + 0 \text{ min} = 5.66 \text{ min} < 6.00 \text{ min}\]
6.4 Deep Tunnel LRT Station

Introduction

This sample calculation illustrates the use of fire walls to create areas of refuge in a new deep tunnel LRT station as a means for meeting the NFPA 130 egress requirements. In addition, the example reflects an operating plan involving alternating train consist lengths. Although egress analyses typically reflect only the maximum train length to be accommodated in a station, there are instances where separate services operate on common station tracks and where physical constraints elsewhere in the system cause the consist lengths for the two services to differ. Thus, during the course of the peak 15 minutes, there could exist a real limit on the number of maximum length trains that arrive at the station. This sample calculation provides a method for computing calculated train loads in such circumstances.

Overview

The LRT station is a two-track station located 160 feet beneath the surface (see Figure 6.4). Due to the considerable depth of the station, three elevators accommodate the entire vertical circulation demand during normal operations. A longitudinal fire wall extends for the entire length of the station, effectively creating a station configuration with two back-to-back side platforms. Passengers are able to move between platforms only by way of three fire door openings in the fire wall. With the fire doors in the closed position, the environment in each train room and on each platform are independently controllable. Although the station contains an emergency stair, the extreme length of the climb make it unsuitable as an emergency egress route for most passengers. Since the elevators are not permissible as a means of emergency egress, compliance with the NFPA 130 relies on a refuge area for meeting the 4- and 6-minute egress time criteria. Two discrete LRT services operate through the station. Although these services operate on a common core alignment, they service different corridors at the system's periphery. Different alignment characteristics in the peripheral corridors dictate a maximum train consist length of three cars for one and two cars for the other service.
FIGURE 6.4  DEEP TUNNEL LRT STATION

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Emergency Condition

Given that (1) peak direction trains accumulate significant passenger loads before arriving at the station and (2) the station is a commuter trip origin station characterized by high station entry volumes in the morning, the AM peak period is the critical analysis period where high entraining and train loads combine for maximum occupant loads. LRT vehicles operate at 3-minute headways in both directions during the analysis period. Given this service frequency, the default duration of 12 minutes applies for the “failure period” during which the entraining load accumulates. After the failure period, three-car LRT trains are assumed to enter the station simultaneously on both tracks. The fire source is located onboard of one (and only one) of the trains entering the station. The platform servicing this train is defined as the “incident platform.”

Platform Occupant Loads

Entraining Load

The entraining load is based on actual peak 15-minute station entrance rates. Patronage forecasts predict boarding and alighting volumes by direction.

\[
\text{Entraining load (p)} = \text{peak 15-min. boarding demand (p)} \times \frac{12 \text{ min}}{15 \text{ min}}
\]

South Platform Entraining Load = \( 476 \text{ p/15 min} \times \frac{12 \text{ min}}{15 \text{ min}} = 380 \text{ p} \)

North Platform Entraining Load = \( 60 \text{ p/15 min} \times \frac{12 \text{ min}}{15 \text{ min}} = 48 \text{ p} \)

Calculated Train Load

The analysis considers alternating arrival of two- and three-car trains at the station. The number of passengers aboard a train is computed as a function of the average passenger occupancy per car (as opposed to train) during the peak 15 minutes. With alternating train lengths, it was assumed that during the peak 15 minutes, three three-car and two two-car trains arrive at the station per direction, yielding a total arrival of 13 cars per direction. The longitudinal fire wall causes the two platforms to function as discrete side platforms (as opposed to one center platform) and the calculated train load is computed as directed for instances “where trains arrive at a platform from only one direction” (C-1.1).

\[
\text{Calculated Train Load (p)} = \frac{15\text{-min. link load (p)}}{\# \text{ cars in 15 min}} \times \frac{3 \text{ cars}}{\text{train}} \times 2
\]

South Platform (eastbound): \( 893 / [13 \times 3] \times 2 = 412 \text{ p} \)

North Platform (westbound): \( 362 / [13 \times 3] \times 2 = 167 \text{ p} \)

For both directions, the calculated train load is less than the maximum train capacity of 200 persons per car, or 600 persons per three-car train.
Platform Occupant Load

Platform Occupant Load = Calculated Train Load + Entraining Load

<table>
<thead>
<tr>
<th>Platform</th>
<th>Occupant Load</th>
<th>=</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Platform</td>
<td>390 + 412</td>
<td>792</td>
<td>p (incident platform)</td>
</tr>
<tr>
<td>North Platform</td>
<td>48 + 167</td>
<td>215</td>
<td>p (refuge area)</td>
</tr>
</tbody>
</table>

Refuge Area

Given that the two train rooms are completely separate, one platform may be designated as a refuge area. Conservatively, the platform with the higher platform occupant load (south platform) is defined as the incident platform from where passengers are required to reach the refuge area or non-incident platform (north platform).

Exit Lanes and Capacity Provided

Since passengers will reach a point of safety by way of horizontal egress from one platform to the other, the fire doors in the longitudinal wall separating the platforms are the only egress elements affecting egress times. Each of the three fire doors has an effective width of 17 feet, which accommodates nine exit lanes.

<table>
<thead>
<tr>
<th>Egress Element</th>
<th>No. of Units</th>
<th>Lanes Each</th>
<th>Capacity per Lane</th>
<th>= PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident Platform To Refuge Area</td>
<td>3</td>
<td>9.0</td>
<td>50</td>
<td>1,350</td>
</tr>
</tbody>
</table>

The location of the fire door openings along the fire wall ensures that the walking distance between the most remote location on one platform and the other platform is significantly shorter than 300 feet.

Test 1: Evacuate Platform Occupant Loads from Platforms in 4 Minutes or Less

Test 1 measures the time required for passengers accumulated on and discharging onto the incident platform (south platform) to pass through the fire doors and reach the non-incident platform, or refuge area (north platform).

\[
W_1 = \frac{\text{Incident Platform Occupant Load (p)}}{\text{Platform Exit Capacity (ppm)}}
\]

<table>
<thead>
<tr>
<th>Platform</th>
<th>Occupant Load</th>
<th>= PPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Platform</td>
<td>792 p</td>
<td>1,350</td>
</tr>
</tbody>
</table>

South Platform: \( W_1 = \frac{792 \text{ p}}{1,350 \text{ ppm}} = 0.59 \text{ min} \) < 4.00 min

Persons on the incident platform are able to evacuate the platform in 0.59 minutes. The non-incident platform does not require evacuation as it is defined as a point of safety.
Test 2: Evacuate Platform Occupant Loads from Most Remote Point on Platforms to a Point of Safety in 6 Minutes or Less

Test 2 requires no further calculation, since the Test 1 requirements were satisfied by evacuating all station occupants to a refuge area (the non-incident platform). Since all persons cleared the incident platform by moving to an area which, for purposes of the NFPA 130 egress requirements, meets the definition of a “point of safety,” the time required for persons to clear the incident platform (calculated to meet the Test 1 requirements) is equal to the time required for all station occupants to reach a point of safety.

The NFPA 130 criteria are met by locating the station occupant load for both platforms, as calculated under NFPA 130, on a single platform (i.e., the non-incident). Placement of this load on a single platform will result in average pedestrian density levels of 4.3 square feet (sf) (0.4m²) per passenger.

Density (p/sf) = \frac{\text{effective platform area (sf)}}{\text{total station occupant load (p)}}

Non-incident platform: \frac{4,277}{(792 + 215)} = 4.3 \text{ sf}
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BIBLIOGRAPHY


