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Automated People Mover Standards



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PREFACE

This standard is a revision of ASCE 21-13, *Automated People Mover Standards*. An automated people mover (APM) is defined as a guided transit mode with fully automated operation, featuring vehicles that operate on guideways with exclusive right-of-way.

Chapters 1 to 11 cover requirements for design of an APM system, and Chapters 12 to 16 cover requirements for an APM in passenger operation, including chapters on security; emergency preparedness; system verification and demonstration; operation, maintenance, and training; and operational monitoring.

The standard also includes

- One mandatory appendix on system safety program plan (SSPP) requirements;
- One nonmandatory reference bibliography of examples and guidance for other SSPPs;
- One nonmandatory informative appendix on inspection and test guidelines;
- Five nonmandatory appendixes: Recommended Practice for Acceptance of an APM System Application; Recommended Practice for Working Safely near APM Systems; Recommended Practice for Accommodating Luggage Carts in APM Systems; Recommended Practice for Measuring Service Availability; and Recommended Practice for Independent Safety Assessment; and
- One commentary on emergency egress provisions.

The provisions of the nonmandatory appendixes and recommended practices are written in permissive language and, as such, offer the user a series of options or instructions, but do not

prescribe a specific course of action. Significant judgment is left to the user of these appendixes and recommended practices.

This revision includes substantive changes and additions of mandatory requirements in a number of chapters. This includes new requirements that address separation assurance for Automated Transit Networks (ATN), revised requirements for the structural design of APM specific guideways, revised requirements for the application of safety provisions, and four new appendixes (F, G, H, and I).

This standard establishes the minimum set of requirements necessary to achieve an acceptable level of safety and performance for an APM system. As such, it may be used in the safety certification process. The overall goal of this standard is to assist the industry and the public by establishing standards for APM systems.

This standard has no legal authority in its own right, but may acquire legal standing in one of more of the following ways:

- Adoption by an authority having jurisdiction,
- Reference to compliance with the standard as a contract requirement, or
- Claim by a manufacturer or manufacturer's agent of compliance with the standard.

This standard will be beneficial to transportation engineers, civil engineers, safety engineers, and contractors of APM systems. Also, anyone who owns, operates, builds, maintains, designs, tests, insures, oversees, or certifies APMs or other innovative technology transit systems, such as magnetic levitation, air cushion, personal rapid transit, and monorail systems, will benefit.

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ACKNOWLEDGMENTS

The ASCE APM Standards Committee formed nearly three decades ago as a volunteer group of individuals sharing a common belief that the fledgling APM industry would benefit by the development of a minimum set of requirements necessary to achieve an acceptable level of safety and performance for the public.

Many individuals and organizations from many backgrounds gave their time, resources, and expertise in hosting meetings, providing web and email communications, drafting sections, and shepherding complicated technical specifications through the challenging consensus process and finally publication.

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CHAPTER 1 GENERAL

1.1 SCOPE

This standard is the revision of ASCE 21-13, which was previously combined from Parts 1, 2, 3, and 4 of ASCE 21-05 and 21-08. The previous numbering system is retained (with additions):

Part 1 of ASCE 21-05 consists of

1. General
2. Operating Environment
3. Safety Requirements
4. System Dependability
5. Automatic Train Control (ATC)
6. Audio and Visual Communications

Part 2 of ASCE 21-08 consists of

7. Vehicles
8. Propulsion and Braking

Part 3 of ASCE 21-08 consists of

9. Electrical Equipment
10. Stations
11. Guideways

Part 4 of ASCE 21-08 consists of

12. Security
13. Emergency Preparedness
14. System Verification and Demonstration
15. Operations, Maintenance, and Training
16. Operational Monitoring

Appendix A. System Safety Program Requirements

Appendix B. Bibliography

Appendix C. Recommended Practice for Acceptance of an APM System Application

Appendix D. Inspection and Test Guidelines

Appendix E. Recommended Practice for Working Safely near APM Systems

1.2 EXISTING APPLICATIONS

Existing installations and projects in progress before the effective date of this standard need not comply with the new or revised requirements of this edition, except where specifically required by the authority having jurisdiction. Existing APMs, when completely removed and reinstalled, shall be classified as new installations.

1.3 NEW APPLICATIONS

New installations begun after the effective date of this standard shall comply with the new or revised requirements of this edition.

1.4 REFERENCE STANDARDS

The following documents or portions thereof are incorporated by reference in this standard:

AASHTO: American Association of State Highway and Transportation Officials

AASHTO LRFD Bridge Design Specifications, 8th Ed. (2017) (cited in Sections 11.9, and 11.9.2)

AASHTO Standard Specifications for Highway Bridges, 17th Ed. (2002) (cited in Section 11.9.2)

ACGIH: American Conference of Government Industrial Hygienists

ACGIH Publication 7 DOC-648 (2016). *Whole Body Vibration: TLV Physical Agents*, 7th Ed. 2016 “Documentation” (cited in Section 7.7.3.2.1)

ANSI: American National Standards Institute

ANSI B11.19-2010 (2010). *Performance Requirements for Safeguarding* (cited in Section 8.5)

ANSI S1.4-1983 (1983a). *Specification for Sound Level Meters* (cited in Sections 2.2.1 and 7.7.4)

ANSI S3.29-1983 (1983b). *Guide to the Evaluation of Human Exposure to Vibration in Buildings* (cited in Section 2.2.2)

ANSI B77.1-2006 (2006). *Passenger Ropeways—Aerial Tramways, Aerial Lifts, Surface Lifts, Tows and Conveyors—Safety Requirements* (cited in Sections 8.2.2 and 11.0)

ANSI Z97.1-2004 (2004). *Safety Glazing Materials Used in Buildings—Safety Performance Specifications and Methods of Test* (cited in Sections 10.2.1 and 10.2.2)

ANSI Z26.1-1997 (1997). *American National Standard, Safety Code for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways* (cited in Section 7.9)

ANSI 117.1-2003 (2003). *Guidelines for Accessible and Usable Buildings and Facilities* (cited in Section 11.5)

APTA: American Public Transportation Association

APTA SS-E-010-98 (1998). *Standard for the Development of an Electromagnetic Compatibility Plan* (cited in Section 2.1.8)

ASHRAE: American Society of Heating, Refrigeration and Air-Conditioning Engineers

ASHRAE Handbook Fundamentals Volume. (2017). Chapter 14 and data provided with edition (cited in Section 7.7.1)

ASTM International: Formerly American Society for Testing and Materials

ASTM D635-06 (2006a). *Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position* (cited in Section 9.3.6)

ASTM C1036-06 (2006b). *Standard Specification for Flat Glass* (cited in Sections 10.2.1 and 10.2.2)

ASTM C1048-04 (2004). *Standard Specification for Heat Treated Flat Glass* (cited in Sections 10.2.1 and 10.2.2)

Austrian Standards Institute

EN 60204-1:2014-10 (2014). *Safety of Machinery – Electrical Equipment of Machines – Part 1: General requirements* [IEC 44709/CDV:2014] (cited in Section 7.12.5)

Code of Federal Regulations

CFR, Title 47, Chapter I, Part 15, *Radio Frequency Devices* (cited in Section 2.2.3)

CFR, Title 47, Chapter I, Part 90, Subparts S and T, *Private Land Mobile Radio Services* (cited in Section 2.2.3)

16 CFR 1201, *Consumer Products Safety Commission Standard on Architectural Glazing Materials* (cited in Sections 10.2.1 and 10.2.2)

EN Eurocodes (European Committee for Standardization).

EN 1990 (2013-03-15). Eurocode: *Basis of Structural Design with Amendment 1: Application for Bridges*

EN 1991 (2017). Eurocode 1: *Actions on Structures*

EN 1992 (2011). Eurocode 2: *Design of Concrete Structures*

EN 1993 (2017). Eurocode 3: *Design of Steel Structures*

EN 1994 (2009). Eurocode 4: *Design of Composite Steel and Concrete Structures*

EN 1997 (2015). Eurocode 7: *Geotechnical Design*

EN 1998 (2013). Eurocode 8: *Design of Structures for Earthquake Resistance*

EN 1999 (2017). Eurocode 9: *Design of Aluminum Structures*

EN 1090 (2017). *Execution of Steel Structures and Aluminum Structures*

Gale Research

Weather of U.S. Cities, 5th Ed., Vols. 1 and 2 (1996), Richard A. Wood (cited in Section 2.1)

IEC: International Electrotechnical Commission

IEC 62236 (2008–2012). Parts 1–5, *Railway Applications—Electromagnetic Compatibility, Edition 2.0.* (cited in Section 2.1.8)

IEEE: Institute of Electrical and Electronic Engineers

IEEE Standard 1474.1-2004 (2004). *IEEE Standard for Communications-Based Train Control (CBTC) Performance and Functional Requirements* (cited in Sections 3.6 and 5.0)

IEEE Standard 242-2001 (2001). *Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems, Section 1.0, First Principles* (cited in Section 9.1.3)

IEEE Standard 519-1992 (1992). *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems* (cited in Section 9.2.3)

IEEE Standard 142-1991 (ANSI C114.1-1991) (1991). *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems* (cited in Section 9.1.4.1)

ISO: International Organization for Standardization

ISO 2631-1 (1997). *Mechanical vibration and shock – Evaluation of human exposure to whole body vibration Part 1: General Requirements*, 2nd Edition (cited in Section 7.7.3.2.2)

Military Standards:

MIL-STD-810 F (2000). *Environmental Test Methods and Engineering Guidelines* (cited in Section 2.1.5)

NACE: National Association of Corrosion Engineers

NACE Standard RP0169-2002 (2002). *Control of External Corrosion on Underground or Submerged Metallic Piping Systems* (cited in Section 9.1.2)

NEMA: National Electrical Manufacturers Association

All NEMA standards (cited in Section 7.12.2.2)

NFPA Publications: National Fire Protection Association

NFPA 72-2002 (2002). *National Fire Alarm Code* (cited in Section 6.1.6)

NFPA 70 (2017). *National Electrical Code* (cited in Sections 7.12.2.2, 7.12.5, 9.1.4.2, 9.2.9, and 9.4)

NFPA 101 (2006). *Life Safety Code* (cited in Section 10.4)

NFPA 130 (2017). *Fixed Guideway Transit and Passenger Rail Systems* (cited in Sections 6.1.2, 7.10, 7.10.1, 7.10.2, 7.11.2, 7.12.2.1, 7.12.3, 9.1.1, 9.2.9, 10.4, 10.5.2, 10.5.3, 11.1, 11.3, 11.3.1, 11.3.2, 11.3.3, 11.4, 11.5, 11.6, and 11.7)

NOAA: National Oceanic and Atmospheric Association

Local Climatologic Data, Annual Summary with Comparative Data, National Oceanic and Atmospheric Administration, updated annually (cited in Section 2.1)

SAE: Society of Automotive Engineers International

SAE J673-2015 (2015). *Automotive Safety Glasses* (cited in Section 7.9)

TIA: Telecommunications Industry Association

Wireless Communications Systems:

Performance in Noise and Interference-Limited Situations—Recommended Methods for Technology-Independent Modeling, Simulation, and Verification, Addendum 1, TIA/EIA *Telecommunications Systems Bulletin TSB-88-A-1*, January 2002 (cited in Section 6.1.6)

UL: Underwriters Laboratories

UL 96A. (2001). *Installation Requirements for Lightning Protection Systems*, 11th Ed. (cited in Section 2.1.4)

UL 813-1993. (1993). *Commercial Audio Equipment* (cited in Section 6.1.3)

1.5 DEFINITIONS

Automated People Mover (APM): Guided transit mode with fully automated operation, featuring vehicles that operate on guideways with exclusive right-of-way.

Automatic Train Control (ATC): System for automatically controlling train movement, enforcing train safety, and directing train operations. ATC includes subsystems for automatic train operation (ATO), automatic train protection (ATP), and automatic train supervision (ATS).

Automatic Train Operation (ATO): Subsystem within the automatic train control system that performs any or all the functions of speed regulation, programmed stopping, door and dwell time control, and other functions otherwise assigned to the train operator.

Automatic Train Protection (ATP): Subsystem within the automatic train control system that provides the primary protection for passengers, personnel, and equipment against the hazards of operations conducted under automatic control.

Automatic Train Supervision (ATS): Subsystem within the automatic train control system that monitors and manages the overall operation of the APM system and provides the interface between the system and the central control operator.

Automated Transit Network (ATN): Subset of Automated People Mover that has all stations offline, switching that requires no track-based moving parts and train capacity less than 25 passengers.

Bogie: Bogie consists of the elements that transmit lateral, longitudinal, and vertical loads between the guideway and the carbody. Bogies are also referred to as trucks.

Bonding: Permanent joining of metal parts together to form an electrically conductive path that has the capacity to conduct safely any fault current likely to be imposed on it.

Braking, Emergency: Irrevocable braking to a complete stop at a rate never less than the minimum guaranteed rate.

Braking, Service: Braking of vehicle motion at a rate that is regarded as comfortable for repeated use in service stopping and/or slowing.

Carbody: Structural body shell, enclosing the passenger compartment(s).

Consist: Makeup or composition (number and specific identity) of a train of vehicles.

Cosmetic Damage: Damage that does not impair system function, performance, safety, or the structural integrity of any safety-critical item.

Dwell Time: Total time the train services the station measured as the time from door open command to the time the doors are closed and locked.

Dynamic Sign: Sign on which the messages can be changed.

Fail-Safe: Characteristic of a system or its elements whereby any failure or malfunction affecting safety causes the system to revert to a state that is known to be safe.

Failure: Inability to perform an intended function.

Free Field: Isotropic, homogeneous sound field that is free from all bounding surfaces.

Grounding (Earthing) Conductor: Conductor that provides an electrical path to earth ground for the vehicle onboard equipment and other metallic/conductive materials (carbody, frame, bogie, etc.) via a grounding electrode(s).

Guideway: Track or other riding surface (including supporting structure) that supports and physically guides transit vehicles specially designed to travel exclusively on it.

Hazard: Existing or potential condition that can result in an accident.

Headway: Time separation between two trains, both traveling in the same direction on the same guideway, measured from the time the head end of the leading train passes a given reference point to the time the head end of the train immediately following passes the same reference point.

Interlock: Arrangement of control elements so interconnected that their operations must succeed each other in proper sequence.

Jerk: Time rate of change of acceleration or deceleration.

MTBHE: Mean time between hazardous events (Table 3-1).

Offline Station: Station in which loading/unloading platforms are located on a siding off the through guideway, so that trains may bypass the station and thus avoid waiting for predecessor trains making a station stop.

Operating Loads: Definitions of operating loads are presented in Section 7.4.4.1.1 as lateral loads, vertical loads, and longitudinal loads.

Overspeed: Train speed that is in excess of the speed limit as defined for the relevant point on the guideway.

Overtravel: Continued movement of a train beyond a specified stopping point.

Passenger Compartment: If a vehicle is divided into separate areas between which passengers are either unable or not permitted to move, each such area is defined as a passenger compartment. If the vehicle is not so divided, then the entire vehicle is the passenger compartment.

Permissive Decision: Granting permission or authority for the system or a part of the system to enter any state other than the safe state.

Risk: Measure of the severity and likelihood of an accident.

Safe State: System state that is deemed acceptable by the hazard resolution process (see Section 3.1.2).

Safety-Critical: Designation placed on a system, subsystem, element, component, device, or function denoting that satisfactory operation of such is mandatory to mitigation of unacceptable and undesirable hazards as defined in Table 3-1.

Separation: Distance between the adjacent ends of two trains traveling along the same guideway as measured along the guideway centerline.

Separation Assurance Zone (SAZ): Distance between the rear of a leading train and the front of a following train that continuously ensures the following train can stop without colliding with the leading train, even in the event of any failure occurring to the leading train.

Shall: In this standard, the word “shall” denotes a mandatory requirement.

Should: In this standard, the word “should” denotes a recommendation.

Slow-Speed People Movers: Site applications in which all vehicles travel no more than 32 km/h (20 mi/h) at any location on their routes during normal operation.

Subsystem: Major functional subassembly or grouping of items or equipment that is essential to operational completeness of a system.

System: Composite of people, procedures, facilities, and/or equipment that are integrated to perform a specific operational task or function within a specific environment.

System Dependability: Overall set of criteria used to measure the performance of an operating system in terms of reliability, maintainability, and availability.

System Safety: Application of engineering and management principles, criteria, and techniques to optimize all aspects of safety within the constraints of operational effectiveness, time, and cost throughout all phases of the system life cycle.

Tabletop Drill: Simulated or theoretical drill in which personnel carry out their functions by discussion.

Through Guideway: Mainline guideway including merges and diverges whereby trains bypass offline stations, maintenance/storage facilities, and so on.

Train: One or more contiguous vehicles combined into an operating unit.

Vehicle: Smallest unit that can operate alone or that comprises one of the basic building blocks of a train.

Zero Speed: Specified speed below which automatic train control considers a train to be stopped.

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CHAPTER 2

OPERATING ENVIRONMENT

There are two aspects to operating environment considerations. One deals with the existing environmental conditions in which the system must operate (ambient), and the other deals with the environment resulting from the existence and operation of the system (induced). Both of these aspects are covered herein.

2.1 AMBIENT CONDITIONS

The following sources of historical climatic data shall be considered when specifying design climatic values. Source number 1 is a basic compilation of low, high, and mean values of temperature, humidity, steady and gusting winds, rainfall rates, and other climatic characteristics, as compiled by the National Oceanic and Atmospheric Administration (NOAA). Source number 2 summarizes the NOAA data in convenient form. Source number 3 provides temperature data and methods for calculating 50-year return temperatures specified in Section 2.1.1.

1. *Local Climatologic Data, Annual Summary with Comparative Data*, National Oceanic and Atmospheric Administration, updated annually
2. *Weather of U.S. Cities*, 5th Ed., Vols. 1 and 2, Richard A. Wood, Gale Research Company
3. *2009 ASHRAE Handbook—Fundamentals*, Chapter 14, “Climatic Design Information”

When the proposed site is located outside of the area of coverage of these documents or within a microclimate, data from these sources shall be augmented with local weather data.

2.1.1 Temperature and Humidity The system shall be designed to, at a minimum, be capable of continuous operation and serviceability in site temperature conditions that represent the 50-year return highest maximum and lowest minimum extreme annual daily temperatures under naturally occurring combinations of temperature and humidity. Chapter 14, “Climatic Design Information,” (ASHRAE 2009) demonstrates the method of calculating the 50-year return temperatures. Also, it is not intended that the automated people mover (APM) system should operate when the service area (e.g., urban area or major activity center) is closed because of any of these extreme conditions.

The temperature and relative humidity limit requirements for equipment shall reflect the operating environment at the location in the system where it is installed. These environmental conditions are not intended for the design and operation of the HVAC systems.

2.1.2 Wind Maximum wind speeds shall be established for at least the following conditions:

1. Normal system operation,
2. Manual operation, and
3. System survival.

The maximum wind speed for normal system operation shall be used as the design wind speed for safe automated system operation. If this wind speed is exceeded, automated operation shall not be permitted or shall be appropriately degraded.

The maximum wind speed for manual system operation shall be used as the design wind speed for safe manual operation. If this wind speed is exceeded, the system shall not be permitted to operate.

The maximum wind speed for system survival shall be the design wind speed for all structures. This wind speed shall be that used by local building codes.

2.1.3 Precipitation If the system is intended for operation while subjected to rainfall, snowfall, and icing, it shall be designed for operation at rates consistent with historical data. Historical data are defined as the extreme conditions under which the area to be served (e.g., urban area or major activity center) would remain in operation and not be closed. It is not intended to impose operational requirements more restrictive than the owner intends.

2.1.4 Lightning Protection shall be provided against lightning incidence in the area for those systems that are susceptible. Such protection should be in compliance with UL 96A, 11th Edition (UL 2001).

2.1.5 Existing Atmospheric Pollution The system design shall tolerate atmospheric pollutants that exist at the site. Such pollutants may include dust, dirt, salt, ozone, smog, and other matter specific to the site. In the cases of dust and dirt, compliance shall be with Military Standard MIL-STD-810-F (2000), Method 510.4.

2.1.6 Solar Heat Load The design of systems that are subject to solar heating shall be based on a peak, direct solar heat gain appropriate to the site. Material selection shall minimize the deleterious effects of ultraviolet radiation.

2.1.7 Flood Zones Flood levels shall be specified as the 100-year flood level. The system shall be capable of surviving flooding with minimal damage to structure and equipment. Equipment and facility elements that can be damaged by flooding shall be protected or installed above the flood plain elevation.

2.1.8 Electromagnetic Background The system and all its components shall be electromagnetically compatible with the site environment at the initiation of system operation. All system electrical and electronic equipment shall function satisfactorily in the presence of electromagnetic emissions generated externally at the site. The environment may include, but is not limited to, communications systems, microwave facilities and transmissions, television and radio transmitters and repeaters, radar systems, computer equipment and accessories, traffic control devices, magnetometers, electric motors, controls, power tools, welders,

X-ray equipment, power substations and equipment, automotive vehicles, aircraft, and high-voltage power lines. The electromagnetic environment particular to the site should be determined, and the design should provide for elimination of the influence of these conditions upon the equipment. Compliance shall be in accordance with requirements of the International Electrotechnical Commission (IEC) 62236 series of standards, in particular,

- IEC 62236-1, "Railway Applications—Electromagnetic Compatibility—Part 1: General"
- IEC 62236-2, "Railway Applications—Electromagnetic Compatibility—Part 2: Emission of the Whole Railway System to the Outside World"
- IEC 62236-3-1, "Railway Applications—Electromagnetic Compatibility—Part 3-1: Rolling Stock—Train and Complete Vehicle"
- IEC 62236-3-2, "Railway Applications—Electromagnetic Compatibility—Part 3-2: Rolling Stock—Apparatus"
- IEC 62236-4, "Railway Applications—Electromagnetic Compatibility—Part 4: Emission and Immunity of the Signalling and Telecommunications Apparatus"
- IEC 62236-5, "Railway Applications—Electromagnetic Compatibility—Part 5: Emission and Immunity of Fixed Power Supply Installations and Apparatus"

An electromagnetic compatibility (EMC) control plan and/or EMC management plan shall be developed in accordance with APTA SS-E-010-98 (1998).

2.2 INDUCED ENVIRONMENTAL PARAMETERS

The system shall be operated, stored, and maintained without imposing on the site any condition that exceeds the limitations defined herein.

2.2.1 Exterior Airborne Noise The following exterior noise levels emanating from the system with all equipment operating normally should not be exceeded under the conditions defined. Exterior noise levels shall be measured using at least a Type II instrument, as defined in ANSI Standard S1.4-1983 (ANSI 1983a) and shall be set for fast or slow response as indicated.

1. Vehicle stopped on the guideway in a free field with all auxiliary onboard equipment in normal operation at a point outside, 1.5 m (5 ft) from the doorway on a line aligned to the centerline of the doorway and perpendicular to the plane of the doorway and 1.5 m (5 ft) above the doorway threshold: 74 dB (slow response).
2. Under all normal operating conditions *in a free field*, 15 m (50 ft) from guideway centerline and 1.5 m (5 ft) above ground level to 1.5 m (5 ft) above guideway running surface: 76 dB (fast response).
3. For the purposes of measurement, the *free field* is approximated in tests carried out in an open area away from any major obstructions or noise reflectors.

Noticeable pure tones are not permitted. A pure tone is defined to exist when one 1/3-octave band exceeds the arithmetic average of the two adjacent bands by 4 dBA or more in the range of frequencies between 250 and 8,000 Hz. If an adjacent band contains a pure tone, the next closest band without a pure tone shall be used in its place. A noticeable pure tone shall be

considered to exist when the 1/3-octave band containing the pure tone contributes more than 1.0 dBA to the overall dB level.

More stringent noise requirements may be necessary to satisfy local environmental limitations.

2.2.1.1 Commentary for Interior Noise Levels (Section 7.7.4) and Exterior Airborne Noise (Section 2.2.1) Limits in Tunnels The following commentary is provided as an explanation of why the standard does not specify noise limits inside buildings and tunnels.

The conditions for measuring vehicle exterior airborne noise are specified in Section 2.2.1 as, "Under all normal operating conditions *in a free field*, 15 m (50 ft) from guideway centerline and 1.5 m (5 ft) above ground level to 1.5 m (5 ft) above guideway running surface."

The conditions for measuring vehicle interior noise are specified in Section 7.7.4 as "... with all auxiliary equipment operating. All noise measurements are to be taken *in a free field environment*, with no passengers (up to three test personnel permitted) in the vehicle. Interior noise levels shall be measured 1.5 m (5 ft) above the floor, above the suspension and/or running gear, and at the geometric center of the vehicle floor..."

In both cases, the vehicle is specified to be operating in a *free field environment* to determine purely the noise energy that is emitted from the train without any content of reflected noise or other noise generators that otherwise can compromise the measurements.

When a vehicle or train is operated inside a tunnel or building, noise emitted from the vehicle or train can be reflected and can increase the amplitude of the measured noise. Because the geometries, designs, and surface materials of such structures can vary significantly, it is not possible to know the extent that reflected noise may be experienced. Hence, neither consistent conditions nor standard tests exist for specifying noise limits in tunnels and buildings.

The current standard sets a limit on the noise energy that can be emitted by a vehicle or train. Designers of buildings and tunnels are provided with the limit on emitted noise energy that they need as an input on which they can make designs. Because they are in control of the architectural structure (size, shape, materials, and reflective surfaces), they are in control of what the resultant noise is in a tunnel or building. Buyers of APM systems can specify noise limits, taking into account the architectural designs they specify.

2.2.2 Structure-Borne Noise and Vibration System-induced vibrations shall be imperceptible at or in surrounding buildings. The threshold of perception shall be as defined by ANSI Standard S3.29-1983 (1983b).

2.2.3 Electromagnetic Radiation The system shall be electromagnetically compatible with its environment. The system shall not produce electromagnetic emissions, whether conducted, radiated, or induced, that interfere with normal operation of electromagnetic devices or equipment used in and around the site at the initiation of system operation.

All systems transmitting and receiving equipment, such as for automatic train control (ATC) and audio and visual communications, shall meet the licensing requirements of the Code of Federal Regulations, Title 47, Chapter I, Part 90, Subparts S and T, and the interference requirements defined in Title 47, Chapter I, Part 15.

CHAPTER 3

SAFETY REQUIREMENTS

A system safety program, per Section 3.1, shall be instituted during the system planning and design phase and shall continue throughout the system construction and operation. The system safety concept shall emphasize the prevention of accidents by resolving hazards in a systematic manner in accordance with Section 3.1.2, Hazard Resolution Process.

3.1 SYSTEM SAFETY PROGRAM

A system safety program shall be implemented to identify and resolve hazards. The owner shall provide for the development of a system safety program plan (SSPP) to assist in implementing and documenting that program. The SSPP shall identify the responsibilities of all parties for implementing a system safety program.

The system safety program and SSPP shall

1. Have as their objective to provide for the safety of the passengers, employees, the general public, and equipment;
2. Encompass all system elements and organizations within the automated people mover (APM) system;
3. Identify the safety roles and responsibilities of all organizational elements and require accountability;
4. Designate one individual to be responsible for the safety of the system who has a clearly defined role and responsibilities established through a written policy;
5. Contain a hazard resolution process that includes the procedures necessary to identify and resolve hazards throughout the system life cycle; and
6. Provide for and maintain owner and management commitment in the form of an adopted policy and the allocation of resources.

The individual identified to carry out the system safety program shall have clear evidence of the authority to ensure its implementation and shall report directly to top management.

3.1.1 System Safety Program Plan An SSPP shall be developed during the planning and design phase of the APM project and shall be maintained current throughout the APM system life cycle. The SSPP shall be prepared in general accordance with Appendix A, System Safety Program Requirements, A.1 (System Safety Program Plan), or the equivalent. The SSPP shall, at a minimum, identify the scope of the system safety program activities, including those identified in Section 3.1.

3.1.2 Hazard Resolution Process The hazard resolution process shall be initiated by defining the physical and functional characteristics of the APM system to be analyzed. These characteristics shall be presented in terms of the major elements that make up the system and its environment, including equipment, facilities, procedures, and people.

The hazards shall be identified. The techniques and methods used to identify the hazards shall include the following:

1. Data from previous accidents or operating experience;
2. Expert opinion and hazard scenarios;
3. Checklists of potential hazards;
4. Previous hazard analyses; and
5. Other analysis techniques, as appropriate.

All identified hazards shall be assessed in terms of the severity or consequence of the hazard and the probability of occurrence.

Risk assessment estimates (Table 3-1) based on mean time between hazardous events (MTBHE) shall be used as the basis in the decision-making process to determine whether individual APM system or subsystem hazards shall be eliminated, mitigated, or accepted. Hazards shall be resolved through a design process that emphasizes the elimination of the hazard. Resolution strategies or mitigations to be used, listed in order of decreasing preference, shall be the following:

1. Eliminate hazards;
2. Design to control hazards;
3. Use safety devices;
4. Use warning devices;
5. Implement special procedures;
6. Accept the hazard; and
7. Eliminate the system, subsystem, or equipment.

This process shall include full documentation of all identified hazards, risk assessments, and the hazard resolution activities in a Hazard Tracking Log. The effectiveness of the mitigations shall be monitored to determine that no new hazards are introduced. In addition, whenever substantive changes are made to the system, analyses shall be conducted to identify and resolve any new hazards.

3.1.2.1 Hazard Analyses Hazard analyses shall be used to assist in the evaluation of potential hazards and to document their resolution. As a minimum, a preliminary hazard analysis (PHA) shall be conducted for each new APM system project. Other detailed analyses, including subsystem hazard analysis (SSHA), system hazard analysis (SHA), and operating and support hazard analysis (O&SHA), shall also be conducted if mandated by the SSPP. These analyses shall be conducted in general accordance with Appendix A, System Safety Program Requirements, Sections A.2 (PHA), A.3 (SSHA), A.4 (SHA), and A.5 (O&SHA), or the equivalent, respectively. The safety requirements and provisions identified by hazard analyses and their verification shall be documented.

Certain specific analyses are required in other chapters of this standard. These are listed in Table 3-2 and cross-referenced to the applicable section of this standard to facilitate planning and verification activities.

Table 3-1. Risk Assessment.

Frequency of occurrence	Hazard severity			
	I Catastrophic	II Critical	III Marginal	IV Negligible
A—Frequent	IA	IIA	IIIA	IVA
B—Probable	IB	IIB	IIIB	IVB
C—Occasional	IC	IIC	IIIC	IVC
D—Remote	ID	IID	IIID	IVD
E—Improbable	IE	IIE	IIIE	IVE

Notes:

IA, IIA, IIIA, IB, IIB, and IC = Unacceptable.

ID, IIC, and IIIB = Undesirable (allowable with agreement from authority having jurisdiction).

IE, IID, IIE, IIIC, IIID, IVA, and IVB = Acceptable with notification to the authority having jurisdiction.

IIIE, IVC, IVD, and IVE = Acceptable.

A—Frequent = MTBHE is less than 1,000 operating hours.

B—Probable = MTBHE is equal to or greater than 1,000 operating hours and less than 100,000 operating hours.

C—Occasional = MTBHE is equal to or greater than 100,000 operating hours and less than 1,000,000 operating hours.

D—Remote = MTBHE is equal to or greater than 1,000,000 operating hours and less than 100,000,000 operating hours.

E—Improbable = MTBHE is equal to or greater than 100,000,000 operating hours.

It is understood that the quantification of the probability or frequency of occurrence of elements within the safety verification process may be required to be subjectively (i.e., qualitatively) determined. All subjectively determined elements shall be identified, and the rationale and justification for the estimation shall be described.

I—Catastrophic = Death, system loss, or severe environmental damage.

II—Critical = Severe injury, severe occupational illness, or major system or environmental damage.

III—Marginal = Minor injury, minor occupational illness, or minor system or environmental damage.

IV—Negligible = Less than minor injury, occupational illness, or less than minor system or environmental damage.

3.2 SAFETY PRINCIPLES

The following safety principles shall be observed in the APM system (Table 3-1 defines unacceptable and undesirable hazards):

1. When the system is operating normally, there shall be no unacceptable or undesirable hazard conditions.
2. The system design shall require positive actions to be taken in a prescribed manner to either begin system operation or continue system operation.
3. The safety of the system in the normal automatic operating mode shall not depend on the correctness of actions or procedures used by operating personnel.
4. There shall be no single-point failures in the system that can result in an unacceptable or undesirable hazard condition.
5. If one failure combined with a second failure can cause an unacceptable or undesirable hazard condition, the first failure shall be detected, and the system shall achieve a known safe state before the second failure occurs.
6. Software faults shall not cause an unacceptable or undesirable hazard condition.
7. Unacceptable hazards shall be eliminated or controlled by design such that the hazard risk is no longer assessed as Unacceptable.
8. Maintenance activities required to preserve risk levels (Table 3-1) shall be prescribed to the individual responsible for the system safety program (Section 3.1) during the design phase. These maintenance activities shall be minimized in both the frequency and in the complexity of their implementation. The personnel qualifications required to implement these activities adequately shall also be identified.

3.3 ATC SYSTEM FAIL-SAFE DESIGN

All safety-critical elements of the ATC system (see Chapter 5, “Automatic Train Control”) shall be designed and implemented in accordance with fail-safe principles and shall use one or more of the techniques described as follows, or the equivalent, to detect potentially unsafe failure modes and force the system to a known safe state. Fail-safe principles shall be realized by designing the system to have intrinsically safe failure characteristics or by designing the system with verifiable techniques that detect potentially unsafe failures and ensure that the system reverts to a known safe state. Documentation of the means used and proof that the fail-safe principle has been met shall be required for every safety-critical system or subsystem.

3.3.1 Intrinsic Fail-Safe Design Intrinsically fail-safe systems shall be designed using verifiable physical, mechanical, and/or electrical component characteristics. For these designs, the effect of every relevant failure mode on the operation of the system shall be considered, analyzed, and documented in a comprehensive failure mode and effects analysis, or the equivalent.

3.3.2 Alternatives to Intrinsic Fail-Safe Design Many control system designs use integrated circuits, microprocessors, and software to achieve the required functional characteristics. Designs that do not exhibit intrinsically safe failure characteristics shall use one or more of the following techniques (Sections 3.3.2.1 through 3.3.2.4). The effectiveness and completeness of these techniques shall be documented and proven as part of system validation and verification (Section 3.4). The measure of the technique’s effectiveness shall be its ability to detect fault conditions and ensure that the technique is installed as designed and as required for the system to operate.

Table 3-2. Index of Required Hazard Analyses.

Reference in ASCE 21	Hazard analysis requirement
3.1 SYSTEM SAFETY PROGRAM	
3.1.2.1 Hazard Analyses	Preliminary hazard analysis (PHA). As mandated by the System Safety Program Plan the following analyses may be required: Subsystem hazard analysis (SSHA), System hazard analysis (SHA), and Operation & Support hazard analysis (O&SHA).
5.1 AUTOMATIC TRAIN PROTECTION FUNCTIONS	
5.1.2 Separation Assurance	Minimum emergency braking condition
5.1.2.1 Separation Assurance for Automated People Movers (APM)	Minimum emergency braking condition
5.1.2.2 Separation Assurance for Automated Transit Network (ATN) Systems	Minimum emergency braking condition Lead train deceleration rate
5.1.10 Door Control Protection Interlocks for APM systems where trains do not achieve a complete stop for boarding and discharging passengers	Acceleration and jerk rates-Train door opening and door closing within designated zone
5.1.13 Propulsion and Braking Interlocks	Reset of emergency braking (unless Chapter 5 is applied)
5.1.14 Guideway Switch Interlocks	Onboard guideway switch interlocks
5.1.15 Offline Sections Operation—Special Conditions (O&SHA)	Contact between two vehicles in Circulation Zone
5.1.15 Offline Sections Operation—Special Conditions	Contact between two vehicles in Docking Zone
5.4 MANUAL OPERATION LIMITATIONS	Manual mode operation
6 AUDIO AND VISUAL COMMUNICATIONS	
6.3.2 Stations	Time period for audio and visual communications UPS Passenger exchange when trains do not make a complete stop
7 VEHICLES	
7.4.4.9.2 Vehicle—Overtravel Protection Device Collision	Maximum speed of contact with vehicle overtravel protection in manual
7.6 SUSPENSION AND GUIDANCE	Failure of pneumatic tire pressure
7.7.2 Ventilation	Time period for fresh air supply
7.8 DOORS, ACCESS, AND EGRESS	Operation of an emergency exit
7.11.2 Emergency Lighting	Time period for emergency lighting power
7.12.2.3 Emergency Power	Time period for emergency power to critical subsystems
8 PROPULSION AND BRAKING	
8.3.2 Emergency Braking	Traction effort and stopping distances for wayside emergency braking systems PBS operation
8.4 PROPULSION AND BRAKING SYSTEM COMPONENT DESIGN	
8.4 PROPULSION AND BRAKING SYSTEM COMPONENT DESIGN	Service life of friction brakes
8.5 INSTALLATION AND PROTECTION	PBS equipment maintenance access along guideway or in stations
8.7 BRAKE TESTING	Frequency for periodic testing of braking systems
9 ELECTRICAL EQUIPMENT	
9.1.4 Grounding	Electrical hazards
9.1.4.2 Facilities and Structure Grounding	Electrical grounds during emergency evacuation
9.2.5 Power Regeneration Equipment	Regenerating power into the deenergized power rail
9.2.8 Restoring Power	Automatic reclosing of power distribution equipment
9.5 UNINTERRUPTIBLE POWER SUPPLY	Time period for UPS for ATC, AV communications, Fire and other safety/security equipment, power distribution system control power at substation
10 STATIONS	
10.2 PLATFORM EDGE PROTECTION	Platform edge protection
10.2.3 Intrusion Detection System	Braking command for entering/approaching station Procedures to reset the detection system and restore traffic
10.5.1 Fire Detection	Response to fire/smoke detection
10.5.2 Fire Containment	Fire separation of stations

Table 3.2 (Continued). Index of Required Hazard Analyses.

Reference in ASCE 21	Hazard analysis requirement
11 GUIDEWAYS	
11.2 INTRUSION PROTECTION AND DETECTION	Forms of intrusion protection and detection
11.3 EMERGENCY EVACUATION AND ACCESS	Activation of vehicle door release
11.3.3 Elevated Guideway	Alternative evacuation means and duration for elevated emergency walkway
11.8.1 (GUIDEWAY ALIGNMENT) Clearances	Clearance for nonstructural system components
11.9 STRUCTURAL CRITERIA – Longitudinal Force, Seismic Force	Guideway design for severe loads caused by failures
16 OPERATIONAL MONITORING	
16.5 CONFIGURATION MANAGEMENT	Design changes to safety-critical items

3.3.2.1 Checked Redundancy The application of the checked-redundant principle shall include at least two parallel systems performing identical functions. A means shall be provided to compare the output of the parallel systems. If the two systems do not agree, then the safety-critical function being performed shall default to a known safe state. The following characteristics shall be incorporated and verified in the checked-redundant design:

1. The checking process shall ensure that agreement shall not be indicated unless the redundant outputs agree. Lack of agreement of the checking process shall result in a known safe state.
2. The checking process shall include the comparison of all safety-critical results with all safety-critical functions.
3. Any failure that could affect system safety in either of the redundant units shall result in a known safe state.
4. The redundant units shall be independent from one another so that no common environmental or power fluctuations, errors, and/or faults can cause unacceptable or undesirable hazards (Table 3-1).
5. The checking process shall be comprehensive in coverage (including functions tested and the rate at which functions are tested) to ensure that the probability of failures or compensating failures producing unacceptable or undesirable hazards is at an acceptable level (Table 3-1).
6. For units using software-programmed elements, the software shall be shown to be free from errors, including any errors introduced during the compilation process, by proven principles and practices of verification and validation (Section 3.4).

3.3.2.2 N-Version Programming The application of the N-version programming principle shall require at least two parallel programmed systems performing identical functions. The software in each system shall be unique and independently written by different persons or teams, using different languages and tools. The hardware may or may not be identical, or it may include both programmed systems within one hardware processing unit. A means shall be provided to compare the output of the parallel programmed systems. If the two systems do not agree, then the safety-critical function being performed shall default to a known safe state. The following characteristics shall be incorporated and verified in the design:

1. The checking process shall be fail-safe. Agreement shall not be indicated unless the redundant outputs agree. Lack of agreement of the checking process shall result in a known safe state.

2. The checking process shall include the comparison of all safety-critical results with all safety-critical functions.
3. Any failure that could affect system safety in either of the units shall result in a known safe state.
4. The parallel programmed systems shall be independent from one another so that no common environmental or power fluctuations, errors, and/or faults can cause unacceptable or undesirable hazards (Table 3-1).
5. The checking process shall be comprehensive in coverage (including functions tested and the rate at which functions are tested) to ensure that the probability of failures or compensating failures producing unacceptable or undesirable hazards is at an acceptable level (Table 3-1).
6. The software processed by the parallel programmed systems shall be proven to be independent.

3.3.2.3 Diversity and Self-Checking The use of diversity and self-checking concepts shall require that all critical functions be performed in diverse ways, using diverse software operations and/or diverse hardware channels, and that critical system hardware be tested with self-checking routines. Permissive outputs shall be allowed only if the results of the diverse operations correspond and the self-checks reveal no failures. The following characteristics shall be incorporated and verified in the design:

1. The checking of the results of the diverse operations shall be fail-safe. Permissive decisions shall not be allowed unless the diverse results agree. Lack of agreement with the diverse checking process or with self-checks shall result in a known safe state.
2. The diverse operations and the self-checking process shall include the verification of all safety-critical results of all the safety-critical functions.
3. Any failure that could affect system safety shall result in a known safe state.
4. The diversity and self-checking routines shall be comprehensive in coverage (including functions tested and rate at which functions are tested) to ensure that the probability of failures or compensating failures producing unacceptable or undesirable hazards is at an acceptable level (Table 3-1).
5. For units using software-programmed elements, the software shall be shown to be free from errors, including any errors introduced by the compilation process by proven principles or practices of verification and validation (Section 3.4).

3.3.2.4 Numerical Assurance The numerical assurance principle shall require permissive decisions to be represented

by large unique numerical values, calculated by combining numerical values representing each of the critical constituents of a permissive decision. The following characteristics shall be incorporated and verified in the design:

1. The numerical values representing the permissive decisions shall be proven to be unique and to require unique values added by each of the critical constituents.
2. All critical processes that do not add unique values to the permissive results, per the previous characteristic, shall generate unique numerical values that are verified for correctness.
3. The system calculating the numerical results must have no prior knowledge of the correct permissive numerical values.
4. The process used to verify the correctness of the numerical results shall be fail-safe.
5. Any failure that could affect system safety shall result in a known safe state.
6. Lack of correctness of any of the numerical results shall result in a known safe state.
7. The numerical process shall be comprehensive in coverage (including functions protected by numerical values and the frequency at which the numerical values are calculated and verified) to ensure that the probability of failures or compensating failures producing unacceptable or undesirable hazards is at an acceptable level (Table 3-1).

3.4 VERIFICATION AND VALIDATION

The design and implementation of all safety-critical hardware and software elements of the system as identified in the hazard resolution process (Section 3.1.2) shall be subjected to verification and validation. This process includes elements designed and implemented in accordance with safety principles (Section 3.2) and ATC system fail-safe design (Section 3.3). The objective of this verification and validation shall be to verify that all safety-critical elements have been designed and implemented to achieve safe operation and to verify the level of safety achieved. The verification and validation process shall include

1. The identification of all factors on which the assurance of safety depends. Such factors shall be directly associated with the design concept used (i.e., checked redundancy, *N*-version programming, diversity and self-checking, or numerical assurance).
2. The identification of all safety-critical functions performed by the system.
3. Analyses demonstrating that all dependent factors have been satisfied and that each safety-critical function has been implemented in accordance with safety principles.

A system safety certification report (SSCR) shall document the status of verification and validation activities of the APM project. The SSCR shall be initiated with the PHA, updated periodically, and maintained current throughout the APM service life.

3.5 ATC SYSTEM MEAN TIME BETWEEN HAZARDOUS EVENTS

The ATC system (see Chapter 5, “Automatic Train Control”) shall, in addition to the aforementioned, have a calculated aggregate mean time between hazardous events (MTBHE) (total of all catastrophic and critical hazards) of 10^8 (1×10^8) system operating hours or greater. System safety documentation shall support this aggregate MTBHE calculation and substantiate the methodology used to arrive at the result.

3.6 COMMENTARY ON CHAPTER 3.0 AND SUBPARTS

Section 3.4 of this standard describes formal procedures for verifying and validating that safety-critical hazards have been identified and resolved. It should be noted that Section 3.4 does not apply just to the ATC system, but rather requires verification and validation of all safety-critical hardware and software elements of the entire APM system that were identified in the hazard resolution process explained in Section 3.1.2 of the standard.

Unlike Section 3.4, Section 3.5 provides an additional MTBHE requirement that applies only to the ATC system.

As noted in Section 3.1.2, all individual APM system or subsystem hazards are to be assessed in terms of both the severity and consequence of the hazard and its likelihood of occurring. The risk assessment table (Table 3-1) provided in the standard is to be used as a basis for deciding whether the hazard needs to be eliminated or mitigated or whether it may be accepted. The table provides guidelines for the level of risk that is completely acceptable, the level allowable provided notice is given to the authority having jurisdiction, and the level that can only be accepted with the specific approval of the authority having jurisdiction. Finally, there is a risk level that is so serious that it cannot be accepted and must be either mitigated or eliminated.

It is important to emphasize that this evaluation is performed on each individually identified system or subsystem hazard for the entire APM system. As noted in Table 3-1, it is understood that quantifiable estimates of probability or frequency of occurrence may not always be available. In that event, it is acceptable to subjectively or qualitatively estimate the risk. If such qualitative estimates are used, all subjectively determined elements are to be identified and the rational justification for the estimate is to be documented.

The results of this process would normally be a set of hazard resolution forms describing each hazard, the consequence of the hazard and its severity, and the steps taken to mitigate or eliminate the hazard if it is not acceptable. The form also documents the residual acceptable risk level after mitigation in the event the hazard has not been completely eliminated.

Section 3.1.2 of the standard lists acceptable approaches to elimination or mitigation of hazards. The preferred solution is to eliminate or control the hazard by a design change. If this solution is not possible, safety or warning devices can be used. If this solution is not practicable, procedures such as periodic inspection are suggested. Finally, the offending equipment responsible for introducing the hazard can simply be eliminated from the design altogether. Acceptance of the hazard is only allowed if it is not in one of the shaded risk categories in Table 3-1. These shaded risk areas represent an unacceptable combination of hazard severity and likelihood of occurrence.

After risks have been determined and risk categories have been assigned to hazards, the recommendation for risk acceptance of hazards assessed as undesirable should reference a generally accepted principle. Examples of risk acceptance principles are

- As Low As Reasonably Practicable (ALARP) principle, practiced in the United Kingdom,
- Globalement Au Moins Aussi Bon (GAMAB) principle, practiced in France, and
- Minimum Endogenous Mortality (MEM) principle, practiced in Germany.

Section 3.5 sets an additional safety criterion for the ATC system over and above the mitigation or elimination of individual hazards required by Section 3.4. This additional safety criterion is

an aggregate MTBHE (total of all catastrophic and critical hazards) for just the ATC system. This MTBHE figure is to be supported by safety documentation.

Two different overall MTBHE values are specified. If the system does not use communications-based train control (CBTC), the requirement is a calculated aggregate MTBHE of 10^{**8} ($1 \times E 8$) system operating hours or greater for the entire ATC system.

If the ATC system uses CBTC, the MTBHE requirement is to be superseded by that specified in IEEE 1474.1-2004 (2004), Section 5.3.4. This section specifies an MTBHE of a least

10^{**9} ($1 \times E 9$) operating hours for all wayside and train-borne CBTC equipment in a contiguous portion of a one-way route that can be traversed by a train traveling at the specified maximum authorized speed for one hour or less. In addition, the maximum number of trains should be in operation on the segment at their peak operating headway.

It should be noted that the 10^{**8} ($1 \times E 8$) number in this standard covers the entire ATC system, whereas the 10^{**9} ($1 \times E 9$) number covers only car and wayside CBTC equipment on only a portion of the total route, so the two numbers are not directly comparable.

CHAPTER 4 SYSTEM DEPENDABILITY

System dependability is the overall set of criteria used to measure the performance of an operating system in terms of reliability, maintainability, and availability.

Throughout this chapter, references to *system* may also be applied to *system subsets* for purposes of determining their individual contribution to overall system dependability.

Partial service or degraded service adjustments may be applied in defining overall system dependability. Factors, ratios, or separate calculations by system subset may be used to provide for such adjustments.

Note: A recommended practice for measuring Service Availability is provided in Appendix G of this standard. It measures the downtime of system equipment with which passengers interface for service, implicitly resulting in the same measure of System Service Availability as the classical approach defined in this chapter.

4.1 SERVICE RELIABILITY

Service reliability is defined as the mean time between system or system subset failures ($MTBF_s$), Equation (4-1).

$$MTBF_s = \frac{\text{Operating Hours}}{\text{Number of Failures}} = \frac{OH_s}{NF_s} \quad (4-1)$$

where OH_s is the total number of hours of scheduled operation over which the service reliability is being determined; the period of operating hours.

NF_s is the number of failures, malfunctions, and operating disruptions classified as service interruptions during the period of operating hours.

4.1.1 Service Interruptions Service interruptions are those events or failures that prevent passenger use of the system or system subset as intended. Service interruptions shall be defined and weighted in accordance with their relative importance. At a minimum, the following types of service interruptions shall be included:

1. Unscheduled stoppage of one or more trains,
2. Rerouting of trains caused by equipment malfunction so that any stations normally served are not served,
3. Malfunctions that prevent passengers from entering or exiting trains at stations in automatic operation,
4. Station platform malfunctions that prevent passengers from using the APM system in automatic operation, and
5. Malfunctions that result in potentially hazardous operations.

The owner will specify if erroneous operator actions that result in service interruptions are to be included.

4.1.2 Exceptions The following shall not be considered service interruptions:

1. Malfunctions that result in an interruption of normal train operations for an interval of time equal to or less than a specified period of time (grace time);
2. Malfunctions or disruptions caused by vandalism, passenger misuse of the system, or passenger-induced delays;
3. Disruptions caused by unauthorized intrusion of persons, animals, or inanimate objects into the system, except where the intrusion or failure results from the malfunction of any security system or devices designed to protect against such intrusion;
4. Disruptions caused by external causes, including loss of primary power, police or security directives, force majeure, or environmental conditions beyond specified limits;
5. Disruptions for special training, guideway inspections, or extended repair purposes that have been arranged in advance; and
6. Stoppages caused by normal functioning of the automatic train control system where specified operating performance requirements are met.

4.2 SERVICE MAINTAINABILITY

Service maintainability is defined as the mean time to restore service ($MTTR_s$) after a system service interruption, Equation (4-2).

$$MTTR_s = \frac{\text{Sum Total Time to Restore Service}}{\text{Number of Failures}} \quad (4-2)$$

$$MTTR_s = \left(\frac{1}{NF_s} \right) \sum_{i=1}^{NF_s} TTR_i$$

where TTR_i is the time to restore service after the i th service interruption (downtime interval), and NF_s is the number of failures, malfunctions, and operating disruptions classified as service interruptions during the period of operating hours.

In computing the cumulative time to restore and the associated number of failures (NF_s), only service interruptions with downtime intervals greater than any grace time (see Section 4.1.2) shall be included. However, once the specified maximum number of grace time allowances has been reached, no further grace time shall be allowed, and all subsequent service interruptions shall be included in the calculation of downtime intervals. In addition, the downtime interval for each such event shall be the full-time interval of cessation of service according to these points:

1. Grace time shall not be subtracted from the TTR_i for a countable system service interruption, and

2. Downtime interval shall be measured from the time of detection of the service interruption until the time of restoration of service for the specific train or equipment that malfunctioned, whether the restoration is accomplished by automatic means or by repair or replacement of the malfunctioning equipment.

4.3 SERVICE AVAILABILITY

Service availability (A_s) is defined in Equation (4-3):

$$A_s = \frac{MTBF_s}{MTBF_s + MTTR_s} \quad (4-3)$$

Service availability shall be calculated over a specified time interval. The calculation of service availability is equivalent to the actual operating hours (scheduled operating hours minus the accumulated downtime) divided by the scheduled operating hours.

CHAPTER 5

AUTOMATIC TRAIN CONTROL

The ATC subsystem shall provide automatic train protection (ATP), automatic train operation (ATO), and automatic train supervision (ATS) functions. ATP shall provide the primary protection for passengers, personnel, and equipment against the hazards of operations conducted under automatic control. ATP functions shall have precedence over both the ATO and ATS functions. ATO shall control basic operations that would otherwise be performed by an operator and does so within the protection limits imposed by ATP. The ATS shall provide system status information and the means for the central control operator to monitor and override the automatic control for various functions of the system.

For automated people mover (APM) systems that use communications-based train control (CBTC) for ATC, the requirements of IEEE 1474.1-2004 (IEEE 2004) shall apply in lieu of the requirements provided in Sections 5.1 and 5.2. Compliance with IEEE 1474.1-2004 is not required by this standard for ATN (Automated Transit Network) systems subject to Section 5.1.2.2.

5.1 AUTOMATIC TRAIN PROTECTION FUNCTIONS

All ATP functions shall be designed and implemented in accordance with Sections 3.2, Safety Principles, and 3.3, ATC System Fail-Safe Design.

5.1.1 Presence Detection Presence detection shall be an ATP function if it is required to ensure the protection aspects of other ATP functions, such as train separation assurance and/or guideway switch interlocks.

As an ATP function, presence detection shall be continuous in accordance with Section 5.1.7 in any and all automated areas of the guideway. All trains and any other vehicles that operate on the system in the presence of trains running in automatic operation shall be detected, regardless of whether they are being operated in automatic or manual control.

The presence-detection function shall be reinitialized, and all trains shall be located and identified by positive detection before the resumption of automatic operation. In no case shall automatic operation be allowed based on manual input of position data.

5.1.2 Separation Assurance Section 5.1.2.1 provides separation assurance standards for automated people movers. Section 5.1.2.2 replaces Section 5.1.2.1 for those APM systems which meet the requirements for ATN systems and intend to operate at closer headways than is permitted by Section 5.1.2.1.

5.1.2.1 Separation Assurance for Automated People Movers Separation assurance shall be a required ATP function for any automated people movers (APM) system configuration that operates trains in following moves around the guideway.

Separation assurance shall provide protection against rear-end collisions for following trains by maintaining a zone at the rear of each train that continuously provides sufficient stopping distance for the following train assuming that the train ahead can stop instantaneously.

Stopping distance shall be calculated analytically using the cumulative worst-case characteristics of relevant elements, where worst case pertains to the characteristic of the element that results in maximum stopping distance. This requirement includes but is not limited to

1. Maximum runaway acceleration,
2. Minimum emergency braking condition,
3. Maximum cumulative time delays,
4. Maximum attainable overspeed,
5. Grade,
6. Worst-case load,
7. Minimum adhesion and traction, and
8. Maximum design tailwind.

For stopping distance calculation purposes, minimum emergency braking condition shall be based on the single worst-case failure conditions of the braking system elements as determined by an appropriate analysis conducted in accordance with the requirements of Section 3.1.2.1, Hazard Analyses.

For APM systems that permit the automated operation of trains in opposing directions on the same track, separation assurance using calculated stopping distances for both trains shall apply for the prevention of head-on collisions.

For APM systems that use automatic coupling, the coupling maneuver shall be permitted, provided the entire maneuver is conducted under the protection of ATP and can be verified and validated to be in accordance with Section 3.3, ATC System Fail-Safe Design.

For APM systems where the separation between successive trains is physically maintained, as it is in a cable-propelled system, and where it can be shown by analysis according to Section 3.1.2.1, that slippage and/or detachment from the physical mechanism is possible, then such slippage or detachment shall be detected and emergency braking shall be initiated to stop the slipping or detached train and all other trains connected to that mechanism.

Comparable separation assurance protection shall be required for APM systems that use other means to maintain separation between successive trains.

5.1.2.2 Separation Assurance for Automated Transit Network Systems This section replaces Section 5.1.2.1 for ATN systems that can be shown to be free from failure modes that can result in Unacceptable hazards as defined in Section 3.2 according to risk assessment for lead train stops conducted in accordance with

Section 3.1.2, including all supplemental provisions added by this Section 5.1.2.2.

The automated operation of trains in opposing directions at the same time on the same through guideway shall be prohibited.

Separation assurance shall be a required ATP function meeting the fail-safe design requirements of Section 3.3 for any ATN system configuration that operates trains in following moves around the guideway. More specifically the ATP shall vitally assure that trains do not exceed their movement authority limits or the safe speed limit.

Separation assurance shall provide protection against following trains colliding with leading trains by maintaining a separation assurance zone (SAZ).

Separation assurance requirements, design, calculations, hazard analyses and mitigation measures shall be independently reviewed by an independent safety assessor (ISA). The ISA shall be approved by the authority having jurisdiction (AHJ). Note: Refer to Recommended Practice for Independent Safety Assessment, Appendix H.

In calculating the SAZ, the following train's use of the lead train's position and velocity information shall include all instrument measurement tolerances, data latencies, and communication delays from the time the location and speed were transmitted by the lead train. It shall also account for deterioration in performance related to environmental constraints of the project (such as poor visibility, inadequate lighting, and Electromagnetic Interference (EMI) conditions), emergency shutdown, and failures of positioning system equipment.

Stopping distance for the following train shall be calculated analytically using the worst-case characteristics of relevant elements, where worst case pertains to the characteristic of the element that results in maximum stopping distance. This requirement includes, but is not limited to

1. Maximum runaway acceleration,
2. Minimum emergency braking condition,
3. Maximum cumulative time delays,
4. Maximum attainable overspeed,
5. Track geometry including grade,
6. Worst-case load,
7. Minimum or variable adhesion and traction,
8. Maximum design tailwind.

For following train stopping distance calculation purposes, minimum emergency braking condition shall be based on the single worst-case failure conditions of the braking system elements as determined by an appropriate analysis conducted in accordance with the requirements of Section 3.1.2.1, Hazard Analyses.

In lieu of assuming the train ahead can stop instantaneously, the lead train deceleration rate shall be analyzed in accordance with the requirements of Section 3.1.2.1, Hazard Analyses and Table 3-1 Risk Assessment. As a minimum, the list of potential hazards or hazardous events shall include:

1. Collision with loose obstacles on the guideway weighing more than 10% of the AW0 weight of the vehicle.
2. Collision with an undetected train stopped on the guideway involving more than one following train. The definition of an *undetected train* shall be a train no longer being tracked by the vehicle location technology due to detection or communication failure and which is assumed to have previously been commanded to stop immediately on loss of detection at the maximum deceleration rate used in determining the SAZ.

3. Switch failure that results in trains losing guidance through a diverging or merging point on the track.
4. Lateral guidance or derailment capture mechanism failure that exposes the train to the possibility of undesigned contact with power rails, guidance surfaces, guideway or external element.
5. Wheel or suspension system failures that can lead to undesigned contact of the train with power rails, guidance surfaces, guideways, or external elements.
6. Rollover.
7. Train hitting fixed obstacle alongside the guideway because of there being inadequate clearance around the guideway.
8. Train hitting fixed obstacle alongside the guideway because of there being inadequate clearance around the guideway where the obstacle is designed to be crashworthy and not cause lead train deceleration exceeding that used in determination of the SAZ.
9. Collision with loose obstacles on the guideway weighing less than 10% of the AW0 weight of the vehicle.
10. Accidental thrust reversal by the train propulsion equipment.
11. Unexpected application of braking systems (service, emergency, and parking if provided) on AW0 train at maximum rate.
12. Wheel bearing seizure.
13. Drive train lockup.
14. Lead train hits overtravel protection device at end of guideway.

Events 1 through 7 shall be subjected to a risk analysis per Table 3-1 and not incorporated in the SAZ. Note: Decelerations cannot be accurately estimated for Events 1 through 7.

All other hazards shall either be eliminated by incorporating their worst-case deceleration rate directly into the SAZ calculation or be subjected to a risk analysis per Table 3-1.

In calculating worst case deceleration, train weight shall be chosen to produce the worst-case deceleration rate. Any relevant effects of grade, minimum passenger load, maximum headwinds, maximum adhesion/traction limits, and minimum initial velocity shall be considered in the analysis.

In using Table 3-1, the frequency of occurrence shall be calculated for the entire ATN system with annual train operating hours per build-out design parameters. Severity of Events 1 through 7 shall be "I – Catastrophic." Severity of Events 8 through 14 shall be at least "II – Critical." Frequency of occurrence shall be mitigated to an "acceptable with notification to the authority having jurisdiction" level per Section 3.2 of the APM Standard.

Any of the aforementioned events involving more than one train and an external object shall be considered "I – Catastrophic." Any of the above events involving more than two trains, shall be considered "I – Catastrophic." Unacceptable hazards shall be eliminated by design.

Provision of all the following three crash mitigation measures shall permit changing severity of failures from "I – Catastrophic" to "II – Critical."

1. All passengers shall be provided with seats and seat belts. There shall be an audible and visual warning to fasten seat belts prior to departure.
2. All trains shall be provided with collision survivability against a head-on impact at half of the maximum cruise speed (including any tolerance) with a rigid immovable wall.

3. Occupant protection from interior impact shall be required including head restraints for fore- and aft-facing seats and use of impact absorbing materials.

Note: In addition, obstacle removal and detection systems may be employed to reduce the risk of foreign objects on the guideway. Other mitigation measures including robustness of design, hardware, software, maintenance methods and operating procedures may be proposed and implemented to control risk in accordance with Section 3.2 Safety Principles.

5.1.3 Unintentional Motion Detection Detection of unintentional motion shall be a required ATP function for all APM systems.

The ATP shall initiate emergency braking in the event that a train is detected to be moving when it has not been commanded to move. Emergency braking shall also be initiated whenever a train is detected to be moving against the permitted travel direction (rollback).

5.1.4 Overspeed Protection Overspeed protection shall be a required ATP function for all APM systems.

Guideway alignment, civil constraints, and train traffic conditions as determined by ATP shall define the speed limits that represent the maximum allowable train speed at any point on the guideway.

The overspeed protection function shall provide speed enforcement, ensuring that the speed of a train never exceeds the defined speed limit anywhere along the entire route. The overspeed protection equipment shall include speed-measuring devices that furnish signals that are a measure of the actual speed of the train. If ever the actual speed of the train exceeds the speed limit, the overspeed protection equipment shall immediately command emergency braking.

5.1.5 Overtravel Protection Overtravel protection shall be a required ATP function for any APM system configuration that permits the automatic operation of trains up to or close to an end-of-guideway terminus.

Overtravel protection shall be incorporated into, or function in conjunction with, overspeed protection to prevent trains from overtraveling the end of the guideway or, if buffers are specified, to prevent trains from exceeding the design limits for impact with an end-of-guideway buffer. Overtravel protection design shall be based on stopping distance calculations using cumulative worst-case characteristics of relevant elements, as in Section 5.1.2.

5.1.6 Parted Consist Protection Parted consist protection shall be an ATP function for APM systems that use separate vehicles coupled together in a consist of two or more vehicles to form a train. Parted consist protection shall be required regardless of whether the individual vehicles are considered to be permanently coupled or whether they are routinely uncoupled for maintenance or operational purposes.

Parted consist protection shall detect the uncoupling, detachment, and/or separation of vehicles in a consist and shall thereupon immediately cause all vehicles of the previously connected train to brake to a full stop.

Presence detection, if applicable under the requirements of Section 5.1.1, shall detect the individual presence and precise location of each separated entity to the extent possible within the limits of the presence detection segmentation.

5.1.7 Lost Signal Protection For all APM systems, all signals that are critical to the functions of ATP shall be continuous or be of such a repetitive nature that signal interruption is detected. Detection of signal interruption shall result in emergency braking

by ATP in sufficient time so as not to compromise any safety aspect of the ATP functional design.

5.1.8 Zero Speed Detection On APM systems where the trains are required to stop, zero speed detection shall be a required ATP function.

Zero speed shall not be registered until a speed of 0.30 m/s (0.95 ft/s) or less is attained and braking is commanded.

5.1.9 Unscheduled Door Opening Protection Unscheduled door opening protection shall be a required ATP function for all APM systems.

If any automatic door or emergency exit door on a train unlocks for any reason while the train is in motion (above zero speed as defined in Section 5.1.8), that train shall be caused to brake to a full stop.

For systems that include train–platform separation walls and automatic station doors, unscheduled door opening protection by ATP shall also apply. If any automatic station door is unlocked for any reason, trains shall be prohibited from entering or leaving that station platform. If any of these doors are unlocked for any reason as a train is entering or leaving the station platform area, the process of braking the train to a full stop shall be immediately initiated.

In the event of any unscheduled door opening (of a train or station), a local manual reset by authorized personnel shall be required before the restoration of automated train operation.

5.1.10 Door Control Protection Interlocks Door control protection interlocks shall be provided by ATP on all APM systems.

These interlocks shall ensure that the following conditions are satisfied before enabling the automatic unlocking and opening of the train doors and, if provided, the station platform doors:

1. The train is properly aligned at a station platform per the criteria in Section 5.2.2,
2. Zero speed is detected,
3. Propulsion power is removed from the motors, and
4. The train is positively constrained against motion.

For APM systems where trains do not achieve a complete stop for boarding and discharging passengers, the following conditions shall be satisfied for automatic unlocking and opening of train doors and station platform doors (if provided):

1. Speed shall not exceed 0.35 m/s (1.1 ft/s).
2. Acceleration and jerk rates shall be limited to values determined to be acceptable by analysis according to the requirements of Section 3.1.2.1, Hazard Analyses.
3. The entire door opening and door closing sequence shall occur within the designated zones as determined by an analysis conducted in accordance with Section 3.1.2.1.

5.1.11 Departure Interlocks Departure interlocks shall be provided by ATP on all APM systems.

Any train stopped in a station shall not be permitted to move until all doors (train and station platform, if provided) are properly closed and locked. Only then shall the constraint against motion be removed and the power be applied to the propulsion motors.

For APM systems where trains do not achieve a complete stop for boarding and discharging passengers, departure interlocks shall be provided to stop the train from departing the station if all doors are not closed and locked.

5.1.12 Direction Reversal Interlocks Travel direction reversal interlocks shall be provided by ATP on all APM systems

requiring bidirectional operation on any segment of the automated guideway.

Any reversal of train travel direction shall occur only after zero speed has been registered (see Section 5.1.8). Reversing of train direction shall occur automatically at stations or terminal zones as required by the system configuration for the support of pinched loop, intermediate turnback loop, reverse direction loop, or shuttle modes of operation.

Any reversal of a train shall also be possible by remote manual command from the central control.

5.1.13 Propulsion and Braking Interlocks Propulsion and braking interlocks shall be provided by ATP on all APM systems.

Emergency braking shall be irrevocable, that is, once it is initiated, it shall remain activated until the train comes to a complete stop. After the train has stopped, the emergency braking shall be required to be reset for normal operation to resume. For situations where the method of reset is not specified by Chapter 5, the method shall be determined by an analysis conducted in accordance with Section 3.1.2.1, Hazard Analyses. If conditions as determined by ATP are not correct for the train to move, the emergency braking shall remain applied regardless of any reset signals or actions, except that it shall be possible to switch to full manual operation, thus disabling the ATP functions of that train. If correct ATP conditions exist after irrevocability has been removed, the train shall be permitted to move, but if a subsequent malfunction occurs, the irrevocable emergency braking shall be applied as before.

The emergency braking controls shall be interlocked with the propulsion controls such that braking commands dominate.

5.1.14 Guideway Switch Interlocks Guideway switch interlocks shall be provided by ATP for any APM system that operates trains under automatic control over a switch or switches installed along the guideway. For switching mechanisms on board the train, comparable interlocks that meet the intent of this section, as determined by analysis in accordance with the requirements of Section 3.1.2.1, Hazard Analyses, shall be provided.

ATP shall prevent a train from entering a switch that is not properly aligned and locked and shall prevent a switch from becoming unlocked and/or moved once a train is committed to traversing it.

Control circuits shall be arranged so that an aligned and locked switch cannot be signaled for a route until each portion of the switch is verified to be in the correct position. When switch conditions are not correct (whether the switch has been activated automatically or manually), the control signals normally transmitted to approaching trains shall ensure that any approaching train in automatic mode shall stop before reaching the entrance point of the switch.

Whenever a train is in the protected zone associated with a switch or a series of switches, route locking shall prevent the automatic or remote manual movement of any of the switches in the protected zone and shall prevent any conflicting train movements from occurring.

Presence detection locking shall be used to prevent a switch from being moved if there is a train occupying it, regardless of whether the switch is being operated under automatic or remote manual control.

Time locking (with approach release of that time locking optional) shall be used in the switching circuits so that, if the section of guideway approaching a switch has been cleared for movement over that switch, the switch cannot be moved until a

definite time has elapsed after the speed limit for the approaching section has been placed in a zero speed condition and the switch is not occupied. The time allowance shall be at least 10% greater than the time required for the train to traverse the stopping distance, as calculated in accordance with Section 5.1.2. If the option of approach release of the time locking is used, then the time can be zero if there is no part of a train occupying the approach section. The length of the approach section for the switch shall be greater than the worst-case stopping distance computed for that specific guideway section.

ATP shall prevent the automatic or remote manual unlocking of a switch after a train has committed to traversing it until the train has cleared the switch. Protection against inadvertent release of locking caused by momentary loss of power or train detection shall be provided.

5.1.15 Offline Sections Operation—Special Conditions Offline sections are defined as guideway sections featuring automatic operation at restricted speed, such as offline stations or vehicle storage areas (lanes). For offline sections operation, three zones are considered:

1. Transition zone to and from the main line,
2. Circulation zone, and
3. Docking zone.

Transition zone: When entering or leaving the main line to or from the off-line section, the vehicle shall be detected by the ATP system of the off-line section, and speed shall be adjusted accordingly. Vehicle movement between main-line and off-line lanes shall be accomplished in accordance with the principles of Section 5.1.14.

Circulation zone: Contact between two moving vehicles may be acceptable at low speed, only under failure conditions, if the contact speed is low enough as determined by an analysis conducted in accordance with Section 3.1.2.1, Hazard Analyses, to (1) protect against damage to vehicles (reversible shock absorbers may be used), and (2) protect against passenger injuries (collision impact shall meet all criteria of Section 7.4.4.9.2).

The permissible contact speed shall be enforced by ATP.

Docking zone: Contact between a moving vehicle and a vehicle stopped at a docking position (with doors open and brakes applied per Section 5.1.8) may be acceptable at low speed, only under failure conditions, if the contact speed is low enough, as determined by an analysis conducted in accordance with Section 3.1.2.1, Hazard Analyses, to

1. protect against damage to vehicles (reversible shock absorbers may be used);
2. protect against passenger injuries (collision impact shall meet all criteria of Section 7.4.4.9.2); and
3. prevent any movement of the stopped vehicle.

Passenger on platform and passenger embarking and disembarking safety shall be in accordance with Section 10.2, Platform Edge Protection. Door control protection and departure interlocks shall be in accordance with Sections 5.1.10 and 5.1.11, respectively.

5.2 AUTOMATIC TRAIN OPERATION FUNCTIONS

The ATO shall function to automatically operate trains around the system in accordance with prescribed operating criteria but within the safety constraints imposed by ATP.

5.2.1 Motion Control The starting, stopping, and regulation of the train speed as it travels along the guideway shall be controlled